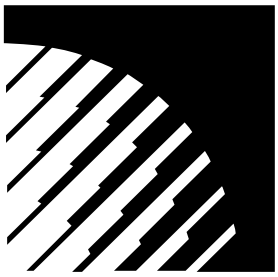

The ATM Forum

Technical Committee

ATM Security Specification
Version 1.1

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Foreword

This document corrects errata, clarifies procedures, and contains editorial corrections to the ATM Security Specification Version 1.0. Due to the errata corrections and procedural clarifications, this specification is not directly interoperable with the Version 1.0 specification.

The following table describes the substantive revisions from the Version 1.0 specification:

Section	Modification
General	Restructured document
General	DES-40 algorithm is deprecated
1.2	Updated normative and informative references
5.1	Removed references to CRL transport in Security Message Exchange
5.1.3.2.3	Created new codepoint for Version 1.1
5.1.3.2.7.2	Clarified procedures for non-explicit security agent addressing
5.1.3.2.8	Clarified procedures for relative ID security agent addressing and assignment of Security Association IDs
5.1.3.2.10	Clarified procedures for using the security service data section
5.1.4.4.2	Clarified procedure for assignment of Version numbers in Security Association Sections
5.1.4.5, 5.1.4.6	Clarified procedures for endpoint request for security services and acknowledgements
5.1.5.3.5	Changed timer and counter values from “recommended” values to specified values
5.1.5.3.6, 5.1.6	Renamed cause code from “security services failure” to “call rejected” to align with signaling addenda. The assigned cause code value was inserted, and the cause code indication of “security exception” was noted for this value.
5.3.1.2	Clarified Session Key Changeover procedure, and added text describing SKC usage with the integrity service.
6.5	Added Specification and Description Language (SDL) diagrams for in-band finite state machines
7.1	Changed codepoints to correct Version 1.0 errors
7.2	Clarified procedures for using the security service specification section (security service declaration and security service options)
7.2.1	Clarified coding of the Security Service Declaration for use in peer to peer and end system to proxy scenarios
7.2.2.2	Added codepoint for data integrity service options (Required, with or without Replay/Reordering Protection)
7.2.2.7	Added certificate exchange service options
7.2.3	Added support for user-defined algorithm details
7.2.3	Clarified procedures for inserting octet groups in the Security Service Algorithm Section and using the Organizationally Unique Identifier (OUI)
7.2.3.7, 7.2.3.8, 7.2.3.9	Clarified coding of algorithm details octets for profile groups
7.2.3.9	Changed codepoint for the hash algorithm details identifier to its correct value
7.3.1	Clarified the contents of the fields in the Confidential Parameters octet group
7.4	Clarified placement of the SAS Digital Signature within the Authentication Section
7.4.5	Clarified the contents of the ConfPar portion digital signature buffer

7.4.6	Clarified the method for calculating the SAS Digital Signature
8.7	Removed the use of point compression for elliptic curve cryptosystems, remove sample curves, and changed recommended field sizes
8.7.6	Added and updated references for elliptic curves
Appendix I	Clarified informative procedure for calculating resynchronization rate
Appendix III	Updated and corrected example SSIE encodings
Appendix IV	Created new informative section on security message coding principles and identifier values

Contents

1 Introduction

This specification defines procedures that provide a number of ATM security services. These services fall into three broad categories–security services for user plane virtual circuits, security services for control plane messages, and supporting services (management plane security services are not provided in this specification). User plane security services are performed on a per-virtual-circuit basis, where a "virtual circuit" can be either a virtual channel connection or a virtual path connection. Security support services include security message exchange and negotiation, which are performed at connection establishment via signaling, and/or within the user plane virtual circuit (after the connection is established, but before data transfer). Once the virtual circuit is established, further in-band messaging is provided by security OAM cells, as required by the negotiated cryptographic services.

This specification is organized as follows: Section 1 describes the scope and goals for this specification, provides definitions and references to supporting specifications, and describes compliance requirements. Section 2 provides a top-level reference model for the security services defined in this specification. Section 3 defines the user plane security services, including entity authentication, data confidentiality, data integrity (also known as "data origin authentication"), and label-based access control. In Section 4, the control plane authentication and integrity security services are defined. Security support services are described in Section 5. These services include security information exchange, negotiation, key exchange, session key update, and certification. Sections 6 through 8 contain text that specifies in detail the in-band security message exchange, octet groups for the Security Services Information Element, the use of various cryptographic algorithms and modes, and algorithm-specific coding details. Finally, this specification contains informative appendices, which include examples related to cryptographic resynchronization rate, label-based access control, and encodings of the Security Services Information Element.

1.1 Goals

This specification defines security services that support the following goals:

1. **Support multiple specification-defined algorithms and key lengths**.
   Since each organization has different security requirements, each site will likely want the opportunity to select from a variety of algorithms and/or protocols for their security designs. Furthermore, the laws of some countries place restrictions on which encryption products may be imported, exported, or used. For these reasons, the ATM security infrastructure and mechanisms specified here must support multiple algorithms and/or key lengths.
2. **Define a security infrastructure that provides interoperability among vendors who support one or more of the algorithms defined in this specification**.
   Since it is not feasible to define one default algorithm to meet all organizations' differing security requirements, this specification defines interoperability parameters for several well-known algorithms and common mechanisms for performing security functions using these algorithms. Devices that implement the algorithms and mechanisms as defined in this specification should interoperate with other devices with which they share a common suite of algorithms.
3. **Define a security infrastructure that provides for negotiation of private algorithms not specified in this specification**.
   Because selection of algorithms is such a sensitive issue, some organizations will want unique security algorithms tailored to their needs. The security infrastructure should provide standardized mechanisms for support of such algorithms, including means for agreement between two devices to use a private rather than a specification-defined algorithm.

4. **Maintain compatibility with devices that do not implement the security extensions**.
   Security messaging and secured communications must be transportable by intermediate network elements that do not understand or implement security.
5. **Minimize the impact on other specifications**.
   Security cannot be implemented without some modifications to existing specifications. These changes should be as minimal as possible without compromising the other goals of security. When possible, mechanisms should be defined to support backward compatibility with existing specifications (e.g. UNI 3.1 and UNI 4.0).
6. **Maintain compatibility across successive versions of the Security Specification**.
   Even though this specification is of limited scope, this specification should define extensible mechanisms to support future capabilities.
7. **Define mechanisms that will scale to a large (potentially global) number of users**.
   ATM security must be as scaleable as other ATM protocols in order to provide security in the broadest context.
8. **Define mechanisms that provide separability of authentication and integrity from confidentiality**.
   Some applications have different security needs from others, and different jurisdictions have varying regulations with respect to these mechanisms. The security mechanisms for ATM should be partitioned such that the functions of authentication and integrity may be implemented and selected independently from confidentiality mechanisms.

1.2 References

This section contains normative and informative references for this specification. Additional references pertaining to elliptic curve cryptosystems are found in Section 8.7.6.

1.2.1 Normative References

The following references contain provisions that, through reference in this text, constitute provisions of this specification. At the time of publication, the editions indicated were valid. All references are subject to revision, and parties to agreements based on this specification are encouraged to investigate the possibility of applying the most recent editions of the references indicated below.

[1] ATM Forum Technical Committee, “B-ICI Specification, Version 2.0,” af-bici-0013.003, December 1995.

[2] ATM Forum Technical Committee, “User-Network Interface (UNI) Specification, Version 3.1,” af-uni-0010.002, September 1994.

[3] ATM Forum Technical Committee, “User-Network Interface (UNI) Signalling Specification, Version 4.0,” af-sig-0061.000, July 1996.

[4] ATM Forum, “UNI Signaling 4.0 Security Addendum,” af-cs-0117.000, May 1999.

[5] ATM Forum, “PNNI Version 1.0 Security Signaling Addendum,” af-cs-0116.000, May 1999.

[6] ATM Forum, “ATM Inter-Network Interface (AINI) Specification,” af-cs-0125.000, July 1999.

[7] Federal Information Processing Standards Publication 46-3 (FIPS PUB 46-3), “Data Encryption Standard (DES),” November 1999.

[8] Federal Information Processing Standards Publication 81 (FIPS PUB 81), “DES Modes of Operation,” December 1980.

[9] Federal Information Processing Standards Publication 180-1 (FIPS PUB 180-1), “Secure Hash Standard,” April 1995.

[10] Federal Information Processing Standards Publication 186-1 (FIPS PUB 186-1), “Digital Signature Standard,” December 1998.

[11] Federal Information Processing Standards Publication 188 (FIPS PUB 188), "Standard Security Label for Information Transfer," September 1994.

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[13] IETF, "The MD5 Message Digest Algorithm," RFC 1321, April 1992.

[14] IETF, "Privacy Enhancement for Internet Electronic Mail: Part I: Message Encryption and Authentication Procedures" RFC 1421, February 1993.

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[21] ISO/IEC 10118-3, "Hash Functions - Part 3: Dedicated Hash Functions," 1997.

[22] ISO/IEC 11770-2, "Information Technology - Security Techniques - Key Management - Part 2: Mechanisms using Symmetric Techniques," 1996.

[23] ITU-T Recommendation I.610, "B-ISDN Operation and Maintenance Principles and Functions," February 1999.

[24] ITU-T Recommendation Q.2931, "B-ISDN DSS2 User-Network Interface Layer 3 Specification for Basic Call/Connection Control," February 1995.

[25] ITU-T Recommendation Q.2971, "B-ISDN DSS2 User-Network Interface Layer 3 Specification for Point-to-Multipoint Call/Connection Control," 1995.

[26] ITU-T Recommendation X.509, "The Directory: Authentication Framework," 1997.

[27] Public Key Cryptography Standards #1 (PKCS #1), "RSA Encryption Standard," RSA Laboratories, Version 1.5, November 1993 (available as RFC2313, March 1998). Note: The current PKCS #1, Version 2.0, available as RFC 2437, October 1998, may be referenced in future versions of this specification.

[28] Miyaguchi, S., *et al.*, "Expansion of FEAL Cipher," *NTT Review*, Vol. 2, no. 6, pp. 117-127, November 1990.

[29] Miyaguchi, S., "The FEAL Cipher Family," *Advances in Cryptology - CRYPTO '90*, LNCS 537, pp. 627-638, Springer-Verlag, 1991.

1.2.2 Informative References

The following references provide additional material to assist in the understanding of this specification.

[30] Agnew, G., R. Mullin, and S.Vanstone, "Improved Digital Signature Scheme Based on Discrete Exponentiation," *Electronic Letters*, Vol. 26, pp. 1024-1025, 1990.

[31] Bird, R., *et al*., "The KryptoKnight Family of Light-Weight Protocols for Authentication and Key Distribution," *IEEE/ACM Transactions on Networking*, Vol. 3, no. 1, pp. 31-41, February 1995.

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[33] Fujioka, A., *et al.*, "ESIGN: An Efficient Digital Signature Implementation for Smart Cards," *Advances in Cryptology — Eurocrypt '91, Springer Verlag Lecture Notes in Computer Science Volume 547, Davies, ed.*, pp. 446-457, 1991.

[34] IETF, “The Internet Key Exchange (IKE),” RFC 2409, November 1998.

[35] ITU-T Recommendation I.361, “B-ISDN ATM Layer Specification,” February 1999.

[36] Okamoto, T., “A Fast Signature Scheme Based on Congruential Polynomial Operations,” *IEEE Transactions on Information Theory*, Vol. 36, no. 1, pp. 47-53, 1990.

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1.3 Definitions

The following definitions apply within this specification.

Access Control - The application of a set of rules to a request for service to prevent the unauthorized use of the service.

Authentication - The process of corroborating that an entity in an instance of a communication is the one claimed.

Certification Authority - An entity trusted by one or more users to create or revoke certificates. Optionally, the certification authority may also create the user’s keys. [32]

Ciphertext Interface - The interface on a security agent that transmits and receives traffic that is cryptographically protected by this security agent’s services.

Confidentiality - The protection of information (e.g., data) from unauthorized disclosure, even in the presence of active, malicious threats.

Cryptographic System - A collection of transformations from plaintext into ciphertext and vice versa, the particular transformation(s) to be used being selected by keys. The transformations are normally defined by a mathematical algorithm. [32]

Digital Signature - Data appended to, or a cryptographic transformation of, a data unit that allows a recipient of the data unit to prove the source and integrity of the data unit and protect against forgery. [32]

EC-GDSA - A mechanism for producing a digital signature using elliptic curves (see Section 8.7).

Endpoint - The entity initiating a request for a security service (e.g., endsystem). See also “User.”

In-Band Message Exchange - The exchange of security information in the previously established user data connection. This connection could be either a VCC or a VPC, and could be established via SVC (signaling) or PVC procedures.

Initiator - The security agent that generates Flow-1 of the security message exchange protocol (described in Section 5.1), or inserts label-based access control information (described in Section 3.4).

Integrity - The detection of unauthorized modifications to information, even in the presence of active, malicious modification threats.

Key - A value or representation used to cryptographically transform information.

Key Exchange - The process of communicating cryptographic key information between two or more entities.

Plaintext Interface - The interface on a security agent that transmits and receives traffic that is not cryptographically protected by this security agent’s services.

Private Key - In asymmetric (public-key) cryptography, that portion of a user’s key pair which is known only to that user.

Public Key - In asymmetric (public-key) cryptography, that portion of a user’s key pair which is publicly known.

Replay Prevention - The process of validating that a message previously communicated is not repeated from an entity impersonating as the original source.

Responder - The Initiator’s peer in the security message exchange protocol, or the target security agent for label-based access control. For label-based access control, multiple responders are permitted.

Secret Key - In symmetric (secret-key) cryptography, a confidential key that is shared by all authorized users.

Security Agent (SA) - An entity that initiates, establishes, provides, discontinues, or terminates any of the ATM Forum Version 1.1 Security Services, such as Access Control, Authentication, Confidentiality and/or Data Integrity. A SA conforms to the top-level reference models, as defined in this specification, Section 2.

Security Association - A secure relationship between two SAs.

Security Negotiation - The process by which a secure environment is initiated, established, or denied between two SAs.

Signaling-Based Message Exchange - The exchange of security information in the signaling channel. In this specification, this exchange is accomplished via procedures described also in [4], [5], and [6].

User - The entity initiating a request for a security service (e.g., endsystem). See also "Endpoint."

1.4 Abbreviations

In addition to other abbreviations in relevant ATM specifications (UNI 4.0, PNNI, etc.), the following is a list of abbreviations commonly found in this specification:

CBC - Cipher Block Chaining [8]. A mode of operation for block ciphers (e.g., DES and FEAL).

CBC-MAC - CBC Message Authentication Code [20]. A mechanism for providing message integrity and authenticity that uses a block cipher in CBC mode.

DES - Data Encryption Standard [7]. A U.S. standard (published by NIST) for data encryption.

DES40 - DES with a forty-bit effective key.

DH - Diffie-Hellman. A key agreement algorithm.

DSA - Digital Signature Algorithm [10]. The algorithm specified by the DSS.

DSS - Digital Signature Standard [10]. A U.S. standard (published by NIST) for digital signatures.

ECB - Electronic CodeBook [8]. A mode of operation for block ciphers (e.g., DES and FEAL).

ECC and **EC** - Elliptic Curve Cryptosystem (see Section 8.7). A public-key cryptosystem.

ECKAS-DH - Elliptic Curve Key Agreement Scheme - Diffie-Hellman. The Diffie-Hellman key agreement scheme using elliptic curve cryptography.

ESIGN - Efficient digital SIGNature scheme [33]. A digital signature algorithm.

FEAL - Fast Data Encipherment Algorithm [28] and [29]. An encryption algorithm.

HMAC - Hashed Message Authentication Code [12].

H-MD5 - HMAC using the MD5 hash algorithm.

H-SHA and **H-SHA-1** - HMAC using the SHA-1 hash algorithm.

LIJ - Leaf Initiated Join. A method of adding leaves to a point-to-multipoint ATM call upon request of a leaf.

MAC - Message Authentication Code.

MD5 - Message Digest 5 [13]. A hash algorithm used for generating MACs or digital signatures and in other cryptographic constructions.

NIST - (U.S.) National Institute of Standards and Technology.

PTI - Payload Type Indicator. A field in the ATM cell header that is used to identify the type of the cell payload contents.

PVC - Permanent Virtual Circuit. An ATM virtual circuit established by management operations.

RSA - Rivest, Shamir, and Adleman [27]. The inventors of this encryption/digital signature algorithm.

SHA-1 - Secure Hash Algorithm (Revision 1) [9]. **SA** - Security Agent. A logical entity that implements ATM security functions. See definition for "Security Agent" in Section 1.3.

SAS - Security Association Section.

SDL - Specification and Description Language

SSCOP - Service Specific Connection Oriented Protocol. The connection-oriented protocol that is used by UNI signaling for reliable delivery of signaling messages.

SKC – Session Key Changeover. The process of changing session keys that are established using the SKE protocol.

SKE - Session Key Exchange. The protocol for exchanging new session keys for previously-activated confidentiality and/or integrity services.

SME - Security Message Exchange. The protocol for authentication, key exchange, and negotiating a security association.

SSIE - Security Services Information Element.

SVC - Switched Virtual Circuit. An ATM virtual circuit established by ATM signaling.

UNI - User to Network Interface.

VC - Virtual Circuit. Can be either a VCC or a VPC.

VCC - Virtual Channel Connection.

VCI - Virtual Channel Identifier. A field in the ATM cell header.

VPC - Virtual Path Connection.

VPI - Virtual Path Identifier. A field in the ATM cell header.

1.5 Specification Scope

The scope of this security specification is indicated in Figure 1. The boxes of the matrix marked X show what is within scope for this specification. The structure of Figure 1 reflects the ATM Reference Model, which defines three planes—the user plane, the control plane, and the management plane—with each plane comprising three or more protocol layers—the physical layer, the ATM layer, the ATM Adaptation Layer (AAL), and upper layers as required. The user plane provides transfer of user data across ATM Virtual Channel Connections (VCCs) and Virtual Path Connections (VPCs). The control plane deals with connection establishment, release, and other connection functions, including UNI, NNI, and ICI signaling. The management plane performs management and coordination functions related to both the user and the control planes (including the PNNI functions related to the establishment of a routing infrastructure).

As indicated in Figure 1, this document specifies mechanisms for authentication, confidentiality, data integrity, and access control for the user plane. It also specifies mechanisms for authentication and integrity for the control plane (UNI and NNI signaling). Excluded from the scope of this specification is management plane security; however, to the extent that management plane entities use user plane connections to achieve their ends, the user plane security specified herein may contribute to management plane security. Also within scope is the infrastructure needed to support these security services: negotiation of security services and parameters, key exchange, key update, synchronization, and certification infrastructure.

	User Plane	Control Plane	Management Plane
Authentication	X	X	
Confidentiality	X		
Data Integrity	X	X	
Access Control	X		

Figure 1: Scope of Security 1.1.

The scope is restricted to *ATM security*: mechanisms that must be implemented in the ATM layer and/or the AAL. The emphasis throughout is on providing *per-connection* security rather than, for example, link or node security. The scope includes all types of ATM connections: channel and path; point-to-point and point-to-multipoint; switched and permanent.

This document provides definitions for specific security mechanisms and protocols to support the development of interoperable ATM security services. These security services are designed to be used in conjunction with appropriate system and network security engineering practices for the enforcement of a security policy. The security services that are in the scope of this specification are described in more detail below.

1.5.1 User Plane Security Services

The user plane security services apply on a per-VC (virtual circuit) basis, where a VC could be either a VCC (virtual channel connection) or a VPC (virtual path connection). Security services for physical links (which may carry many VCs) are *not* provided in this specification. The following security services for the user plane are defined: authentication, data confidentiality, data integrity, and access control. These services are supported in point-to-point and point-to-multipoint connections for both SVCs and PVCs.

1.5.1.1 Authentication

User plane authentication (also described as "entity authentication") determines at the beginning of the connection that the identities of the calling and/or called parties are genuine. Since this service provides protection against impersonation or "spoofing" threats, it is essential for establishing secure connections and the operation of other security services, including key exchange (described below), and the secure exchange of security negotiation parameters.

Authentication can be either mutual or unilateral. If authentication is mutual, then both parties are authenticated to each other, whereas with unilateral authentication, only one party is authenticated to the other.

Authentication is specified in this document to use cryptographic algorithms, including asymmetric (public key) algorithms (e.g., RSA) and symmetric (secret key) algorithms (e.g., DES-MAC). These classes of algorithms are described in more detail in [37].

1.5.1.2 Confidentiality

User plane confidentiality provides cryptographic mechanisms that protect "user" data on a VC from unauthorized disclosure. (The term "user" refers to the protocol entity that directly uses ATM services.) This specification defines ATM confidentiality at the cell level, rather than the AAL level, because the fixed-length of the ATM cell allows for efficient encryption. Furthermore, only the payload of the cell is encrypted–the header is sent in the clear. This allows the encrypted cell to be switched by the network without decryption at each hop.

The confidentiality service is specified in this document to use symmetric (secret key) algorithms. Symmetric algorithms are suitable for ATM cell encryption due to their speed, block sizes, and security properties.

1.5.1.3 Integrity

The data integrity service (also described as "data origin authentication") provides a mechanism that allows for detection of modification to data values or sequences of data values, even in the presence of malicious modification threats. This service is provided between endpoints at the AAL Service Data Unit (SDU) level for AAL 3/4 and AAL 5. In addition, two options are provided for this service: 1) data integrity without replay/reordering protection, and 2) data integrity with replay/reordering protection.

When data integrity is provided without replay/reordering protection, the source appends a message authentication code (MAC) to the tail of each AAL SDU before transmission. This MAC is calculated over the entire AAL SDU. This option is useful to higher layer protocols that provide their own sequence numbers (e.g., TCP), without the added overhead required to duplicate this function at the AAL.

When the data integrity service is provided with the replay/reordering protection option, the data integrity service provides protection against replay and reordering attacks, so that "old" or "reordered" AAL-SDUs are detected and may be discarded. At the source, this is achieved by first appending a sequence number to the tail of each AAL-SDU and then computing a MAC on the totality of the AAL-SDU including the sequence number. This MAC, which protects both the AAL-SDU and the sequence number, is then appended to the total AAL-SDU (which includes the sequence number). This method provides protection for ATM applications that do not implement their own sequence numbers.

As with the confidentiality service, the integrity service is specified in this document to use symmetric (secret key) algorithms.

1.5.1.4 Access Control

Access Control is the application of a set of rules to a request for a service. These rules may depend upon attributes of the invoking entity, such as identity, attributes of referenced parameters, such as a target address, system attributes, such as time, and the history of prior requests by this and/or other client entities. Access control rules can be thought of as a predicate over the state space formed by all such attributes. If the predicate is satisfied, the requested service is performed, if the predicate is not satisfied, the requested service is not performed.

User plane access control requires mechanisms to transport access control information used during connection establishment, as well as mechanisms within ATM components to use that information to determine whether access to the connection should be granted. User plane access control can be based on security labels (e.g., Standard Security Label [11]), source or destination user identities, time of day, type of service, upper-layer protocol (e.g., AAL type) fields, or other parameters that can be determined during connection establishment.

1.5.2 Control Plane Security Services

The control plane is the mechanism that allows devices to configure the network to achieve some objective (for example, to establish a switched virtual circuit). Since control plane messages can affect the state and availability of a network, their protection is extremely important.

In this Security Specification, a mechanism for signaling is defined that can provide strong cryptographic data integrity with replay/reordering protection. This mechanism allows ATM control plane entities to verify the source and contents of a signaling message before resources are allocated to the request. This protects the network from a number of attacks, as described below.

Other security mechanisms for the control plane (e.g., control plane confidentiality) may be provided in future specifications.

1.5.2.1 Authentication and Integrity

Control plane authentication and integrity is the ATM security service that binds an ATM signaling message to its source. By creating this binding, the message recipient can confidently verify that the

message originated from its claimed source. This provides a mechanism that mitigates a number of threats. For example, a denial of service attack, which attempts to tear down an active connection by surreptitiously injecting RELEASE or DROP PARTY messages, can be prevented when authenticity assurances are in place for the signaling channel. This service also protects against spoofing and malicious modification threats. In this specification, a mechanism for control plane authentication and integrity between adjacent signaling entities is defined. The mechanism is identical to the one provided for user plane data integrity with replay/reordering protection.

1.5.3 Support Services

This specification also defines a set of "support services," which are needed to provide scaleable and high-performance security services:

- Security message exchange and negotiation of security options,
- Key exchange,
- Key update,
- Certification infrastructure.

1.5.3.1 Security Message Exchange and Negotiation

In order to perform many of the security services described above, messages must be exchanged between the involved security agents (SAs). This specification describes two methods for security message exchange: 1) message exchange within UNI 4.0, PNNI 1.0, and AINI signaling and 2) in-band message exchange (that is, security message exchange within the relevant user plane virtual circuit).

The in-band message exchange method also provides a mechanism for negotiation of security options. Since security requirements vary among organizations, it is important to provide a variety of security services, algorithms, and key lengths, which meet a wide range of security needs. In addition, the export, import, or usage laws of some countries place restrictions on which encryption products may beavailable. For these reasons, the ATM security mechanisms support multiple security services, algorithms, and key lengths. In order for security agents to agree on common security parameters (such as algorithms and key lengths), these security message exchange methods provide for negotiation of these parameters as part of the security establishment procedure for the VC.

1.5.3.2 Key Exchange

Key exchange is the mechanism by which two security agents exchange secret keys for use by the confidentiality and/or integrity services. In order to protect against "man in the middle"-type attacks, key exchange is often coupled with the authentication service. This can be accomplished by including "confidential" key exchange parameters within the authentication flows.

Like authentication, key exchange is performed with either symmetric (secret key) or asymmetric (public key) algorithms. In addition, key exchange may either be bi-directional (two-way), or uni-directional (one-way).

1.5.3.3 Session Key Update

Session keys are the keys used directly to provide user plane confidentiality and integrity services over an ATM virtual circuit. Due to the potentially high data rate of the virtual circuit, it is imperative that keys be periodically changed to avoid "key stream re-use" or certain other attacks. This specification defines a session key update service that provides this capability.

This service is performed in two phases–a session key exchange phase and a session key changeover phase. The session key exchange phase uses a "master key," which is exchanged at connection setup (using the key exchange service), to encrypt the new session key. Upon receipt of the encrypted session key, the recipient decrypts the session key using the shared master key, and stores it for the second phase–key changeover.

1.5.3.4 Certification Infrastructure

In a public key cryptosystem, each party (security agent) *X* has a pair of keys: one of these is publicly known, that is *X*'s "public key" (PK_X), and the other known only by *X*, that is *X*'s "private key" (SK_X). In order for party *A* to send secret information to party *B* (or, alternatively, in order for *A* to be able to verify a signature produced by *B*), *A* needs to obtain *B*'s public key, PK_B. Though PK_B is public by definition, it should not be possible for any party *X* to substitute another value (e.g., PK_X) for PK_B. To prevent this kind of attack, public keys can be exchanged in the form of "certificates."

A certificate contains the party's name, its public key, and some additional information and is signed by a trusted party, a "certification authority" (CA). This signature unforgeably binds the public key to the subject party. Any party with access to the CA's public key can verify the genuineness of the certificate (by checking the CA's signature in the certificate) and recover the public key that was certified. Certificates can be transmitted via non-secure message exchanges.

1.6 Compliance

Compliance for an ATM security implementation is defined on a per-security-service basis, for each of the five services specified in this document:

1. User Plane Authentication (AUTH)
2. User Plane Confidentiality (CONF)
3. User Plane Data Origin Authentication and Integrity (INTEG)
4. User Plane Access Control (ACC)
5. Control Plane Authentication and Integrity (CP-AUTH)

To claim compliance with this specification, an implementation must support at least one security service (that is, user plane authentication, user plane confidentiality, user plane integrity, access control, or control plane authentication). For the user plane authentication, confidentiality, and integrity services, the implementation must support:

1) One or more of the SME profiles listed in Table 6

And,

2) At least one of the following:
   a) One or more algorithm profiles listed in Section 1.6.1,
   b) One or more user-defined algorithms.

For user plane access control, the implementation must support the access control profile in Table 4. For control plane authentication, the implementation must support one of the control plane authentication profiles in Table 5.

The compliance statement for the implementation must specify the security services and associated algorithms and security messaging profiles supported. In addition, the compliance statement must specify all additional algorithms defined in this specification and implemented for the five security services areas. These additional algorithms must be implemented as specified herein.

1.6.1 Security Algorithm Profiles

Table 1 through Table 5 list the algorithms and modes (where applicable) required for each ATM security service. Compliance requirements for each service are specified in their respective sections, and compliance requirements for each algorithm are specified in the normative reference for that algorithm specified in the respective service sections. These profiles represent a subset of all possible algorithm combinations, and some algorithms defined in this specification do not appear in the algorithm profiles.

Table 1: Authentication Algorithm Profiles.

Profile	Signature	Hash	Notes
AUTH-1	DES/CBC MAC	n/a	1,2
AUTH-2	DSA	SHA-1	1
AUTH-3	EC-GDSA	SHA-1	1
AUTH-4	ESIGN	MD5	1
AUTH-5	FEAL/CBC MAC	n/a	1,2
AUTH-6	RSA	MD5	1

Note 1: Support for the Security Message Exchange (SME) is also required.

Note 2: No hash function is used with this profile.

n/a : not applicable

Table 2: Confidentiality Algorithm Profiles.

Profile	Encryption	Mode	Signature	Key Exchange	Hash	Key Update	Notes
CONF-1	DES	CBC	RSA	RSA	MD5	MD5	1
CONF-2	DES	CBC	DSA	DH	SHA-1	SHA-1	1
CONF-3	DES	CBC	EC-GDSA	ECKAS-DH	SHA-1	SHA-1	1
CONF-4	DES	CBC	DES/CBC MAC	DES/CBC	n/a	MD5	1
CONF-5	DES	Counter	RSA	RSA	MD5	MD5	1
CONF-6	DES	Counter	DSA	DH	SHA-1	SHA-1	1
CONF-7	DES	Counter	EC-GDSA	ECKAS-DH	SHA-1	SHA-1	1
CONF-8	DES	Counter	DES/CBC MAC	DES/CBC	n/a	MD5	1
CONF-9	Triple-DES	CBC	RSA	RSA	MD5	MD5	1
CONF-10	Triple-DES	CBC	DSA	DH	SHA-1	SHA-1	1
CONF-11	Triple-DES	CBC	EC-GDSA	ECKAS-DH	SHA-1	SHA-1	1
CONF-12	Triple-DES	CBC	Triple DES/CBC MAC	Triple DES/CBC	n/a	MD5	1,2
CONF-13	Triple-DES	Counter	RSA	RSA	MD5	MD5	1
CONF-14	Triple-DES	Counter	DSA	DH	SHA-1	SHA-1	1
CONF-15	Triple-DES	Counter	EC-GDSA	EC/DH	SHA-1	SHA-1	1
CONF-16	Triple-DES	Counter	Triple DES/CBC MAC	Triple DES/CBC	n/a	MD5	1,2
CONF-17	FEAL	CBC	ESIGN	DH	MD5	MD5	1
CONF-18	FEAL	CBC	FEAL/CBC MAC	FEAL/CBC	n/a	MD5	1
CONF-19	FEAL	Counter	ESIGN	DH	MD5	MD5	1
CONF-20	FEAL	Counter	FEAL/CBC MAC	FEAL/CBC	n/a	MD5	1

Note 1: Support for the Security Message Exchange is also required.

Note 2: This mode is included for compatibility with 3DES hardware, although the security is limited by the 64-bit MAC value.

n/a : not applicable

Table 3: Integrity Algorithm Profiles.

Profile	MAC	Signature	Key Exchange	Hash	Key Update	Notes
INTEG-1	DES/CBC MAC	RSA	RSA	MD5	MD5	1,2
INTEG-2	DES/CBC MAC	DSA	DH	SHA-1	SHA-1	1,2
INTEG-3	DES/CBC MAC	EC-GDSA	ECKAS-DH	SHA-1	SHA-1	1,2
INTEG-4	DES/CBC MAC	DES/CBC MAC	DES/CBC	n/a	MD5	1,2
INTEG-5	H-MD5	RSA	RSA	MD5	MD5	1,2
INTEG-6	H-MD5	DES/CBC MAC	DES/CBC	n/a	MD5	1,2
INTEG-7	H-SHA-1	DSA	DH	SHA-1	SHA-1	1,2
INTEG-8	H-SHA-1	EC-GDSA	ECKAS--DH	SHA-1	SHA-1	1,2
INTEG-9	H-SHA-1	DES/CBC MAC	DES/CBC	n/a	SHA-1	1,2
INTEG-10	FEAL/CBC MAC	ESIGN	DH	MD5	MD5	1,2
INTEG-11	FEAL/CBC MAC	FEAL/CBC MAC	FEAL/CBC	n/a	MD5	1,2

Note 1: Support for the Security Message Exchange is also required.

Note 2: Support for the two versions of integrity, i.e., with and without replay protection, is required. The selection is determined at call setup time.

n/a : not applicable

Table 4: Access Control Label Profiles.

Profile	Label Formats	Notes
ACC-1	Standard Security Labels	1

Note 1: Because access control labels are processed independently at each security agent that performs access control, support for the Security Message Exchange is not required.

Table 5: Control Plane Authentication Algorithm Profiles.

Profile	MAC	Key Update	Notes
CP-AUTH-1	H-MD5	MD5	1
CP-AUTH-2	H-SHA-1	SHA-1	1
CP-AUTH-3	DES/CBC MAC	SHA-1	1
CP-AUTH-4	FEAL/CBC MAC	MD5	1

Note 1: Because control plane authentication messages are processed independently at each security agent that performs this service, support for the Security Message Exchange is not required.

1.6.2 Security Message Exchange Profiles

Three security message exchange profiles are specified for ATM security messaging:

1. In-band, three-way messaging (SME-1),

2. Signaling-based, two-way messaging, with a fall-back to in-band security messaging (SME-2),
3. Signaling-based, two-way messaging for the point-to-multipoint ADD PARTY message (SME-3).

Table 6 specifies the sections required for compliance with each profile. The implementation shall be compliant with the mechanisms specified in the referenced mechanism section. Note that the initial connection in a point-to-multipoint call is accomplished using SME-2. SME-3 is defined only for subsequent ADD PARTY messages.

Table 6: ATM Security Message Exchange Profiles.

Profile	ATM Bearer Service	Security Message Service	Message Exchange Protocol	Mechanisms	Notes
SME-1	Pt-pt PVCs Pt-pt SVCs	In-Band 3-Way	5.1.1.1	5.1.5.2 5.1.5.3 6	
SME-2	Pt-pt SVCs	Signaling-Based 2-Way, with In-Band Fall-Back	5.1.1.2 (for Signaling-Based) 5.1.1.1 (for In-Band)	5.1.4.1 5.1.4.4 5.1.5.3 6	1
SME-3	Pt-mpt SVCs (ADD PARTY)	Signaling-Based 2-Way	5.1.1.2	5.1.4.2 5.1.4.4	2

Note 1: "In-Band Fall-Back" refers to the ability of the security agent to perform additional messaging using the in-band SME (i.e., SME-1).

Note 2: Support for SME-3 requires SME-2 for the initial connection establishment.

2 Top-Level Reference Models

This informative section presents several reference models that help define and clarify the intended scope and functionality of this specification. It also presents a high-level overview of the security services and mechanisms.

Note that the Access Control security service is different from the other security services–it is not negotiated, and many of the other concepts associated with the other services do not apply to this service. Consequently, this section concentrates on the other three security services; the reader is referred to Section 3.4 for reference models for the access control service.

2.1 Security Associations and ATM Interfaces

A *security agent* negotiates and provides the security services for a VC. Figure 2 shows the simplest case, in which security agents are collocated with ATM end systems. In this case, the end systems interface to an ATM network via a UNI. For each VC that is established by an end system, the Security Agent (SA) at that end system:

- Negotiates the service or services with the peer SA,
- Determines which security services, if any, need to be applied to that VC,
- Authenticates and exchanges keys, if necessary,
- Applies the required security service(s) to the VC.

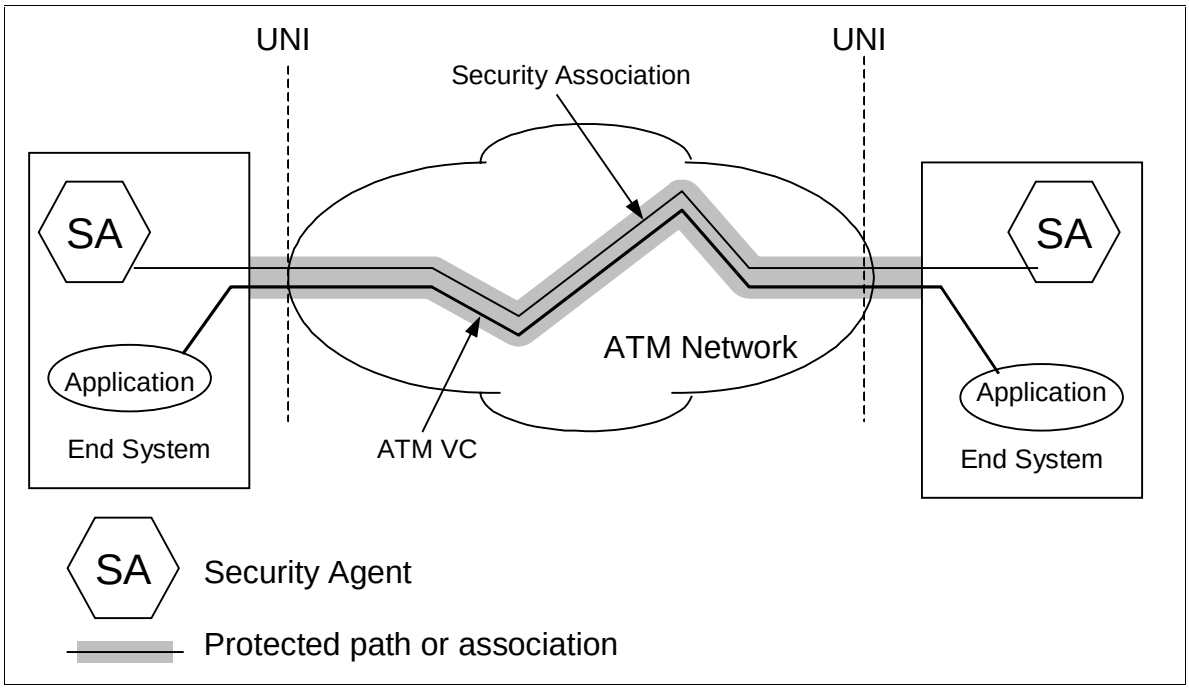


Figure 2: Security Association between Security Agents at End Systems.

The determination of which security services are needed for which VCs is a matter of *security policy*, which is beyond the scope of this document. Also, the existence and nature of any interaction between the end-system application and its local security agent is beyond the scope of this document.

The negotiation of services with a peer security agent takes place via Security Information Exchange, an overview of which Section 2.3 presents. Via negotiation, the peer SAs establish one *Security Association* for each service to be provided. Thus, if authentication, confidentiality, and data integrity are all required for a given VC, there are three Security Associations between the peers, one for each service. A Security Association is the distributed contextual information (e.g., cryptographic algorithm, mode of operation, optional features enabled, etc.) controlling the nature of the security service to be provided for a given VC.

If required, authentication and initial key exchange also occur during service negotiation. Key exchange is required for support of the confidentiality and data integrity services. The negotiation supports the exchange of connection master keys (keys used to generate future connection "session" keys if needed) and initial connection session keys for encryption and/or cryptographic checksums.

The application of the services to the VC varies according to the service. For authentication, the service is effected during negotiation. For confidentiality, encryption is applied to ATM data cell payloads, with maintenance of cryptographic state and session key updates provided (optionally) via OAM flows. For data integrity, a cryptographic checksum and a sequence number (optional) are appended to AAL 3/4 and AAL 5 service data units (SDUs).

Note: The end-system-to-end-system model in Figure 2 is the only one that applies for the data integrity security service. This is because data integrity is applied at the AAL.

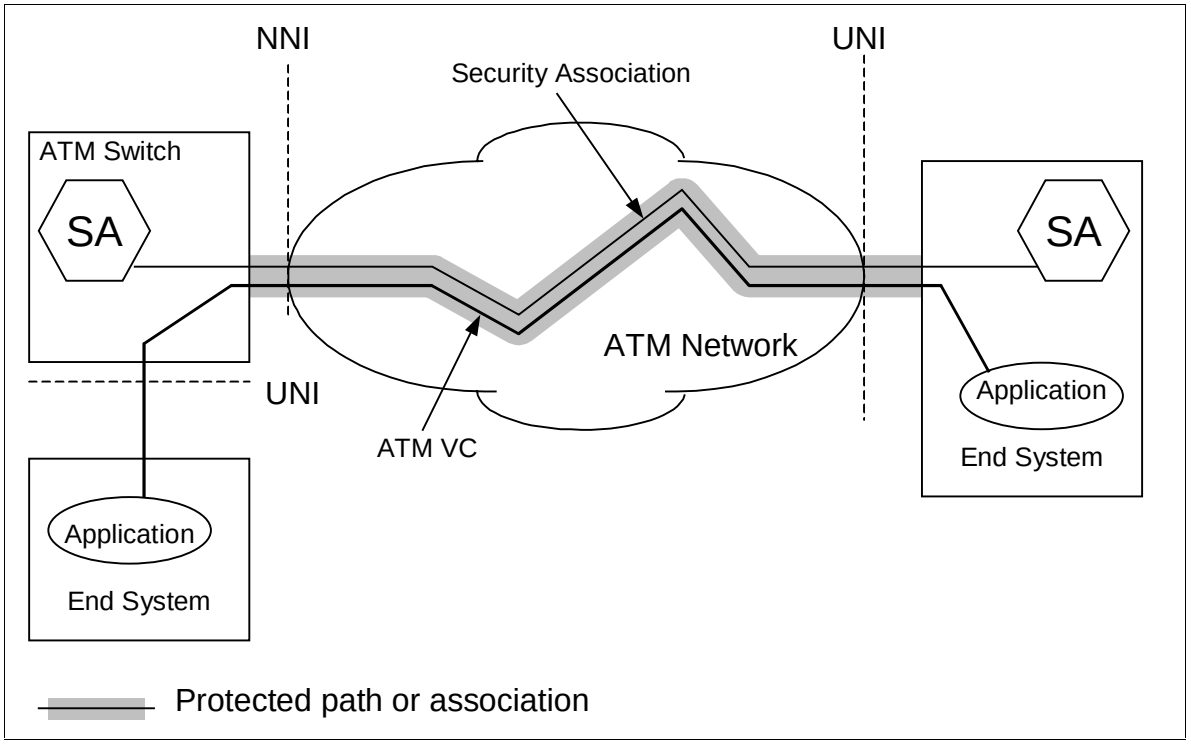


Figure 3: Security Association between a SA at a Switch and a SA at an End System.

Figure 3 shows another configuration of SAs. In this figure, one SA is located within an ATM end system and one is located within an ATM switch. The overall operation is the same as that reflected in Figure 2: negotiation, determination, and application of security services via Security Associations between peer Security Agents. However, Figure 3 highlights some possibilities–and some interactions–which might not be immediately obvious from Figure 2. Figure 3 implies the possibility of "firewall" Security Agents–SAs that provide security services for one or more networks "behind" a firewall. It also implies a close coupling of signaling entities and the security agent. Finally, it implies that switches that come equipped with Security Agents will be required to perform functions not normally associated with switches–for example, encryption of cell payloads.

The security agent within the switch could maintain an identity distinct from those of any end systems, or it could serve as a *proxy* for one or more end systems. In the former case, the remote peer SA would explicitly authenticate (assuming authentication is required) the SA at the switch (i.e., the SA identifier would not imply collocation with the end system); in the latter case, the remote peer SA would authenticate a virtual SA at the end system. With proxies, the identities and accompanying authentication information (e.g., public and private keys) are kept and vested with the proxy agents rather than distributed among the end systems.

Note that a security service is only applied to that portion of a VC between the peer SAs providing the service. So, as pictured in Figure 3, there is no security applied to the VC between the left-hand end system and the switch containing the security agent. Whether or not this is acceptable, is, once again, a matter of security policy. However, as the next section shows, it is possible to provide different levels of security for different portions of a VC.

2.2 Multiple Security Associations and Nesting

Figure 4 shows that more than one pair of security agents–and more than one security association–might be involved in providing security services for a given VC. In this figure, SA_1 and SA_4 have a security association in which they provide (say) end-to-end authentication. Independent of this association, SA_2 and SA_3 have an association in which they provide confidentiality. These two associations are independent in terms of the services they provide. This independence allows multiple (and different) security policies to be in force simultaneously for different parts of the network.

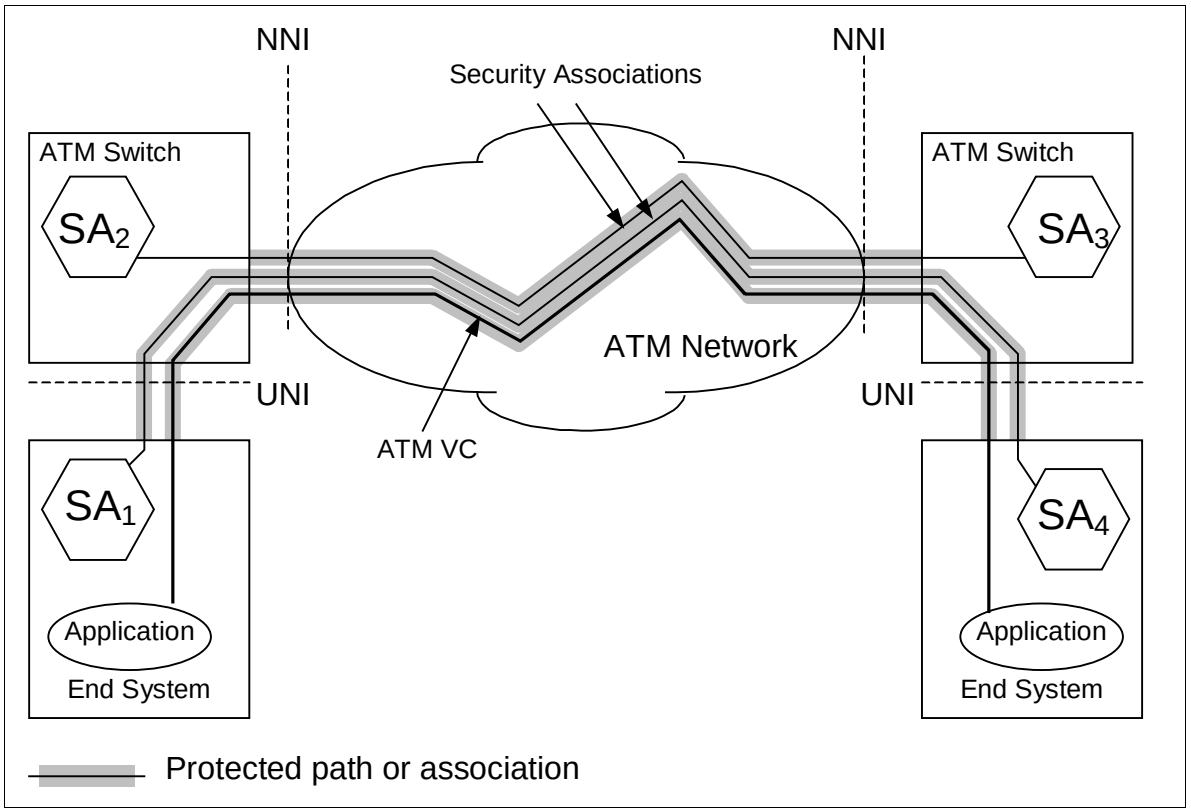


Figure 4: Two Nested Security Associations.

There are some dependencies and restrictions, however, on what might be called the *topology* of security associations; these dependencies result from the mechanisms chosen to negotiate security services and form security associations. By *topology* is meant the way different security associations are allowed to overlap along the path of a VC. Figure 4 shows one type of overlap that is permitted–nesting. The VC "segment" [SA_2, SA_3] could be described as being *contained in* the [SA_1, SA_4] segment. Another permissible relationship among associations is *no overlap*. If, instead of what is pictured, the associations were between SA_1 and SA_2, and SA_3 and SA_4, the segments [SA_1, SA_2] and [SA_3, SA_4] would have no overlap and the associations would be permissible. Similarly, if the associations were between SA_1 and SA_3, and SA_3 and SA_4, the segments [SA_1, SA_3] and [SA_3, SA_4] would have no overlap and the associations would be permissible. (This could with justification be called one-point overlap, but it is a permissible arrangement which is referred to as the "no overlap" case.) *Nesting* and *no overlap* are the only permissible arrangements. The mechanisms will not support simultaneous associations between SA_1 and SA_3, and SA_2 and SA_4, for example.

In addition to these topological restrictions, there is also a limit of 16 on the *nesting* level–the total amount of nesting at any given point along the VC's path. Note that this is not a limit *per se* on the total number of security associations for any given VC.

Figure 5 shows one example of the types of topologies that the security mechanisms support. The maximum nesting level in this example is 3. It would not be possible in the situation pictured in this figure to support another security association involving (say) SA_3 and SA_8, as this would violate the topological restrictions.

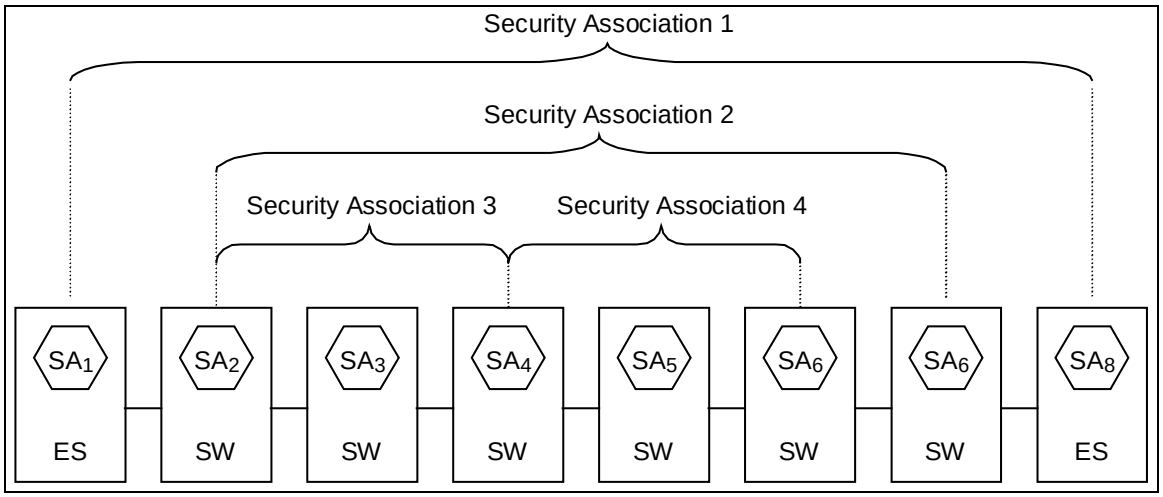


Figure 5: Multiple Associations with Nesting.

2.3 Security Information Exchange

Figure 6 shows the three types of information exchange that might be involved in establishing and maintaining security associations. The Security Message Exchange (SME) protocol is used to negotiate security services, establish security associations, authenticate the peer security agents (if required), and establish connection master keys and initial session keys. The SME can operate over the signaling channel (for networks that support the UNI Signaling 4.0 Security Addendum [4], PNNI Version 1.0 Security Signaling Addendum [5], or the AINI Specification [6]) or over the data channel that is pre-established or in the process of being established. The former is referred to as "Signaling-Based SME" and the latter as "In-Band SME." Support for SME within B-ICI and other signaling protocols is not currently defined.

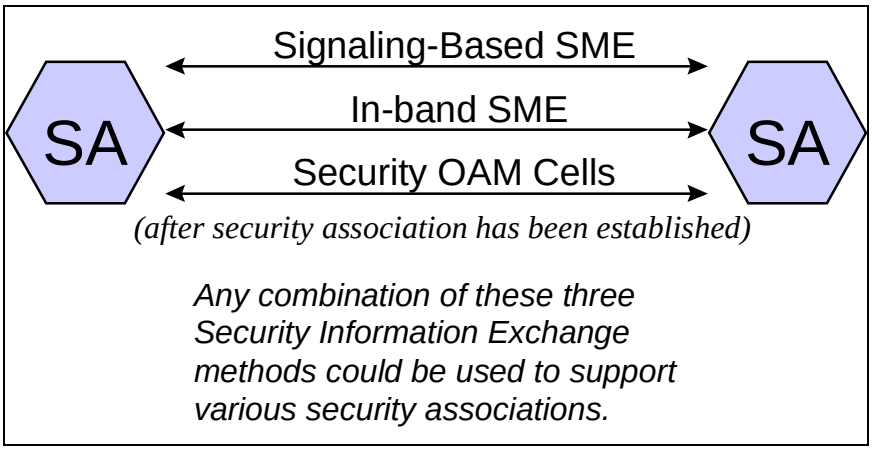


Figure 6: Security Information Exchange Methods.

An example of SME in a network that supports Signaling-Based SME [4][5] is shown in Figure 7 (where "UNI 4.0 + sec" and "PNNI 1.0 + sec" denote links that implement the UNI and PNNI security addenda). In this case, the end systems (with Security Agents) append the SSIE to the signaling message, and as the network establishes the call, the SSIE is passed without modification.

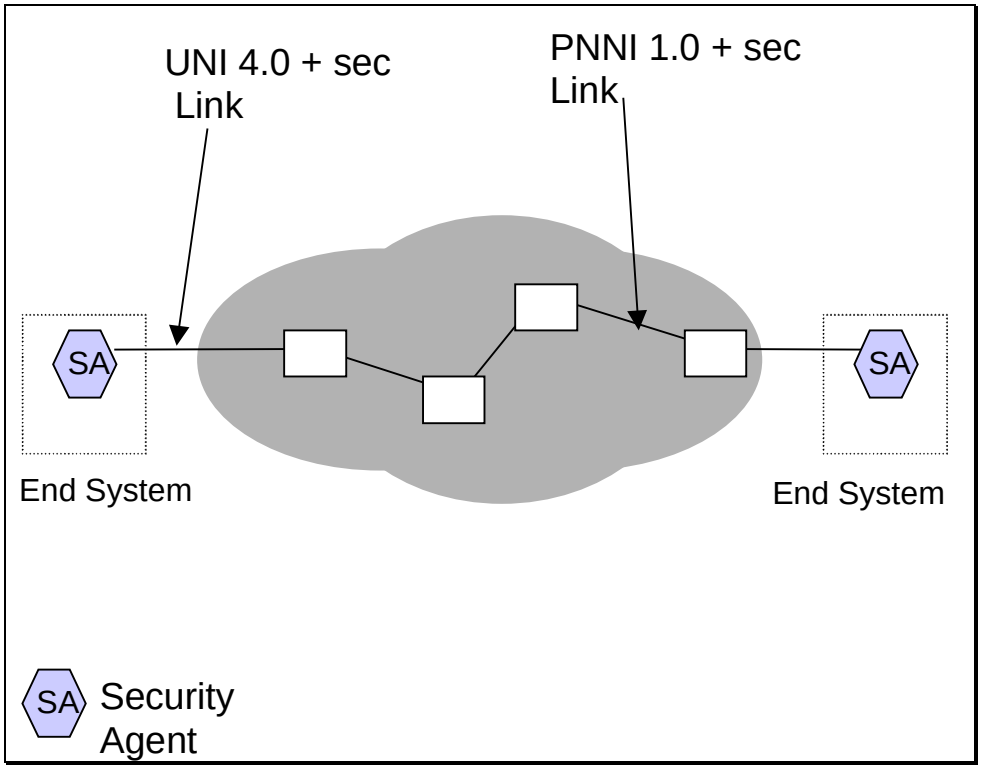


Figure 7: Entire Network Supports Signaling-Based SME.

A more likely scenario is one that contains network elements that do not support signaling-based SME. An example of this scenario is shown in Figure 8.

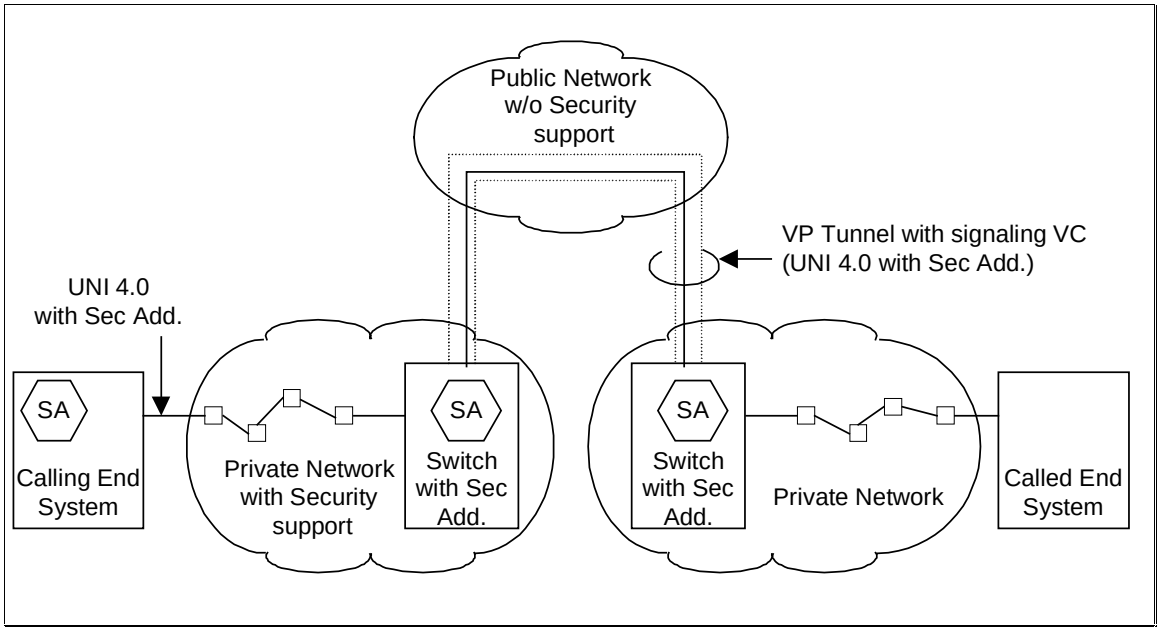


Figure 8: Portion of Network Does Not Support Signaling-Based SME.

In this scenario, the calling end system is attached to a network that supports signaling-based SME. The initiating security agent in this end system supplies security information along with the connection setup

signaling message, and the message traverses the private network. When the message reaches the final switch in the private network, it is signaled through a Virtual Path tunnel through the public network to the remote switch, which also supports signaling-based SME. Although the public network does not support signaling-based SME, the VP tunnel allows the two border switches to signal each other directly, and hence, allows SME to traverse the public network.

Since the first switch in the destination network contains a security agent that terminates the security association, the remaining network elements do not need to support signaling-based SME.

If none of the network elements are expected to support signaling-based SME, then the In-Band SME protocol introduced earlier can be used instead. An example of where this protocol should be used is illustrated in Figure 9.

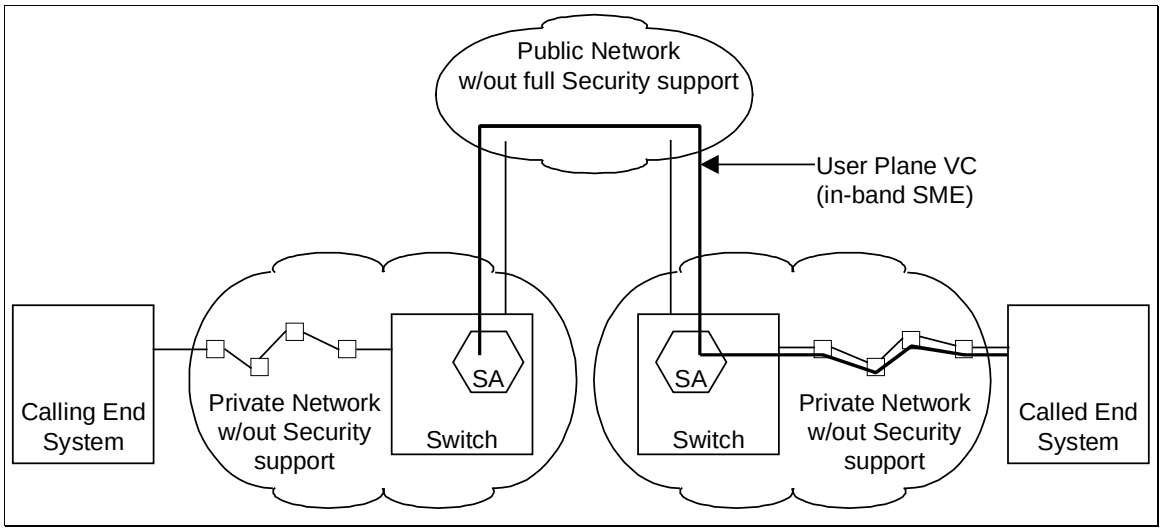


Figure 9: Using the In-Band SME Protocol in Networks that do not support Signaling-Based SME.

In this case, the two security agents are configured to perform SME in band because the public network does not support SME via signaling. The calling end system initiates the connection setup request, and the request propagates to the called end system as usual, where a connection confirmation message is generated. As the network propagates the connection confirmation, the user plane virtual circuit is constructed along the way. When the connection confirmation signal reaches the security agent in the source private netowrk, the user plane VC connects the two security agents (as shown in Figure 9), data transfers from the end systems are blocked, and the SAs perform the SME protocol within this virtual circuit. After successful completion of the SME protocol, the connection confirmation is forwarded to the calling party, and data transfer from the end systems through the user plane VC is allowed. This protocol is described in more detail in Section 5.1.5.

Note: For voice calls, the voice path is typically cut through (voice traffic is allowed) in both directions except at the terminating exchange. At the terminating exchange the path is not cut through to the called party. The backward path is cut through to allow for the calling party to hear tones and announcements that may occur before answer (e.g., ringing, busy, “the number you have dialed is no longer in service”) and to avoid speech clipping when the called party picks up and says hello. If the Security Agent blocks the voice path to be used in the backward direction prior to connect (e.g., after an ALERTING or PROGRESS message) then the calling party might abandon the call or miss receiving important in-band information. In the case where an end station requests security services, it should not assume such services are operational until the CONNECT message is received and the SME is complete.

Regardless of the SME method used, after the SME is complete, OAM flows may be used to maintain the state of the security associations. Specifically, Security OAM cells are used:

- To exchange additional connection session keys for confidentiality and data integrity as needed. (Note that the initial session keys are established during SME.)
- To maintain synchronization of encryption engines relying on the counter mode of operation.

For the purposes of exposition, the functions of the Security Agent may be decomposed into several sections:

- SA_{sme}, those functions of the security agent that interact with signaling, or with a peer security agent, to perform the Security Message Exchange,
- $SA_{service}$, those functions of the security agent that provide the actual authentication, integrity check, and confidentiality services,
- SA_{policy}, those functions of the security agent that determine when and how security must be applied,
- SA_{misc}, the remaining functions of the security agent such as OAM cell processing.

This division is for descriptive purposes only and does not imply how a specific implementation of a security agent is constructed.

3 Security Services for the User Plane

3.1 Entity Authentication

3.1.1 Authentication Reference Model

Authentication is provided via an exchange of information between SA_{sme}s that proves to the authenticating $SA_{service}$ that the authenticated $SA_{service}$ possesses a secret that is known solely by the authenticated entity (or its proxy) or exclusively by the two entities (or their proxies). Authentication may be either bi-directional (calling party to called party or parties and vice versa) or uni-directional. The authenticated entities in all cases are the Security Agents associated with the user plane entities that terminate the ATM virtual path or channel. If provided, ATM authentication shall be on a *per-VC basis*. This means that

- The decision to authenticate or not is determined on a VC-by-VC basis.
- Authentication is performed once for a connection, at the beginning of that connection.

Authentication is accomplished by using nonces, time stamps, and symmetric or asymmetric cryptographic mechanisms.

As Sections 5.1.4 and 5.1.5 explain, two ways are specified for negotiating security services: signaling-based and in band. There are differences in the reference models for how the authentication service is provided for the two cases.

Figure 10 shows the object and layer reference models for the authentication service in the case where security messaging is signaling-based. In this case SA_{sme} is called by signaling. The SA_{sme} coordinates with the control entity so that authentication is provided for the user plane entities requesting it.

The object and layer reference models for the case where security messaging is in band (Figure 11) is similar to the signaling-based model except that the SA_{sme} completes its exchange by passing messages in the user data stream, as shown in Figure 11. Otherwise the object interactions are as for the signaling-based case.

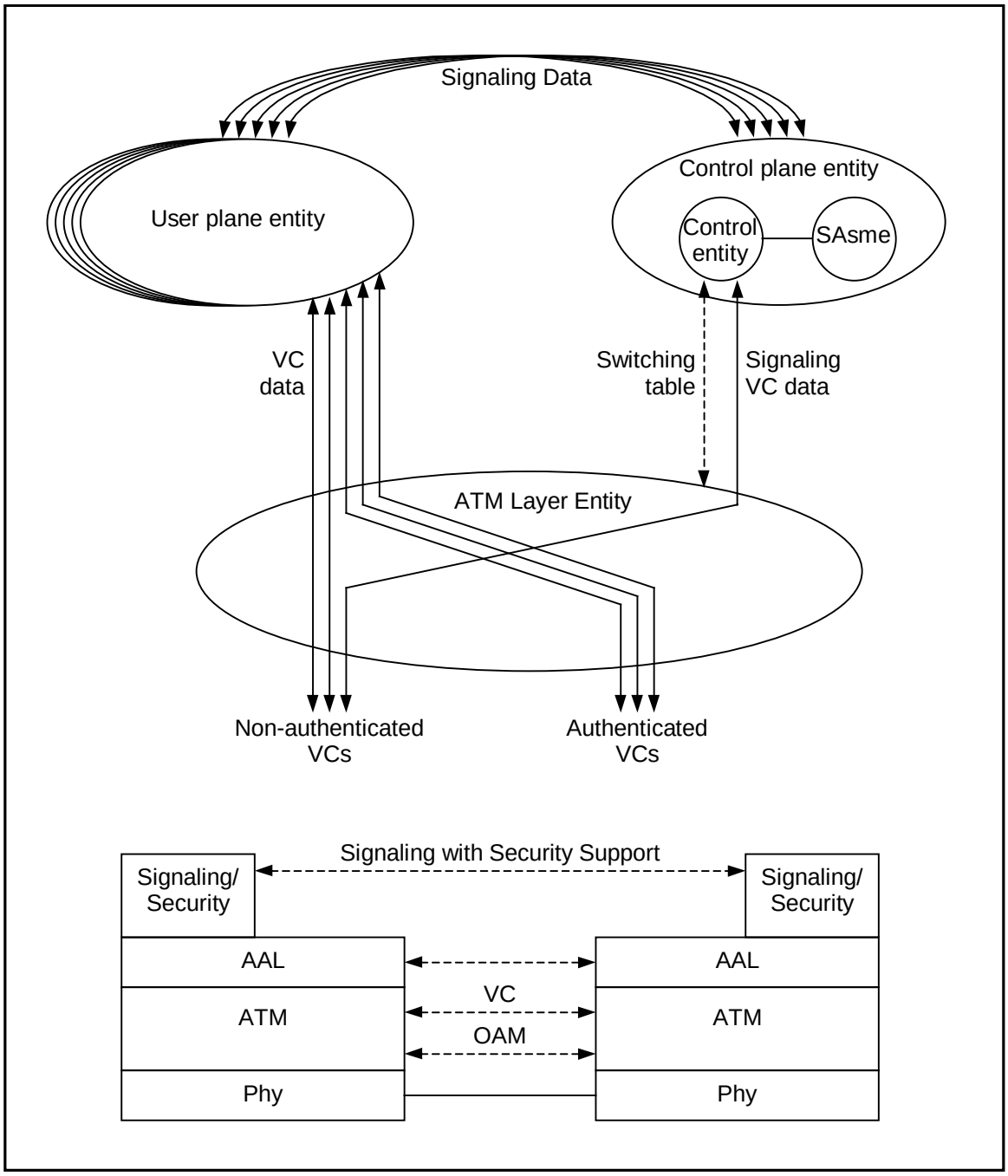


Figure 10: Object and Layer Reference Models for Authentication with Signaling-Based SME.

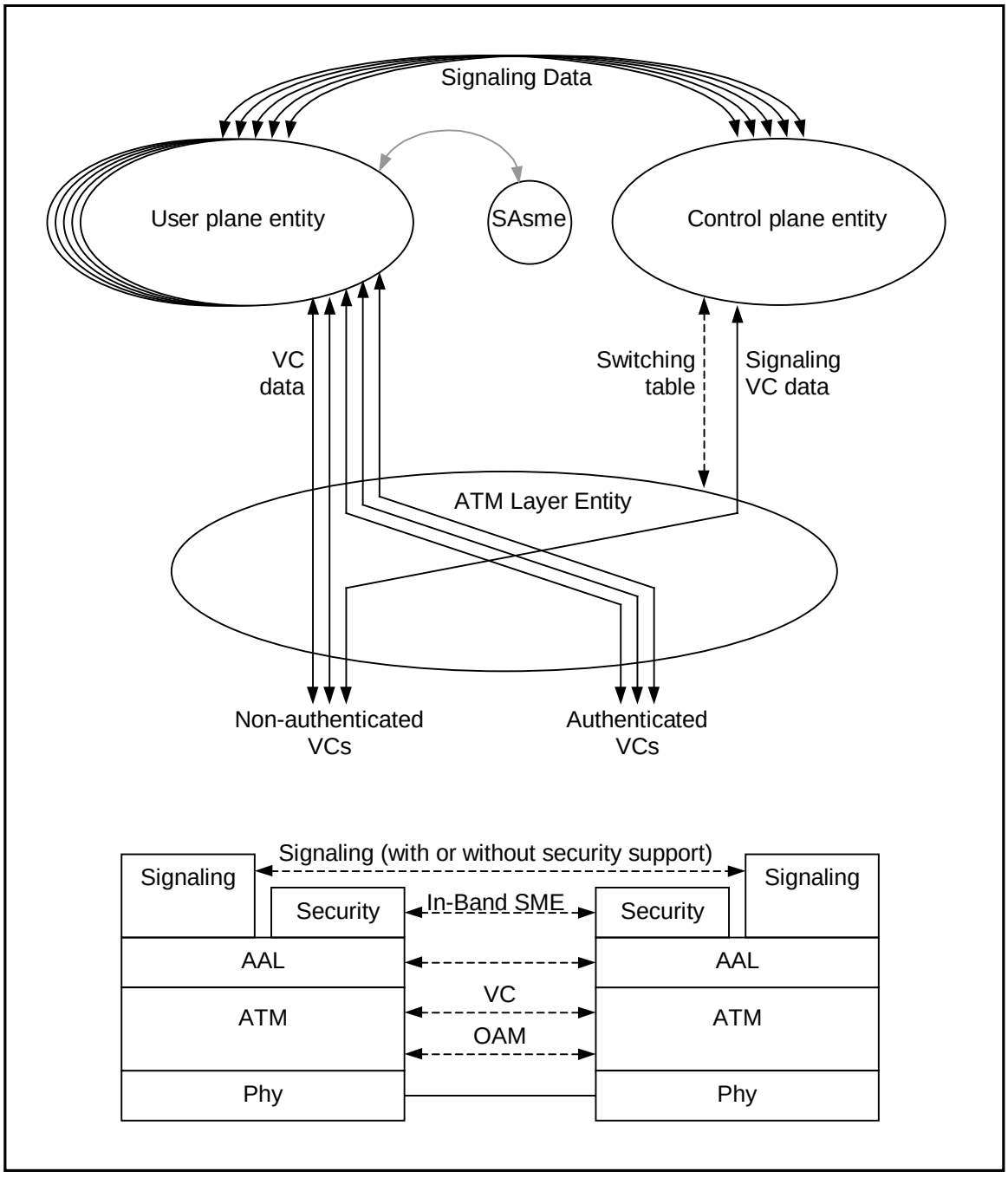


Figure 11: Object and Layer Reference Models for Authentication with In-Band SME.

3.1.2 Authentication Infrastructure and Mechanisms

The authentication service is described in the context of the "security message exchange protocol" in Section 5.1. The messages that are used by this protocol are described in Section 5.1.5.3, Section 5.1.4.4, [4], [5], and [6].

3.1.3 Authentication Algorithms

Authentication is performed using either symmetric (secret) key algorithms (such as DES) or asymmetric (public) key algorithms (such as RSA). With symmetric algorithms, before authentication can take place between two nodes, the two nodes need to have a shared secret key. With asymmetric algorithms, the nodes only need to know each other's public keys.

Before authentication can take place between two security agents, the two $SA_{service}$s need to obtain keys for the cryptographic techniques.

In the case of symmetric algorithms, the two $SA_{service}$s need to have a pair of shared secret uni-directional keys. These keys are pre-placed through methods outside the scope of this document (e.g., manual configuration).

In the case of asymmetric algorithms, the $SA_{service}$s need to know each other's public keys. These public keys may be obtained in three ways:

1. By retrieving the SA's public key certificate from a public key directory,
2. By exchanging public key certificates directly during security negotiation, or
3. By pre-placing public keys using methods outside the scope of this document.

Note: the generation, distribution, and storage of the secret, private, and/or public keys is outside the scope of this specification. In addition, certificate verification may require the retrieval and verification of certificate chains, and policy checking. These operations are also outside the scope of this specification.

The following sections define which algorithms may be used with either method (symmetric or asymmetric) of this authentication protocol. Note that before this protocol can commence, both parties must negotiate the algorithm. This negotiation protocol is described in the context of the "security message exchange protocol" in Section 5.1.

Associated with each algorithm is a codepoint that is used for identification when negotiating security options. These codepoints are listed in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

3.1.3.1 Asymmetric Digital Signature Algorithms

The following asymmetric (public-key) digital signature algorithms are defined in this specification for user plane authentication.

Algorithm	Normative Reference
RSA	[27]
DSA	[10]
EC-GDSA	Section 8.7
ESIGN	Section 8.3

3.1.3.2 Symmetric Digital Signature Algorithms (MACs)

The following message authentication codes are defined in this specification for user plane authentication.

Algorithm	Normative Reference
DES/CBC MAC	[7], [20], Section 8.4
DES40/CBC MAC*	[20], Section 8.4, Section 8.5
Triple DES/CBC MAC	[7], [20], , Section 8.4
FEAL/CBC MAC	[20], [28], [29], Section 8.4

*Although a codepoint for this mode is assigned, this mode is deprecated.

3.1.3.3 Hash Functions

The following hash functions are defined in this specification for use with both asymmetric digital signature algorithms and MACs.

Hash Function	Normative Reference
MD5	[13]
SHA-1	[9]
RIPEMD-160	[21]

3.1.4 Error Processing

Error processing for the entity authentication service is described in the context of the security message exchange protocol in Section 5.1.

3.2 Confidentiality

3.2.1 Confidentiality Reference Model

Confidentiality is provided via *encryption*. If provided, ATM encryption shall be on a *per-VC basis.* This means that:

- Encryption is applied to the sequence of data cells in a single VC.
- The decision to encrypt or not is determined on a VC-by-VC basis.
- For encrypted VCs, encryption parameters are determined (and may vary) on a VC-by-VC basis.

In all cases, encryption is applied to all or part of the 48-octet payloads of the relevant ATM cells. In terms of ATM architecture and layering, then, encryption takes place at the ATM layer. Other approaches to confidentiality (e.g., bulk link encryption, AAL-level encryption) are outside the scope of this document.

As Sections 5.1.4 and 5.1.5 explain, there are two ways specified for negotiating security services: signaling based and in band. There are differences in the reference models for how the confidentiality service is negotiated and established for the two cases.

Figure 12 shows the object and layer reference models for the confidentiality service in the case where SME is signaling based. In this case, the SA_{sme} is called by the control plane entity. As explained above, the encryption/decryption function of $SA_{service}$ is logically part of the ATM layer entity, because all encryption is applied on a per-VC basis. When required by the selected cryptographic mode, the

encryption/ decryption function of $SA_{service}$ maintains the state via OAM cells carried over end-to-end F4 or F5 flows (for VPCs or VCCs respectively).

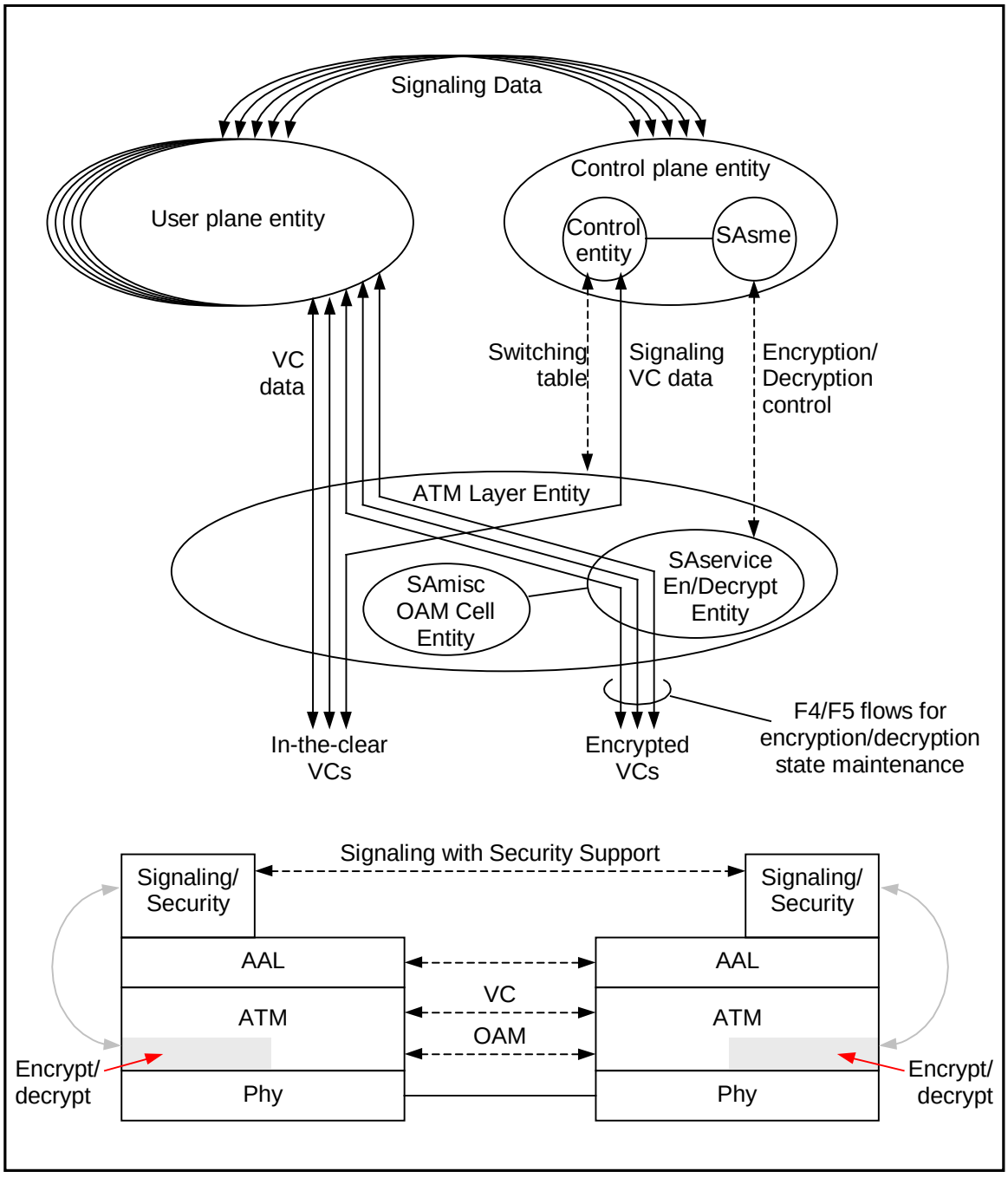


Figure 12: Object and Layer Reference Models for Confidentiality with Signaling-Based SME.

The object and layer reference models for the case where security messaging is in band (Figure 13) are similar to the signaling-based models except for the placement of the SA_{sme}. For the in-band case, the

SA_{sme} is moved out of the control plane entity, as shown in Figure 13. Otherwise the object interactions are as for the signaling-based case.

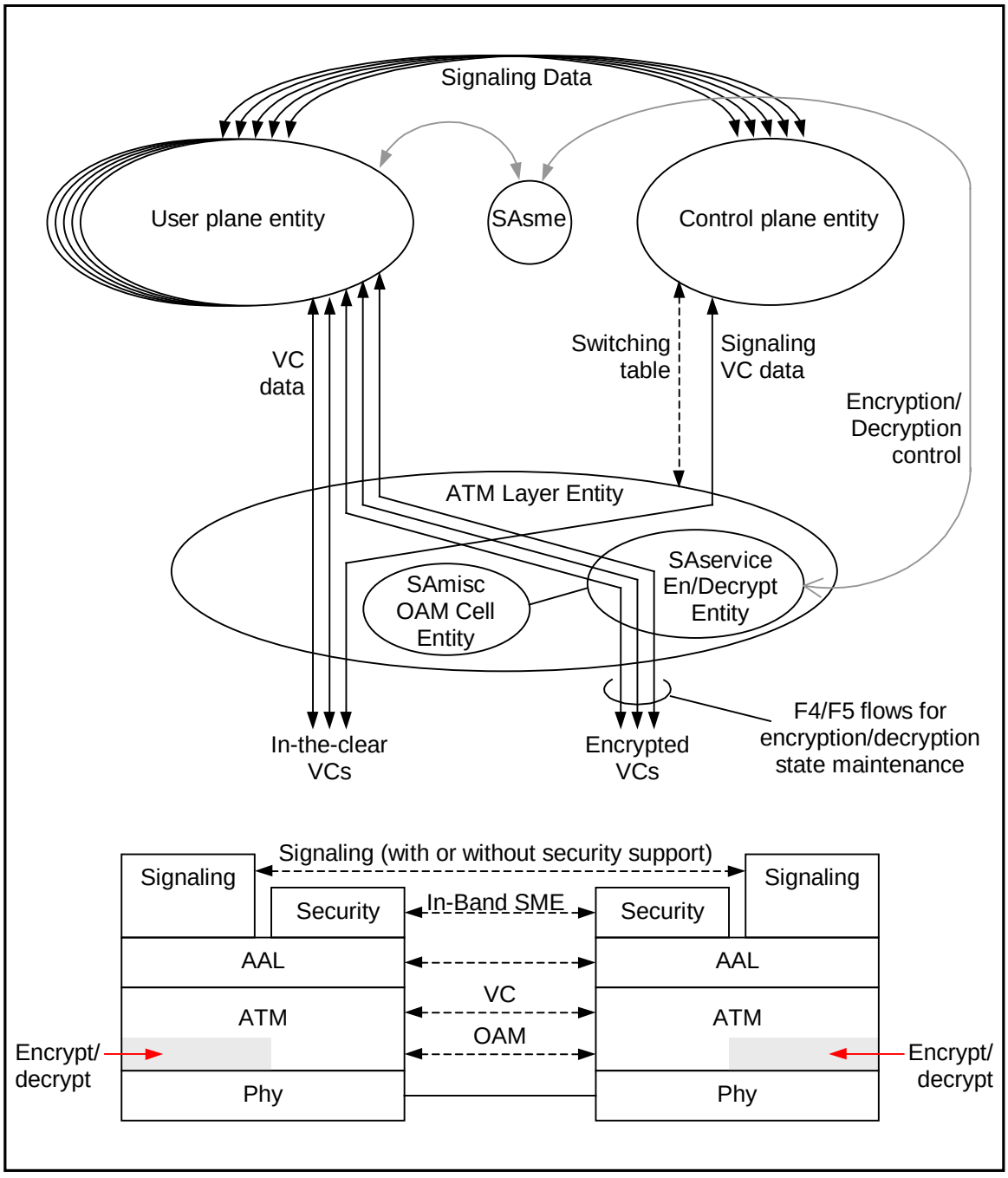


Figure 13: Object and Layer Reference Models for Confidentiality with In-Band SME.

3.2.2 Confidentiality Infrastructure and Mechanisms

In this specification, symmetric (secret key) algorithms provide user plane confidentiality. In addition, the algorithms listed below must be used in a specific mode of operation. Keys for these algorithms can be

either pre-placed (configured manually) or determined using the Key Exchange methods described in Section 5.2.

Associated with each algorithm and mode of operation is a codepoint that is used for identification when negotiating security options. These codepoints are listed in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

The following algorithms are defined in this specification for user plane confidentiality.

Algorithm	**Normative Reference**
DES	[7]
DES40*	Section 8.5
Triple DES (keying option 2)	[7]
FEAL (64 bit key, no key block parity, N=32)	[28], [29]

*Although a codepoint for this mode is assigned, this mode is deprecated.

The following modes of operation are defined in this specification for user plane confidentiality.

Mode	**Normative Reference**
Cipher Block Chaining (CBC)	[8]
Counter Mode	Section 8.2
Electronic Codebook (ECB)	[8]

Counter Mode is not self-synchronizing. Therefore, it is necessary to maintain synchronization of cryptographic state between the encrypting and decrypting security agents. This is accomplished via the OAM cells as described in Section 8.2.

This specification provides a mechanism for changing session keys for the confidentiality service. This mechanism is described in Section 5.3.

3.2.3 Bypass of Special Network Cells

Because the data confidentiality service is defined at the ATM layer, it is necessary to clarify its operation with respect to special network cells, that is, cells other than user data cells. Because these special cells, i.e. OAM cells or RM cells, are interpreted by intermediate nodes in the network, they must be excluded by the encryption process. Otherwise they would be rendered meaningless, as it is not possible or desirable to have these intermediate nodes involved in the encryption process. To this end the following shall apply:

- For Virtual Channel Connections (VCCs), cells with a Payload Type Indicator (PTI) field of 1xx (binary) shall bypass the encryption process, and be transmitted in clear (where “x” in the PTI means don’t care). In addition, unless specifically defined herein, these cells shall not change the cryptographic state of the security agent.
- For Virtual Path Connections (VPCs), cells with a Virtual Channel Identifier (VCI) field with the following values: 3, 4, and 6-15 shall bypass the encryption process and be transmitted in clear. In

addition, unless specifically defined herein, these cells shall not change the cryptographic state of the security agent.

3.3 Data Origin Authentication and Integrity

3.3.1 Integrity Reference Model

Data integrity is provided by means of cryptographic checksums (also known as message authentication codes [MACs]) appended to AAL 3/4 and AAL 5 "Common Part" service data units (SDUs). Data integrity service is available only for virtual channels, not for virtual paths. If provided, ATM data integrity shall be on a *per-VCC basis*. This means that:

- Integrity protections do not apply to VPCs.
- Checksums are applied to the sequence of Common Part SDUs in a VCC.
- The decision to provide integrity or not is determined on a VCC-by-VCC basis.
- For VCCs with checksums, integrity keys are determined (and may vary) on a VCC-by-VCC basis.

In terms of ATM architecture and layering, the data integrity function takes place at the AAL. Other approaches to data integrity are outside the scope of this document.

As Sections 5.1.4 and 5.1.5 explain, there are two methods specified for negotiating security services: signaling based and in band. There are differences in the reference models for how the data integrity service is provided for the two cases.

Figure 14 shows the object and layer reference models for the data integrity service in the case where security messaging is signaling based. In this case, the SA_{sme} is called by the control plane entity upon receipt of, or prior to sending, all messages. As explained above, the data integrity function of $SA_{service}$ is logically part of the AAL entity, because MACs are applied on a per-VCC basis

The object and layer reference models for the case where security messaging is in band (Figure 15) is similar to the signaling-based model except for the placement of the SA_{sme}. For the in-band case, the SA_{sme} is moved out of the control plane entity, as shown in Figure 15. Otherwise the object interactions are as for the signaling-based case.

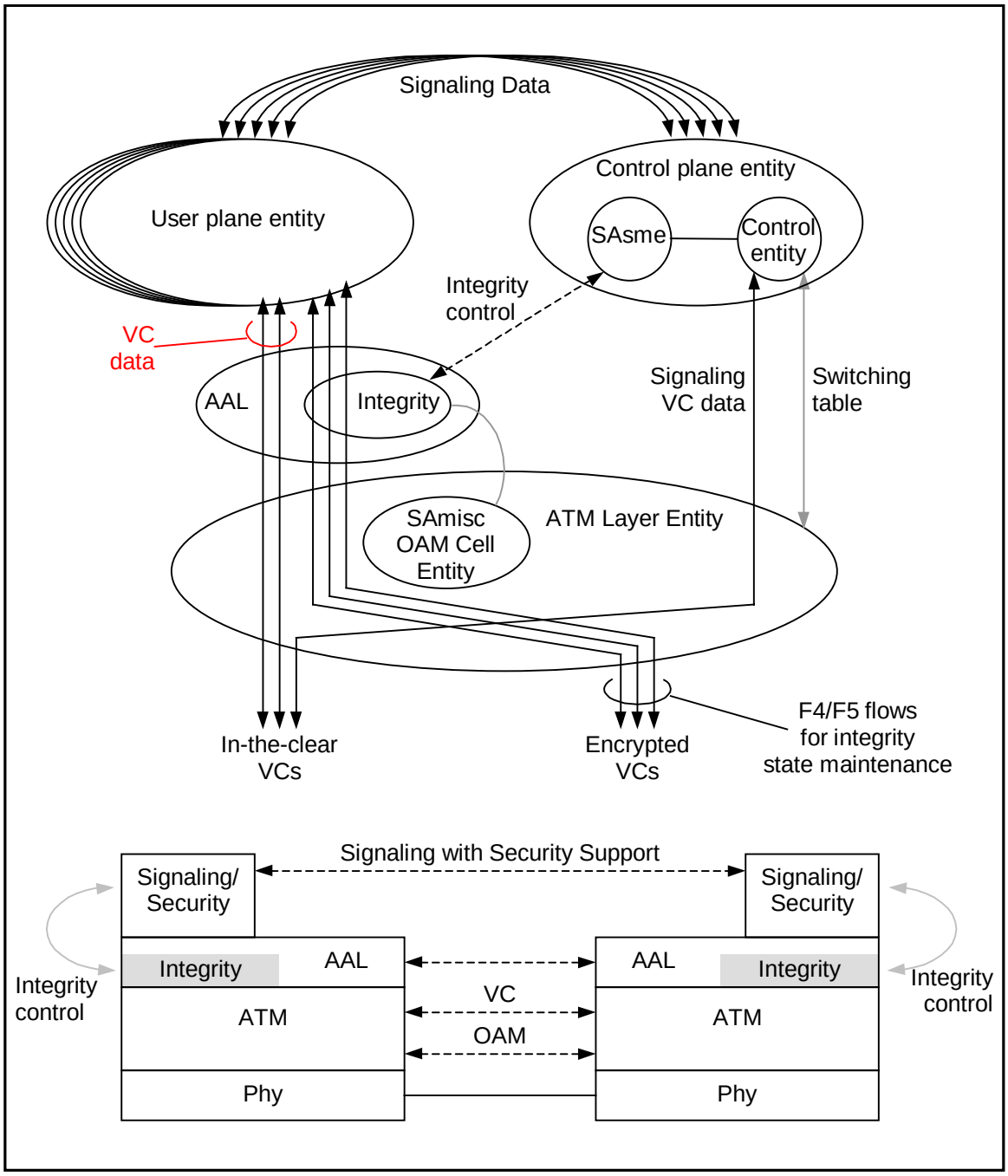


Figure 14: Object and Layer Reference Models for Data Integrity with Signaling-Based SME.

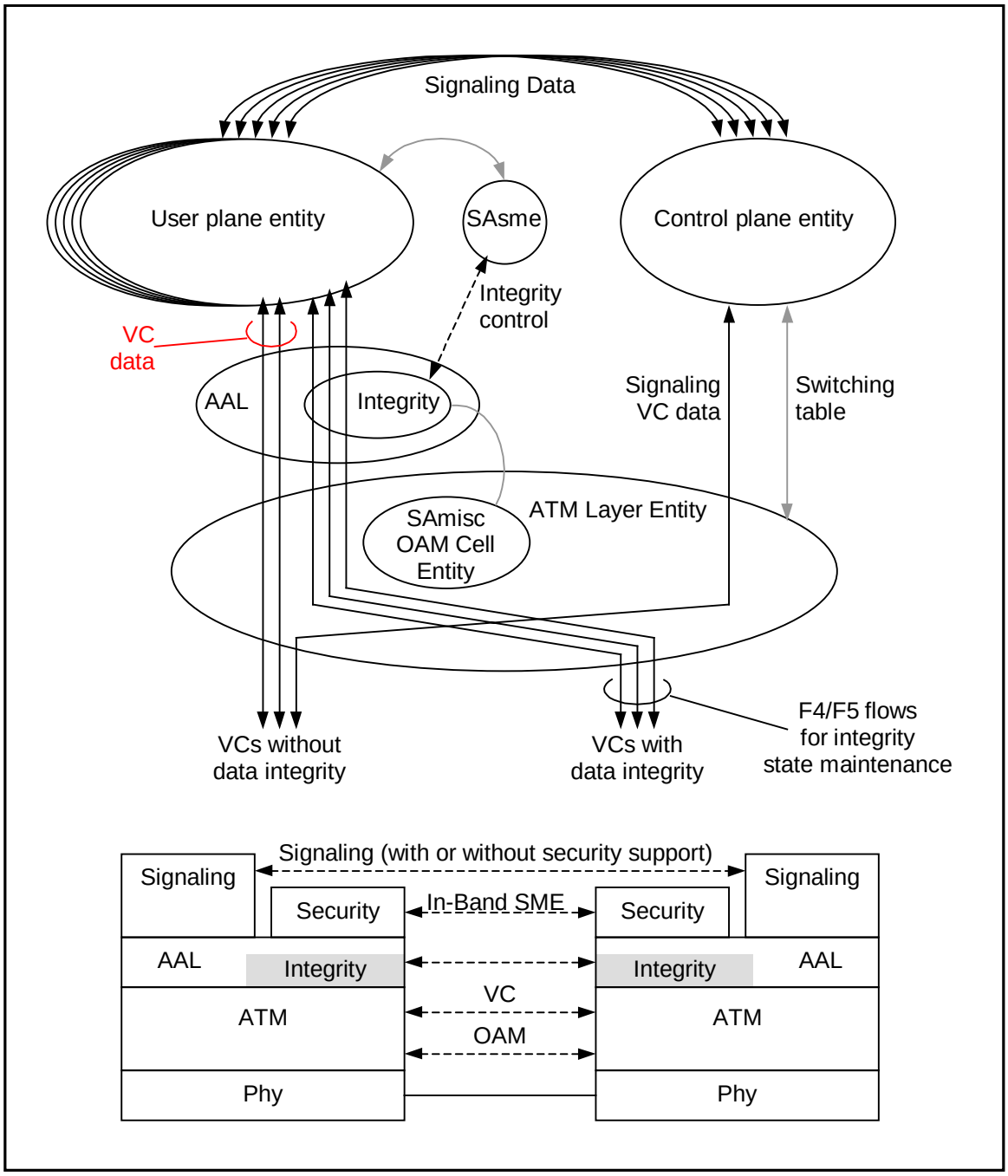


Figure 15: Object and Layer Reference Models for Data Integrity with In-Band SME.

3.3.2 Integrity Infrastructure and Mechanisms

The data integrity mechanism supports data integrity for the “Common Part” AAL SDU in AAL type 3/4 and AAL type 5 for user data on a per VCC basis. The VCC may be a switched VCC (i.e., SVC) or a permanent VCC (i.e., PVC).

The data integrity service is provided with two options: 1) data integrity without replay/reordering protection, and 2) data integrity with replay/reordering protection. The option to be used for a connection may be negotiated at the time the connection is established.

When data integrity is provided without replay/reordering protection, the source appends a cryptographic checksum, commonly referred to as message authentication code (MAC), to the tail of each Common Part AAL-SDU before transmitting it, as shown in Figure 16a. The MAC is computed over the Common Part AAL-SDU.

At the destination, when a Common Part AAL-SDU is received, the security agent verifies the MAC. If the MAC does not check, it simply discards the AAL-SDU.

When data integrity is provided with replay/reordering protection, the data integrity service provides protection against replay and reordering attacks, so that “old” or “reordered” AAL-SDUs are detected and discarded. At the source, this is achieved by first appending a sequence number to the tail of each Common Part AAL-SDU and then computing a MAC on the totality of the Common Part AAL-SDU including the sequence number. This MAC, which protects both the AAL-SDU and the sequence number, is then appended to the total Common Part AAL-SDU (which includes the sequence number), as shown in Figure 16b.

The sequence number is set to zero when the connection is established and each time the session key for data integrity is updated (i.e., changed over). The sequence number is incremented with each AAL-SDU that the source sends. The sequence number is a 6-octet number. The sequence number shall not wrap around during the life of a session integrity key.

At the destination, when a Common Part AAL-SDU is received, the security agent verifies that the MAC is valid. If the MAC is not valid, it discards the AAL-SDU. If the MAC is valid, then it checks the sequence number to ensure that it is valid.

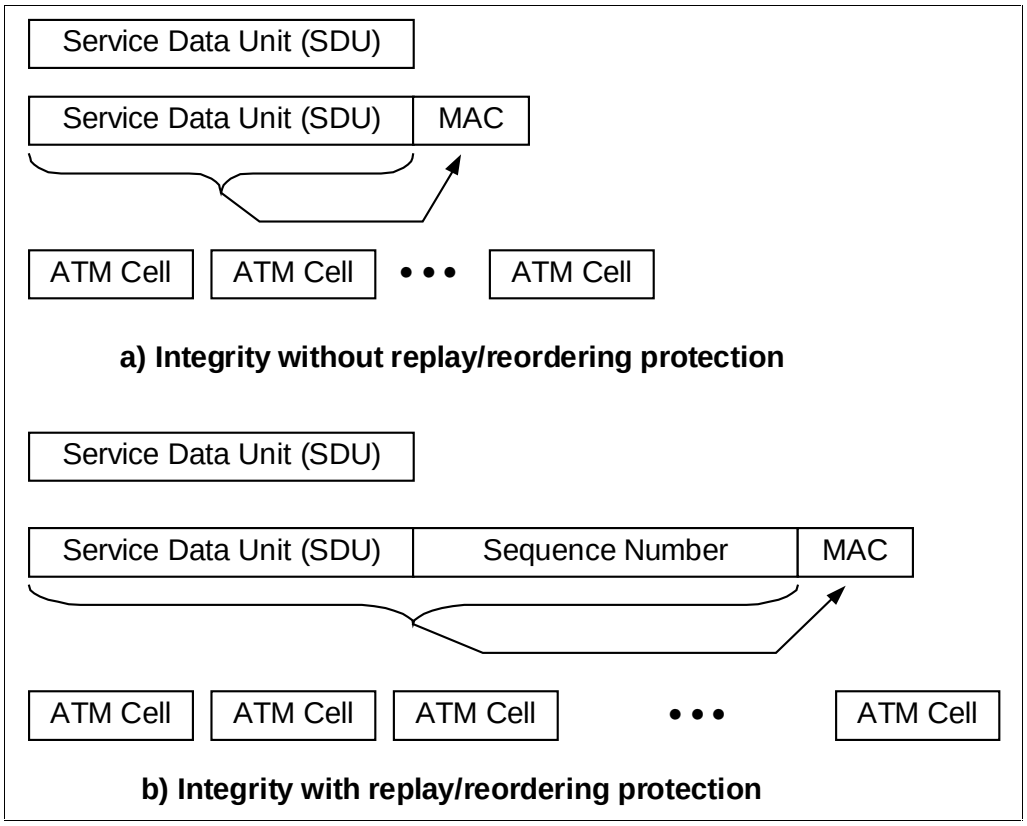


Figure 16: AAL-SDU Level Data Integrity.

The receiving security agent tests the sequence number as follows. When there is a previously received valid Common Part AAL-SDU, then the sequence number associated with the current Common Part AAL-SDU is valid only if it's greater than the sequence number associated with the last valid Common Part AAL-SDU received. When there is no previously received valid Common Part AAL-SDU, the sequence number associated with the current Common Part AAL-SDU is accepted as valid. If the sequence number fails these tests, the security agent discards the AAL-SDU.

The receiving security agent saves the sequence number associated with the last valid Common Part AAL-SDU received to check the validity of the next Common Part AAL-SDU that it may receive. The saved sequence number is set to zero whenever the data integrity session key is changed.

3.3.2.1 Message Authentication Code

The message authentication code (MAC) to be used for the connection's integrity service is negotiated at the time the connection is established.

Associated with each algorithm is a codepoint that is used for identification when negotiating security options. These codepoints are listed in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

The following algorithms are defined in this specification for user plane integrity. In the first three cases, HMAC is implemented with $t = 96$ (see [12]).

Algorithm	Normative Reference
HMAC-MD5	[12], [13]
HMAC-SHA-1	[9], [12]
HMAC-RIPEMD-160	[12], [21]
DES/CBC MAC	[7], [20], Section 8.4
DES40/CBC MAC	[20], Section 8.4, Section 8.5
Triple DES/CBC MAC	[7], [20], Section 8.4
FEAL/CBC MAC	[20], [28], [29], Section 8.4

As with the confidentiality service, this specification provides a mechanism for changing session keys for the integrity service. This mechanism is described further in Section 5.3.

3.4 Access Control

3.4.1 Access Control Reference Model

Access control is provided on a per-VC basis. In general, access control is performed during connection establishment based on information contained in the security message exchange and network configuration parameters.

Sections 5.1.4 and 5.1.5 specify two methods for negotiating security services: signaling based and in band. Figure 17 and Figure 18 show the different reference models for these two methods.
Figure 17 shows the access control layer reference model for the access control service in the case where security messaging uses the signaling-based method of negotiating security services. In this case, the SA_{sme} is logically part of the control plane entity.

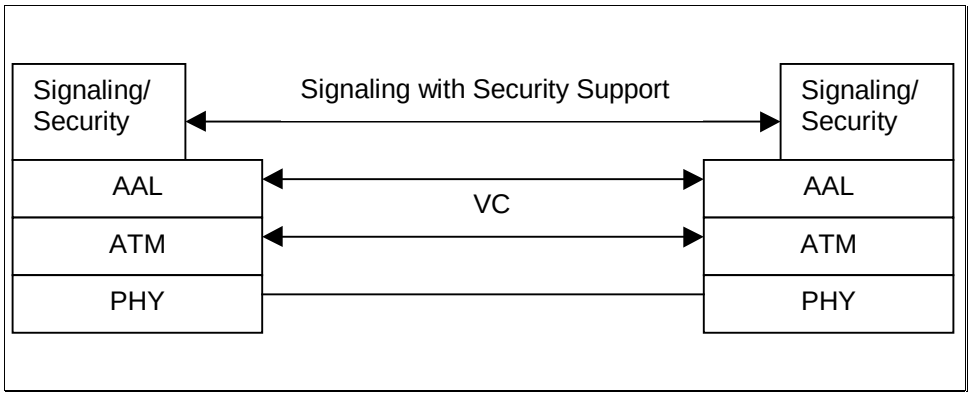


Figure 17: Access Control Layer Reference Model for Signaling-Based Messaging.

The access control layer reference model for the in-band method of negotiating security services (Figure 18) is similar to the signaling-based model except for the placement of the SA_{sme}. For the in-band case, the SA_{sme} is moved out of the control plane entity, as shown in Figure 18. Otherwise, the interactions are the same as for the signaling-based case.

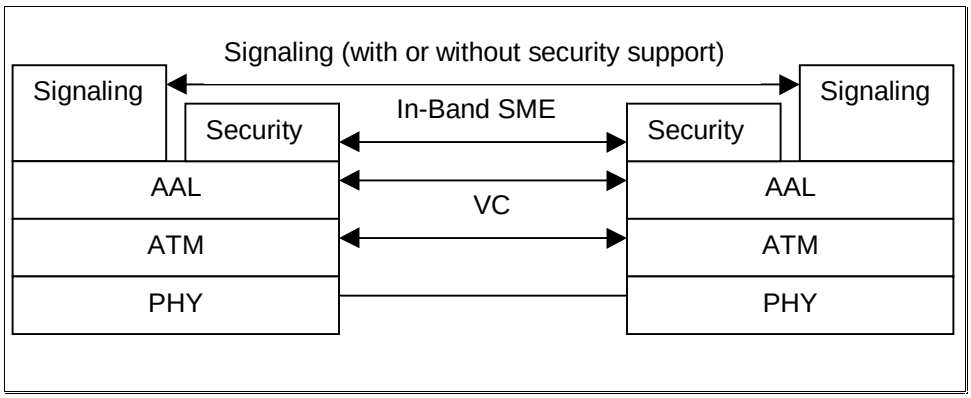


Figure 18: Access Control Layer Reference Model for In-Band-Based Messaging.

3.4.2 Access Control Infrastructure and Mechanisms

Associated with each mechanism is a codepoint that is used for mechanism selection when negotiating security options. These codepoints are not listed here, but rather in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

Access control data are sent in the initial exchange between security agents so that access control decisions can be made, as necessary, at each ATM component in the connection path during connection establishment.

The following algorithms are defined in this specification for user plane access control.

Algorithm	**Normative Reference**
Standard Security Label	[11]

Appendix II provides additional information on the use of security labels within an ATM network.

3.4.3 Error Processing

If an error prevents establishing a connection, an error message shall be returned to the calling party to enable connection tear-down along the path of the connection setup according to the error processing procedures described in Sections 5.1.4 and 5.1.5. The amount of diagnostic information provided in the Cause Information Element shall be configurable.

4 Security Services for the Control Plane

4.1 Control Plane Data Origin Authentication and Data Integrity

For Version 1.1 of this specification, Control Plane data origin authentication and data integrity are accomplished in a hop-by-hop manner between adjacent signaling elements. Figure 19 shows the reference model for this service. This service is accomplished by applying the user plane data origin authentication and integrity service (Section 3.3) to the Signaling AAL (SAAL) SDU connecting two signaling entities.

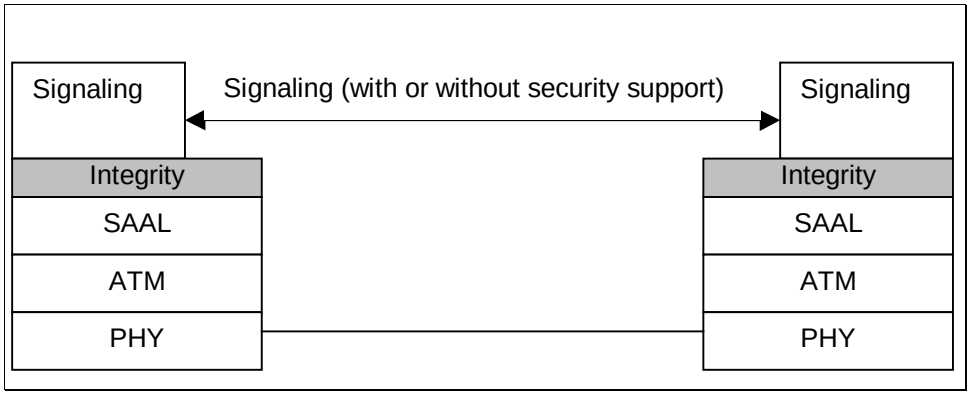


Figure 19: Control Plane Data Origin Authentication and Integrity Layer Reference Model.

The particulars for the Control Plane data origin authentication and integrity service are as follows:

The provision of control plane data origin authentication and data integrity and the algorithms and parameters required to effect this service are not dynamically negotiated; rather, management prearranges them. See Section 3.3.2.1 for a list of the MAC algorithms that may be used and Section 7.2.3.2 for the parameters needed to operate those algorithms.

The control plane data origin authentication and data integrity service shall support session key update. The provision of session key update and the algorithms and parameters required to effect it are not dynamically negotiated; rather, management prearranges them. See Section 5.3 for a list of the MAC algorithms that may be used and Section 7.2.3.6 for the parameters needed to operate those algorithms.

The two ends of the signaling channel shall be preconfigured with a shared secret master key and initial session keys. Session key updates shall take place according to the procedures in Section 5.3.

The control plane data origin authentication and data integrity service shall always use the “data integrity with replay/reordering protection” option.

The mechanisms that provide Control Plane data origin authentication and data integrity service are identical to those described in Section 3.3.2 with the following exception:

The Control Plane data origin authentication and data integrity service operates at the SAAL SDU level rather than at the AAL5 common part SDU level.

Thus, the Control Plane data origin authentication and data integrity service operates above the SAAL and below the signaling protocol. For outgoing signaling messages, sequence numbers and MAC fields are added to the SAAL SDU. For incoming signaling messages, the fields are removed from the SDU and processed by the $SA_{service}$ before the signaling messages are passed to the signaling entity for further processing.

4.1.1 Error Conditions

If the two endpoints of a signaling channel are not compatibly configured, the SSCOP connection will never be established, so no signaling messages will ever pass between the two entities. If the AAL5 SDU is modified in transit, it will be discarded as defined in Section 3.3, and SSCOP will retransmit.

5 Support Services

This section describes the mechanisms that are required to support the security services described in Section 3 and Section 4. Specifically, the following support services are addressed in this section:

- Security message exchange protocols and basic negotiation,
- Security messaging in the control plane,
- Security messaging in the user plane,
- Key exchange,
- Session key update,
- Certificates.

Security message exchange protocols that support the entity authentication and negotiation services that are described in Section 3 are summarized here and described in detail in Section 5.1.

The three-way security message exchange protocol described in Section 5.1.1.1 may be used for establishing security associations for a point-to-point connection as well as for the first leaf in a point-to-multipoint connection. This protocol is used for security associations that require negotiation of security options. The three-way exchange has the advantage that it does not use time stamps, and therefore does not require clock synchronization.

The two-way security message exchange protocol described in Section 5.1.1.2 may also be used for establishing a security association for a point-to-point connection or a point-to-multipoint connection. This protocol is used for security associations that do not require negotiation of security parameters, and for adding leaves to multipoint connections. A disadvantage of the two-way exchange protocol is that it requires clock synchronization between the party that generates the security information and the party that validates the security information.

This specification defines two mechanisms for transporting security information. These are the signaling-based security message exchange mechanism (described in Section 5.1.4) and the in-band security message exchange mechanism (described in Section 5.1.5). In both cases, the Security Services Information Element (described in Section 5.1.3) is used to carry the security information.

The method for performing the two-way exchange protocol in security-enhanced signaling [4] [5] [6] flows is described in detail in Section 5.1.4. (The three-way message exchange protocol is not supported in signaling in this specification.)

For point-to-multipoint connections after the first leaf is established, subsequent leaves are added with a two-way security message exchange. This is consistent with the fact that negotiation of security options may be performed only when establishing the first leaf—subsequent leaves must accept the options that the root and the first leaf agreed upon.

The method for performing the three-way message exchange protocols in the user plane VCC/VPC is described in detail in Section 5.1.5. This method applies to SVCs, PVCs, and permanent virtual path connections. In order to provide a reliable transport service for in-band message flows, an in-band message exchange protocol is defined in Section 5.1.5.3. As with the signaling-based approach, this protocol uses the Security Services Information Element to convey security-related parameters.

PVCs (permanent virtual circuits) are provisioned connections. Security services negotiation, authentication, certificate exchange, and key exchange can be done via provisioning at the time PVCs are established, or in-band as described in Section 5.1.5. Once security services for PVCs are established, the data confidentiality and data integrity services for PVCs are provided the same way as they are provided for SVCs. Likewise, session key update (for data confidentiality and data integrity services) for PVCs is done the same way as it is done for SVCs.

When a SVC or PVC is established, a shared master key and initial session keys may need to be established. To prevent active attacks, key exchange must be bound to strong authentication between the SAs, as explained in Sections 5.1.1 and 5.2.

Once a shared master key and initial session keys are exchanged, there is no need for security message exchanges in the middle of connection after the connection is established. However, session keys for these services may have to be changed periodically. Section 5.3 describes the key update mechanism (for the data confidentiality and data integrity services), which uses OAM cells to perform this function.

Section 5.4 describes the certification infrastructure and mechanisms for transporting certificates. These certificates can be exchanged during the three-way security message exchange protocol or through some other means that is outside the scope of this specification (e.g., directory servers).

5.1 Security Information Exchange

5.1.1 Security Message Exchange and Negotiation Protocols

The two-way (signaling-based only) and three-way (in-band only) security message exchange protocols are not dependent on the use of any particular cryptographic algorithm and are based on the "strong authentication" procedures of the ISO/IEC 9594-8 [18] asymmetric (public key) based authentication and the ISO/IEC 11770-2 [22] symmetric (secret key) based authentication. Both protocols provide the following functions:

- Unilateral authentication,
- Mutual authentication,
- One- or two-way key exchange.

The three-way (in-band) message exchange protocol provides the following additional functions:

- Support for large messages (up to 65536 octets)
- Certificate exchange,
- Negotiation of security services and options.

In the two- and three-way security message exchange protocols, one user of the protocol assumes the "initiating" role and the other user assumes the "responding" role.

When setting up a security association for a point-to-point connection or for the first leaf of a point-to-multipoint connection, the initiator has the option to use either the two-way security message exchange protocol or the three-way security message exchange protocol. When setting up a security association for subsequent leaves in a point-to-multipoint connection, the initiator can only use the two-way security message exchange protocol.

The following table shows the symbols and abbreviations used throughout the discussion of two- and three-way security message exchange protocols:

X	Entity *X* distinguished name (ID). Authentication requires that the entity to be authenticated have a distinguished name (ID) and an associated key. So, *X* represents the ID of the entity to be authenticated.
K_X	When *X* uses an asymmetric (public) key algorithm (such as RSA), K_X represents the public or private component of *X*'s asymmetric key. When *X* uses a symmetric (secret) key algorithm (such as DES), K_X is *X*'s symmetric (secret) key.
$Enc_{K_X}(text)$	Encryption of *text* under *X*'s key. When *X* uses an asymmetric (public) key algorithm (such as RSA) for encryption, K_X is the public component of *X*'s asymmetric key. When *X* uses a symmetric (secret) key algorithm (such as DES) for encryption, K_X is *X*'s symmetric (secret) key.
$Sig_{K_X}(Hash(text))$	*X*'s digital signature computed over the hash of *text* under *X*'s key. When *X* uses an asymmetric (public) key algorithm (such as RSA) for digital signature, K_X is the private component of *X*'s asymmetric key. When *X* uses a symmetric (secret) key algorithm, or a message authentication code (such as DES/CBC MAC) for digital signature, K_X is *X*'s symmetric (secret) key and no hash function is applied.
Hash(text)	One-way hash of *text*, where *Hash* is a strong one-way hash function.
R_X	Random number (nonce) generated by *X*.
T_X	$T_X = (Time_X, Seq_X)$, time-variant time stamp generated by *X*. The time stamp is a combination of two values ($Time_X$, Seq_X). $Time_X$, is a 4-octet coordinated universal time, the Greenwich Mean Time (GMT) at which the signature was generated. This is the binary encoding of the number of seconds since 00:00:00 GMT on January 1, 1970 (same as UNIX time). Seq_X is a 4-octet sequence number that is incremented with each authentication flow that is sent to the same destination with the same $Time_X$ value. When the $Time_X$ value changes, Seq_X is reset to 0. (Because this time value wraps around late in the first half of the 21st Century, this parameter is likely to change in future releases.)
{.}	Optional token. A token included in {.} is only needed when the specific security service that requires it is invoked. For example, *{ConfPar}* is present only if the key exchange service is required for the connection.
SecOpt	In the two-way security message exchange protocol, the initiator uses the *SecOpt* token to indicate to the responder what security services are to be provided for the connection. *SecOpt* carries the security services, options, and parameters requested for the connection. This includes the type of security services to be provided for the connection (e.g., authentication, data confidentiality) and the algorithms and modes of operation to be used for each security service (e.g., authentication using DSA; key exchange using RSA; data confidentiality using DES in CBC mode). Additionally, *SecOpt* includes the parameters associated with each selected algorithm and mode of operation (e.g., initialization vector for CBC mode).
SecNeg_	In the three-way security message exchange protocol, the "initiator" and "responder" use $SecNeg_a$ and $SecNeg_b$ to negotiate the security services, options, and parameters for the connection. The initiator presents to the responder the following information using the $SecNeg_a$ token: **1)** the security

	services (e.g., authentication, data confidentiality) to be provided for the connection and any other security service that will be provided for the connection should the responder request it; **2)** for each security service that the initiator has requested and any other security service that will be provided for the connection should the responder request it, one or more sets of options for each service. Options shall be presented in order of preference, with the highest preference option first and the lowest preference option last. The responder must select the first compatible option presented to it. The responder can only select one of the options presented to it. For example, for data confidentiality, the initiator may indicate Triple-DES as first choice and FEAL as second choice. For authentication hash algorithm, the initiator may indicate SHA-1 as first choice and no other choices. For authentication signature algorithm, the initiator may indicate DSA as first choice and RSA as second choice, etc. **3)** The parameters associated with each option (for example, initialization vector for DES in CBC mode). When the responder receives these three pieces of information (i.e., items 1-3) from the initiator, it makes its selection from the list of options presented to it and communicates that to the initiator through the $SecNeg_b$ token, if any of the options presented to it is satisfactory. The connection setup can proceed only if the security negotiation step is successful, otherwise the security agent will cause the call to be dropped.
ConfPar_	When the key exchange support service option is invoked, $ConfPar_a$ is used to securely carry the initiator's keys from the initiator to the responder. $ConfPar_a$ contains: 1) the initiator's contribution to the master key, 2) the initiator's first session key for the data confidentiality service when the data confidentiality service is requested for the connection, and 3) the initiator's first session key for the data integrity service when the data integrity service is requested for the connection. Similarly, $ConfPar_b$ is used to securely carry the responder's keys from the responder to the initiator. $ConfPar_b$ contains: 1) the responder's contribution to the master key, 2) the responder's first session key for the data confidentiality service when the data confidentiality service is requested for the connection, and 3) the responder's first session key for the data integrity service when the data integrity service is requested for the connection.
Cert	In the security message exchange protocol, when the certificate exchange support service option is invoked, $Cert_a$ is used to carry the initiator's certificate from the initiator to the responder and $Cert_b$ is used to carry the responder's certificate from the responder to the initiator.

The formats of these tokens are defined in Section 7.

In the following discussion, when an asymmetric (public) key algorithm is used, it is assumed that each authentication entity (i.e., *A* and *B*) possesses a public/private key pair. K_a represents the public component of *A*'s asymmetric key when it's used for encryption. K_a represents the private component of *A*'s asymmetric key when it's used for digital signature. Similarly, K_b represents the public component of *B*'s asymmetric key when it's used for encryption. K_b represents the private component of *B*'s asymmetric key when it's used for digital signature.

In the following discussion, when a symmetric (secret) key algorithm is used, it is assumed that the authentication entities *A* and *B* share two uni-directional secret keys K_a and K_b, or a single secret key $K_a = K_b$.

Note: If party A or B uses different public/private key pairs for signature and encryption, the method for obtaining all of the required certificates is outside the scope of this specification.

Note: The generation and storage of the secret, private, and public keys is outside the scope of this specification.

5.1.1.1 Three-Way Security Message Exchange Protocol

Figure 20 shows the three-way security message exchange protocol. This protocol supports both asymmetric and symmetric algorithms.

When authentication or key exchange is invoked, this protocol uses a nonce-based mutual authentication method. As a result, *A* gets authenticated to *B* and *B* gets authenticated to *A*. However, note that *A* is not authenticated to *B* until FLOW3-3WE is received and checked.

This protocol involves the following steps, and is implemented in the In-Band Security Message Exchange Protocol described in Section 5.1.5.3. If an error occurs during processing of this protocol, then the error procedures described in Section 5.1.5.3.6 shall apply.

1. *A* sends FLOW1-3WE (which contains the following required tokens: *A*, R_a, and $SecNeg_a$) to *B*. When certificate exchange is needed, $Cert_a$ is also included in FLOW1-3WE.

   FLOW1-3WE: A → B

   $$A, \{B\}, R_a, SecNeg_a, \{Cert_a\}$$

2. When *B* receives FLOW1-3WE, it carries out the following actions:
   - Checks that *B* itself is the intended recipient, when *B* is included.
   - Extracts $SecNeg_a$ and interprets it for its reply.
   - When authentication or key exchange is required
     - ⇒ Extracts the nonce R_a for its reply.
     - ⇒ Extracts $Cert_a$ if present and verifies its validity.
3. *B* sends FLOW2-3WE (which contains the following required tokens: *A*, *B*, and $SecNeg_b$) to *A*. When authentication or key exchange is required, the authentication token (i.e., $\{R_a, R_b,,...\}$) is included in the flow. When key exchange is needed, $ConfPar_b$ is also included in FLOW2-3WE. When certificate exchange is needed, $Cert_b$ is also included in FLOW2-3WE.

   FLOW2-3WE: B → A

   $$A, B, SecNeg_b, \{Cert_b\}, \{R_a, R_b, \{Enc_{k_a}(ConfPar_b)\}, Sig_{k_b}(Hash(A, B, R_a, R_b, SecNeg_a, SecNeg_b, \{ConfPar_b\}))\}$$

4. When *A* receives FLOW2-3WE, it carries out the following actions:
   - Checks that *A* itself is the intended recipient.
   - Extracts $SecNeg_b$ and interprets it.
   - When authentication or key exchange is required
     - ⇒ Verifies the signature, and thus the integrity of both FLOW1-3WE and FLOW2-3WE.
     - ⇒ Checks that the received R_a in FLOW2-3WE is identical to the one that sent in FLOW1-3WE.
     - ⇒ Extracts the nonce R_b for its reply.
     - ⇒ Extracts $ConfPar_b$ if present and interprets it.

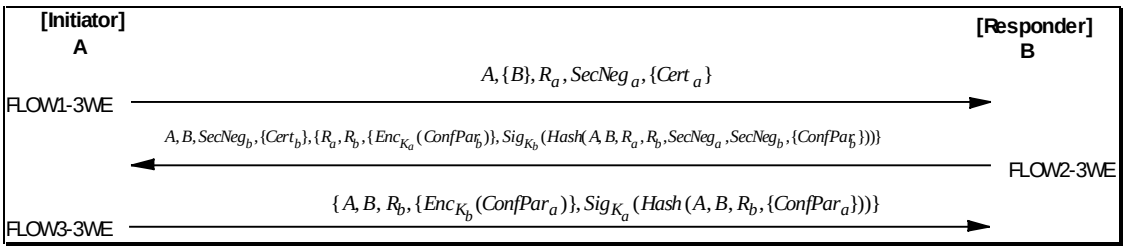


Figure 20: Three-Way Security Message Exchange Protocol.

⇒ Extracts $Cert_b$ if present and verifies its validity.

5. When authentication or key exchange is required, *A* sends FLOW3-3WE (which contains the following tokens: *A, B,* $R_{b,}$ *Sig*) to *B*. When key exchange is needed, $ConfPar_a$ is also included in FLOW3-3WE.

   FLOW3-3WE: A → B

   $$\{A, B, R_b, \{Enc_{k_b}(ConfPar_a)\}, Sig_{k_a}(Hash(A, B, R_b, \{ConfPar_a\}))\}$$

6. When *B* receives FLOW3-3WE, it carries out the following actions:
   - Checks that *B* itself is the intended recipient.
   - When authentication or key exchange is required
     ⇒ Verifies the signature, and thus the integrity of FLOW3-3WE.
     ⇒ Checks that the received R_b in FLOW3-3WE is identical to the one sent in FLOW2-3WE.
     ⇒ Extracts $ConfPar_a$ if present and interprets it.

5.1.1.2 Two-Way Security Message Exchange Protocol

Figure 21 shows the two-way security message exchange protocol. This protocol supports both asymmetric and symmetric algorithms.

When authentication or key exchange is invoked, this protocol uses a time stamp and nonce-based mutual authentication method. As a result, *A* gets authenticated to *B*, and *B* gets authenticated to *A*.

This protocol involves the following steps and is implemented within signaling, as described in Section 5.1.4. If an error occurs during processing of this protocol, then the error procedures described in Section 5.1.6 shall apply.

1. A sends FLOW1-2WE (which contains the following required tokens: *A*, *B*, and *SecOpt*) to *B*. When authentication (initiator -> responder) or key exchange is required, the authentication token (i.e., $\{T_a,R_a,...\}$) is included in the flow. When key exchange is needed, $ConfPar_a$ is also included in FLOW1-2WE. When certificate exchange is needed, $Cert_a$ is also included in FLOW1-2WE.

   FLOW1-2WE: A → B

   $$A, B, SecOpt, \{Cert_a\}, \{T_{a,} R_a, \{Enc_{k_b}(ConfPar_a)\}, Sig_{k_a}(Hash(A, B, T_a, R_a, SecOpt, \{ConfPar_a\}))\}$$

2. When *B* receives FLOW1-2WE, it carries out the following actions:
   - Checks that *B* itself is the intended recipient.
   - Extracts *SecOpt* and interprets it.
   - When authentication or key exchange is required
     ⇒ Verifies the signature, and thus the integrity of FLOW1-2WE.

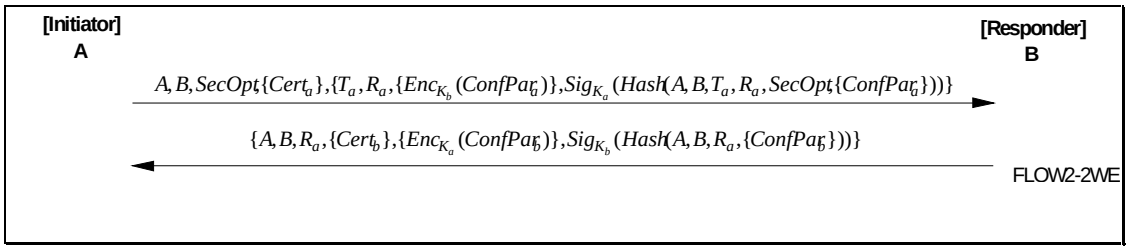


Figure 21: Two-Way Security Message Exchange Protocol.

⇒ Checks that the time stamp is fresh and that the flow is not a replay or out-of-order.

⇒ Extracts the nonce R_a for its reply.

⇒ Extracts $ConfPar_a$ if present and interprets it.

⇒ Extracts $Cert_a$ if present and verifies its validity.

3. When authentication (responder -> initiator) or key exchange is required, *B* sends FLOW2-2WE (which contains the following required tokens: *A, B,* R_a *Sig*) to *A*. When key exchange is needed, $ConfPar_b$ is also included in FLOW2-2WE. When certificate exchange is needed, $Cert_b$ is also included in FLOW2-2WE.

   FLOW2-2WE: B → A

   $$\{A, B, R_a, \{Cert_b\}, \{Enc_{k_a}(ConfPar_b)\}, Sig_{k_b}(Hash(A, B, R_a, \{ConfPar_b\}))\}$$

4. When *A* receives FLOW2-2WE, it carries out the following actions:
   - Checks that *A* itself is the intended recipient.
   - When authentication or key exchange is required
     ⇒ Verifies the signature, and thus the integrity of FLOW2-2WE.
     ⇒ Checks that the received R_a in FLOW2-2WE is identical to the one which sent in FLOW1-2WE.
     ⇒ Extracts $ConfPar_b$ if present and interprets it.
     ⇒ Extracts $Cert_b$ if present and verifies its validity.

The use of time stamp, $T_A = (Time_A, Seq_A)$, will need to have three properties: 1) Freshness: the receiver is assured that the received flow has originated within a specified range of the receipt time. 2) Uniqueness: the receiver is assured that the received flow has never been received before from the same sender. 3) Ordering: the receiver is assured that the received flow has not originated before a previously received flow from the same sender.

When the initiator generates $Time_A$ for FLOW1-2WE, it determines whether its value is greater than the $Time_A$ used in the previous FLOW1-2WE sent to this destination. If current $Time_A$ is the same as the previous one, then the initiator increments Seq_A. Otherwise, it resets Seq_A to 0.

When the responder receives a FLOW1-2WE from a source, it checks whether it has received another FLOW1-2WE from this source within a time-out period *W*.

If the responder has received another FLOW1-2WE from the same source within the time-out period *W*, it compares $Time_A$ values to ensure that the $Time_A$ in the recently received flow is greater than the $Time_A$ in the previously received flow. If they are the same, then it checks that Seq_A is greater than the previous one

received from this source. If the time stamp fails these tests, then the authentication fails and the information is discarded.

If the responder has not received another FLOW1-2WE from the same source within the time-out period *W*, then it checks to ensure that $Time_A$ is within time *W* of its (the responder's) current local clock. If the time stamp fails this test, then the authentication fails and the information is discarded. This implies that the initiator and responder must be synchronized within the time period *W*.

When the time stamp test succeeds, the responder saves the time stamp and holds it for *W* seconds.

The value of the time-out period *W* is an implementation parameter and need not be specified here. Larger values of *W* imply higher clock drift tolerance and larger storage requirements.

5.1.2 Label Transport

Label Based Access Control uses a uni-directional security protocol between two ATM security agents, separate from the Security Message Exchange. Labels are transported in the SSIE (described in Section 5.1.3) using either the signaling-based or in-band mechanism. When labels are provided in signaling, any security agent that is involved in the connection SETUP or CONNECT message (or corresponding point-to-multipoint signaling messages) can make an access control decision based on the contents of the labels. Because of this, the labels are generally not discarded by the security agent that inspects the labels. When labels are passed in band, the security agents who receive the in-band exchange can enforce the access control policy.

5.1.3 Security Services Information Element

The Security Services Information Element (SSIE) is the principal communication method used by ATM Security Agents to establish security services for ATM VCs during ATM Call Establishment, as described in Sections 5.1.4 and 5.1.5.

The SSIE supports the transport of SME information in signaling and within the user plane connection as outlined above. It supports:

1. Signaling-based security message exchange.
2. In-band security message exchange.
3. Multiple nested security services.
4. Proxy security agents.
5. User plane security services.

The SSIE is composed of a Security Service Information Element header and any number of Security Association Sections (SAS). Each SAS contains the information needed to establish and maintain the security associations needed to provide a security service. In order to accomplish this, each SAS identifies the security service that is being established or maintained, specifies the security agent, and specifies the relative security context to which the section pertains.

5.1.3.1 Security Services Information Element Format

This specification defines the Security Services Information Element (SSIE). The header octets of this IE (octets 1-4) are specified in the UNI Signaling 4.0 Security Addendum [4], PNNI Version 1.0 Security Signaling Addendum [5], and the AINI Specification [6]. The use of SSIE octets 5, etc. are specified in the following section.

5.1.3.2 Security Association Section

The Security Association Section provides the information needed to establish a single security association between two ATM security agents.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Association Section Type								5 (Note)
Security Association Section Length								5.1 (Note)
Security Association Section Length (cont.)								5.2 (Note)
Version			Transport Ind.		Flow Indicator		Discard	5.3 (Note)
Scope								5.4 (Note)
Scope								5.5 (Note)
Relative ID								5.6 (Note)
Relative ID								5.7 (Note)
Target Security Agent Identifier								5.8* (Note)
Security Service Data								5.9* (Note)

* Optional octet group

Note: Octet group 5 can be repeated to form new octet groups numbered sequentially as octet groups 6, 7, … *N*.

When an SSIE is used within Signaling Support for Security Message Exchange, the total length of the SSIE, including all SASs, is limited in [4], [5], and [6]. Coding details for these octets are defined below.

5.1.3.2.1 Security Association Section Type

This octet identifies the Security Association Section type for this SAS.

Bits								
8	7	6	5	4	3	2	1	Octet
Security Association Section Type								

Security Association Section Type

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Not used
0	0	0	0	0	0	0	1	ATM Forum Security Service, Security Message Exchange
0	0	0	0	0	0	1	0	ATM Forum Security Service, Label Based Access Control
0	0	0	0	0	0	1	1	Reserved for ATM Forum assignment
				.				.
				.				.
				.				.
0	1	1	1	1	1	1	1	Reserved for ATM Forum assignment

1 0 0 0 0 0 0 0	Reserved for user assignment
.	.
.	.
.	.
1 1 1 1 1 1 1 1	Reserved for user assignment

5.1.3.2.2 Security Association Section Length

This 16-bit octet group is the length of this Security Association Section, excluding the Security Association Section Type octet, and the SAS length octets, octets 5.1-5.2. The minimum length of a SAS is 8 octets, and so the minimum value for this field is 5.

Bits								
8	7	6	5	4	3	2	1	Octet
Security Association Section Length								5.1
Security Association Section Length (cont.)								5.2

Security Association Section Length

This is a 16 bit binary value.

5.1.3.2.3 Version

These 3 bits denote the specification to which this specific SAS type is compliant.

Bits								
8	7	6	5	4	3	2	1	Octet
Version								5.3

Version

8 7 6	**Meaning**
0 0 0	Version 1.0 Security Service
0 0 1	Version 1.1 Security Service
0 1 0 ⎫	
• ⎪	
• ⎬	Reserved
• ⎪	
1 1 1 ⎭	

5.1.3.2.4 Transport Indicator

This field provides the security agents a means of indicating what transport method will be used to perform the indicated security information exchange protocol for this security service. The format of this field is indicated below.

Bits								
8	7	6	5	4	3	2	1	Octet
			Transport Ind.					5.3

Transport Indicator

5	4	**Meaning**
0	0	Signaling
1	1	In-Band Messaging

The transport method is a negotiable parameter, developed during ATM call establishment. The initiating security agent must specify its preferred method for exchanging security information in the Initial Security Service SAS. Intermediate and responding security agents can modify this field to indicate that the transport method must change in order to accommodate conditions in the network. Intermediate and responding security agents may also modify this field from Signaling to In-Band Messaging if they are unable to continue the SME protocol in signaling. Security agents may not, however, modify this field from In-Band Messaging to Signaling.

5.1.3.2.5 Flow Indicator

This field is used to identify the flow number of the Security Information Exchange for this Security Association Section. The format of this field is indicated below.

Bits								
8	7	6	5	4	3	2	1	Octet
					Flow Ind.			5.3

Flow Indicator

3	2	**Meaning**
0	0	First Flow
0	1	Second Flow
1	0	Third Flow
1	1	Fourth Flow

The Flow Indicator field declares the flow number of the Security Information Exchange Protocol that the SAS is supporting. When the Flow Indicator is zero (0), the SAS represents the initiation of a new security service and generally indicates to the responding security agent that a new security association is being requested. When signaling is the SME Transport, all SASs with zero Flow Indicator values must be introduced in the SETUP or ADD PARTY message. Any SAS's with the Flow Indicator set to zero in other messages will be treated as processing errors.

The Flow Indicator field has relevance to other fields in the SAS. When the Flow Indicator is zero (0), the Scope and Relative ID fields are used by receiving security agents to determine whether the SAS is relevant to this security agent. A non-zero value for the Flow Indicator indicates that this SAS is part of an ongoing Security Message Exchange Protocol session, the Scope field is not used, and the Relative ID is significant to both peers. As a result, when the Flow Indicator is non zero, security agents will use the

Relative ID field as a Security Association ID to indicate that this particular SAS is significant to the receiving security agent.

5.1.3.2.6 Security Association Section Discard Indicator

This indicator specifies whether a peer security agent should discard the SAS after processing. The format of this field is indicated below.

Bits								
8	7	6	5	4	3	2	1	Octet
							Discard	5.3

Discard Indicator

1	**Meaning**
0	Do Not Discard SAS After Processing
1	Discard SAS After Processing

The discard bit is used to specify whether the SAS should be discarded by the peer security agent after processing. Most SASs will have this bit set (1). Clearing this bit to (0) allows an initiating security agent to pass an SAS to multiple security agents along the VC path.

In this specification, this bit shall be set (1) when this SAS is used for any services other than label-based access control. This bit may be cleared (0) for Label-Based Access Control when it is intended that the label be presented to all appropriate security agents along the VC path.

5.1.3.2.7 Scope

These octets describe the intended scope of the security services association by providing an implicit identification of the peer responding security agent or proxy security agent for which this SAS is relevant. The format of this field is indicated below. Section 5.1.3.2.7.1 defines Explicit Security Agent Specification. Section 5.1.3.2.7.2 defines Non-Explicit Security Agent Specification. Section 5.1.3.2.7.2.1 defines the Local, Remote, and Transit tests. Section 5.1.3.2.7.2.2 defines the User, Enterprise Border, and Network/Link tests.

Bits								
8	7	6	5	4	3	2	1	Octet
Scope								
Region								5.4
Explicit	Local	Remote	Transit	Reserved	Reserved	Reserved	Reserved	
Role								5.5
User	EB	N/L	Reserved	Reserved	Reserved	Reserved	Reserved	

Explicit (Bit 8 of Octet 5.4)

8	**Meaning**
0	Non-Explicit specification is being used
1	Explicit specification is being used

Local (Bit 7 of Octet 5.4)

7	Meaning
0	Initiating SA does not want “Local” test performed by potential responders
1	Initiating SA will accept response from SA passing the “Local” test

Remote (Bit 6 of Octet 5.4)

6	Meaning
0	Initiating SA does not want “Remote” test performed by potential responders
1	Initiating SA will accept response from SA passing the “Remote” test

Transit (Bit 5 of Octet 5.4)

5	Meaning
0	Initiating SA does not want “Transit” test performed by potential responders
1	Initiating SA will accept response from SA passing the “Transit” test

User (Bit 8 of Octet 5.5)

8	Meaning
0	Initiating SA does not want “User” test performed by potential responders
1	Initiating SA will accept response from SA passing the “User” test

Enterprise Border (EB) (Bit 7 of Octet 5.5)

7	Meaning
0	Initiating SA does not want “Enterprise Border” test performed by potential responders
1	Initiating SA will accept response from SA passing the “Enterprise Border” test

Network or Link (N/L) (Bit 6 of Octet 5.5)

6	Meaning
0	Initiating SA does not want “Network/Link” test performed by potential responders
1	Initiating SA will accept response from SA passing the “Network/Link” test

Note 1: Reserved bits shall always be coded as 0.

In the path of any given VC, a number of security agents may be at work, depending on the security policies of the involved administrative domains. An ATM User may need to establish security associations with a number of security agents in the intended VC’s path. As an example, the end system may be required to authenticate to its “first hop” switch, authenticate to a remote network security agent, and support confidentiality security services “end-to-end” before a VC can be established between the calling and called parties. In addition, other security services may also be employed along the VC path that are not known to the calling party or specified by local, intermediate, or remote administrative domains. An example of this would be enterprise-to-enterprise encryption.

A specific mechanism is needed to indicate which security agent is supposed to act on a specific SSIE SAS. To support nested security services, the SAS message header provides both explicit and non-explicit security agent specifications.

5.1.3.2.7.1 Explicit Security Agent Specification

With explicit specification, security agents are explicitly referenced by a Security Agent Identifier that is unique along the VC’s path. A receiving security agent takes action on an explicitly directed SSIE SAS, only when the Security Agent Identifier references **THIS** particular security agent, or in the case of a proxy security agent, where the proxy is acting on behalf of the security agent explicitly identified in the SSIE SAS.

When explicit specification is being used, the **Explicit** bit (8) of the **Region** field is set (1), bits 7-1 of the region field are all zero (0), bits 8-1 of the **Role** field are all zero (0), and the Target Security Agent Identifier field is coded with the target security agent identifier for this SAS (Section 5.1.3.2.9).

The explicit security agent specification mechanism is not designed to provide any assurances with regard to entity authentication. This mechanism is simply intended to provide assistance in transporting the SSIE SAS to its intended security agent. It is expected that if authentication of the security agent is required, then an appropriate SAS Authentication Section (Section 7.4) and the appropriate SA identifiers (Section 7.1) have been employed that provide mechanisms required to assure security agent identification.

5.1.3.2.7.2 Non-Explicit Security Agent Specification

Non-explicit specification provides the initiating security agent with a method to specify the Region and the Role of the intended responder. This can be used to direct SSIE SASs to specific agents, in the absence of explicit mechanisms.

The identifiers that are available for specifying security agents are broken into two categories. The first is the **Region**, which can be Local, Remote, or Transit. The second category is **Role,** which specifies whether the security agent is providing security for the User, an Enterprise Border (EB), or Network or Link (N/L) for the links internal to a network for some portion other than the enterprise border.

In support of this function, security agents should have a description of the **Region** and **Role** that the security agent plays, relative to other security agents in the network. This may take the form of explicit assignment of **Regions** and **Roles**, along with the required supporting data. **Region** assignments can be satisfied by providing the network address prefix for the local network that a security agent is acting in. **Role** assignments may be derived from the port type on which a signaled message was received. The actual management of security agent **Region** and **Role** descriptions is an implementation and configuration issue.

The intent is that if any **Region** or **Role** bit is set in Flow-1, then the initiating security agent is requesting that potential responding or proxy security agents should perform the indicated test. In order for an SAS to fall within the scope of a particular security agent, both a **Region** test AND a **Role** test must be TRUE. If all **Region** bits are cleared (0), no tests are performed and the **Region** test by default returns true. If any **Region** bits are set, then the test returns the resulting OR of each **Region** test indicated. The **Role** test operates in a similar manner: if all **Role** bits are cleared (0), no tests are performed and the **Role** test by default returns TRUE. If any **Role** bits are set, then the test returns the resulting OR of each **Role** test indicated.

For all flows after Flow-1 (i.e., for all flows for which the Flow Indicator is nonzero), bits 8-1 of the Region and Role octets should be set to zero (0).

5.1.3.2.7.2.1 Region

For simplicity the Region semantics are always interpreted relative to an ATM User initiating security agent. This means that the Calling and Called Party IDs are the reference for determining the intended Region of a particular SSIE SAS.

Local Test

When the **Local** bit is set (1) in the **Scope** field, the security agent tests the Calling Party Address against the security agent's local network prefix. If there is a match, then the SSIE SAS falls within the scope of this security agent and the **Local Test** returns TRUE.

If the test fails, and the **Local** bit is the only **Region** bit set within the SAS, then the Security Agent (SA) performing the test has the option, based on its security policy, of declaring the call in error, removing the SAS, or allowing the SAS to remain in the SSIE. If the SA deems that the call is in error, the call is cleared and an appropriate error cause code is returned.

If the Calling Party Address is not available, the test cannot be performed, and as a result, the **Region** test returns TRUE**.**

Remote Test

When the Remote bit is set (1) in the Scope field, the security agent compares the Called Party Address to the security agent's local network prefix. If they are in the same network then the SSIE SAS falls within the scope of this security agent, and the **Remote Test** returns TRUE.

If the Called Party Address is not available, the test cannot be performed, and as a result, the **Remote Test** returns TRUE.

Transit Test

When the Transit bit is set (1) in the Scope field, the security agent compares both the Calling and Called Party Addresses to the security agent' s local network prefix. If the SA's prefix is neither the prefix for the calling party nor the prefix for the called party, the **Transit Test** returns TRUE. For the sake of the **Transit Test**, unavailable prefixes are regarded as not matching.

5.1.3.2.7.2.2 Role

A Security Agent (SA) can be located at different positions in the network, depending upon the security policy and function that it is performing. SAs can be located at an end user device to protect or authenticate the traffic to or from that device. In addition, SAs may be located at the border of a private enterprise to protect or authenticate the traffic entering or leaving the enterprise. Finally, SAs may be located at the border of a public enterprise to protect the traffic entering or leaving the public enterprise. The actual type of interface (e.g., UNI or PNNI) that the SA is on is as relevant to a security policy as the logical location or function that the SA is performing. Each Security Agent should be configured with information specifying the role(s) in which it functions. The Security Agent uses this information in performing the following **Role Tests.**

User Test

When the User bit is set (1) in the Scope field, the Security Agent checks whether its configured Role information indicates it provides security for a user or end station. If it does, then the **User Test** returns TRUE.

Enterprise Border (EB) Test

When the Enterprise Border bit is set (1) in the Scope field, the Security Agent checks whether its configured Role information indicates it provides security services at the entrance or exit of an enterprise (public or private). If it does, then the **Enterprise Border Test** returns TRUE.

Network/Link Test

When the **Network/Link** bit is set (1) in the Scope field, the Security Agent checks whether its configured Role information indicates it provides security services for the links internal to a network or for some portion other than the enterprise border. If it does, then the **Network/Link Test** returns TRUE.

Examples of the use of the **Role** bit are provided below. All bits are set to zero except where noted:

1. Policy may require that this security service be performed end to end. Targeting a security agent at the destination end user device: Remote = 1, User = 1.
2. Policy may require that all calls leaving the local enterprise be authenticated. Targeting a security agent at the local enterprise border: Local = 1, EB = 1.
3. Policy may require that a private enterprise authenticates calls to the public carrier network or that a public carrier authenticates to another public carrier. Targeting a call to the public carrier network: Transit =1, EB =1.
4. An end station may need to request security services from a proxy SA acting on behalf of the user. Targeting a security exchange with the local proxy SA: Local = 1, User = 1.
5. A node may request security services from the next node in the network. Targeting a security exchange with the next node: Local = 1, N/L = 1.
6. The initiating SA may not know which type of responding SA will process the call. In this case: Remote = 1, User =1, EB = 1, N/L = 1.

5.1.3.2.7.3 Relative ID Security Peer Specification

The previous methods are used by the initiating security agent to specify the intended responding security agent at the time of security service initiation, i.e. when the Flow Indicator is zero (0). During this flow, the security service association is bound to the Security Association. This process is described in detail in the next section. For all subsequent flows, the Relative ID is used exclusively as the indicator that a Security Agent should process a particular SAS. For all flows after Flow-1 (i.e., for all flows for which the Flow Indicator is not zero) bits 8-1 of the Region and Role octets should be coded as zero (0).

5.1.3.2.8 Relative Identifier

The Relative Identifier provides Security Association Identification and explicit Security Association Section ordering. The format of this field is indicated below

Bits								
8	7	6	5	4	3	2	1	Octet
Relative ID								
Security Association ID								5.6
SAS Number				Reserved				5.7

Security Association ID (Octet 5.6.)

This octet represents the Security Association Identifier to which this Security Association Section applies.

SAS Number (Bits 8-5 Octet 5.7.)

This field provides precedence order for SASs within an SSIE. This is used to provide explicit ordering of multiple SASs that are involved in the establishment of the same security association.

Reserved (Bits 4-1 Octet 5.7.)

This field is reserved for future use and shall be encoded to all zeros (0).

A security service is generally managed through the establishment of a security service association between two security agents. If there are more than two security agents that are active on a single VC, there is a need to support multiple security associations within a given VC. If a pair of security agents is providing multiple security services, multiple security associations may be supported on the VC.

The Relative ID is used to identify the security association to which a SSIE SAS belongs, and to provide a means of specifying the order in which SSIE SASs will be processed within that association. The procedures developed for processing the Relative ID provide the mechanisms needed to support multiple nested security services on a single VC.

The Relative ID is divided into two fields, the Security Association ID and the SAS Number. Relative ID numbers are assigned by initiating security agents, and **SHALL NOT** be modified by any other security agents along the VC.

Once established, the Security Association ID is used by each security agent throughout the life of the VC.

As a Flow-1 message proceeds through the network, when an initiating security agent wants to establish a security association with a responding security agent, it must allocate a Security Association ID for thatassociation. Each SSIE SAS that is used to support this new security association will share the same Security Association ID. With 8 bits available for the Security Association ID, the greatest nesting depth of security associations possible is 256.

To allocate a new Security Association ID, the security agent scans all existing SSIE SASs, and notes the largest Security Association ID. If no SSIE SASs exist, then the Security Association ID is zero (0). Otherwise, the new Security Association ID for this service is one plus the largest value of all existing Security Association IDs. This is an 8-bit unsigned ADD operation. If, as a result of this ADD operation, the new Security Association ID is zero (0), then a processing error has occurred, and the call must fail, with an appropriate error cause code.

Receiving security agents process SSIE SASs based on the SASs' 12-bit Relative ID, in descending order. If the initiating security agent requires explicit ordering of security SASs by the responding security agent, then the SASs must be numbered to reflect that ordering precedence. The 4-bit SAS Number field is used for this purpose. This limits the total number of strictly ordered SSIE SASs per security service to sixteen (16). If order is not a requirement, then the SSIE SASs can share the same SAS number. If ordering is not required then the number of SASs per security service is unlimited. Combinations of ordered and unordered SSIE SASs can be accommodated using this convention.

Receiving security agents consider the SASs with the highest Security Association ID, and determine whether or not their scope field indicates that the SA should process these SASs. If the scope indicates that these should be processed by this SA, they are processed in decreasing order of Relative ID and then the scope of the SASs with the next highest Security Association ID is checked. When the scope of the SAS with the highest remaining Security Association ID indicates that this SA should not process these SASs, all remaining SASs are not processed by this SA. If some but not all of the SASs with the same Security Association ID have a scope that matches this SA, this is an error.

If the security association requires further processing, such as when using the Security Message Exchange Protocol's 2-Flow and 3-Flow methods, the Security Association ID is used in subsequent SSIE SASs to reference the peer security association.

5.1.3.2.9 Target Security Agent Identifier

This optional octet group is the explicit security agent identifier of the target security agent for this specific SAS. This group is included only when the Explicit bit is set and all other bits are zeroed in the Scope field (Octets 5.4 and 5.5). This octet group may contain one of the Security Agent Identifiers defined in Section 7.1: Initiator Distinguished Name, Responder Distinguished Name, or Security Agent Distinguished Name. If there is a Responder Distinguished Name in the SAS, then it is used in the target security agent ID. Otherwise the Security Agent Disgtinguished Name is used.

5.1.3.2.10 Security Service Data Section

This section defines the format of the Security Service Data Section of the SAS. The Security Service Data Section may contain either a security message exchange data section or label-based access control section. Each of these data sections is composed of various octet groups which are specified in detail in Section 7 of this specification.

5.1.3.2.10.1 Security Message Exchange Data Section

When signaling-based transport is used, this section is required, otherwise this section is optional.

The sections contained in the Security Message Exchange Data Section after the identifier octet are all optional and, if present, may be included in any order, each not more than once.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
0	0	1	0	0	1	x	x	5.9
						SME Type		
Security Message Exchange Format Identifier								
Security Agent Identification Section								5.9.1 etc
Security Service Specification Section								5.9.2 etc
Confidentiality Section								5.9.3 etc
Authentication Section								5.9.4 etc

Security Message Exchange Format Identifier (Octet 5.9)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	1	0	0	1	0	0	SME Protocol type unspecified
0	0	1	0	0	1	0	1	Two Way Security Exchange Protocol, Flow-2 is optional
0	0	1	0	0	1	1	0	Two Way Security Exchange Protocol, Flow-2 is required
0	0	1	0	0	1	1	1	Three Way Security Exchange Protocol

Security Agent Identification Section (Octet 5.9.1 etc.)

This section contains up to two octet groups that provide the identity of the agent(s) involved in the security exchange. The octet groups that can appear in this section are described in detail in Section 7.1.

Security Service Specification Section (Octet 5.9.2 etc.)

This section contains octet groups that provide the security negotiation parameters that are used in the Security Message Exchange Protocol, and is described in detail in Section 7.2.

Confidentiality Section (Octet 5.9.3 etc.)

The Confidentiality Section is described in detail in Section 7.3.

Authentication Section (Octet 5.9.4 etc.)

The Authentication Section is described in detail in Section 7.4.

5.1.3.2.10.2 Label Based Access Control Section

Label Based Access Control is a uni-directional security service whereby an initiating ATM security agent provides an access control label from which other security agents can make ATM level access control decisions. Access control labels will generally be limited to a region within which the label has significance. Any security agent processing a Flow-1 or Flow-2 message can make an access control decision based on the contents of the label. Because of this, the label is generally not discarded by the security agent that inspects the label. The SSIE is used to transport security labels in signaling or in band.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
0	0	1	0	1	0	0	0	
Label Identifier								5.9
Label Length								5.9.1
Label Type								5.9.2
Label-Specific Data								5.9.3 etc.

Label Length (Octet 5.9.1)

This octet indicates the length of the Label-Specific Data. It can be any value in the range from 0 to 255.

Label Type (Octet 5.9.2)

0000 0001 FIPS 188

This octet group indicates the security label for the connection in the FIPS 188 format.

Label-Specific Data (Octets 5.9.3, etc.)

⇒ FIPS 188 Coding Details [11]

5.1.4 Message Exchange within Signaling

This section describes the signaling support for the security message exchange protocols in point-to-point and point-to-multipoint connections using UNI v4.0 [3] [4], PNNI v1.0 [5], or AINI v1.0 [6].

5.1.4.1 Point-to-Point Connections

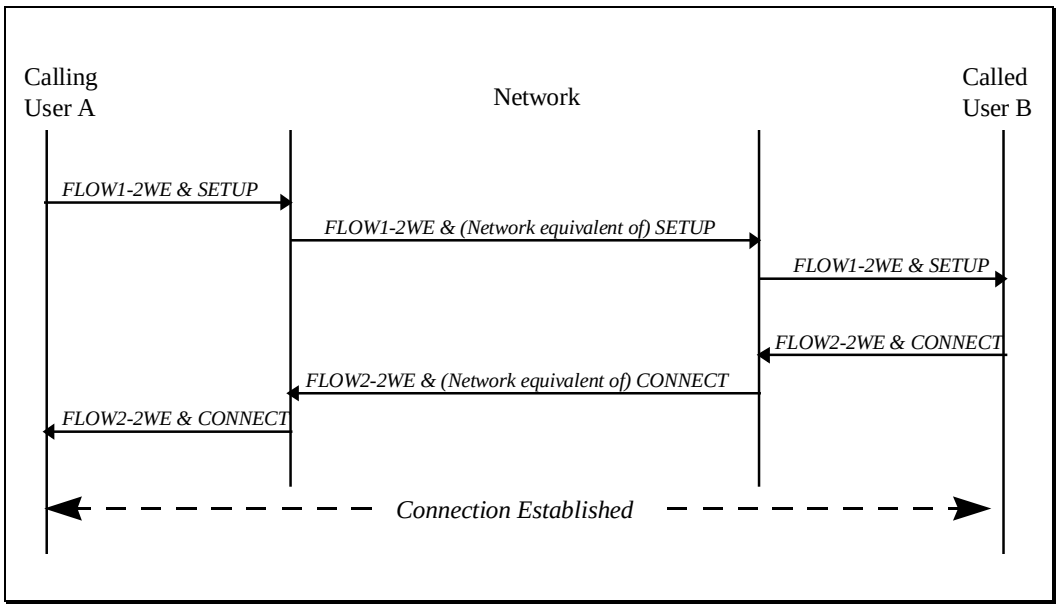


Figure 22: Point-to-Point Signaling Support for Two-Way Security Message Exchange.

Figure 22 shows the signaling support for the two-way security message exchange protocol in point-to-point connections. (Note: signaling support for the three-way security message exchange protocol is not provided in this specification.)

At the UNI interface, FLOW1-2WE is carried in the SETUP message and FLOW2-2WE is carried in the CONNECT message.

At the PNNI, AINI, and B-ICI interfaces, FLOW1-2WE is carried in the network equivalent of the UNI SETUP message and FLOW2-2WE is carried in the network equivalent of the UNI CONNECT message.

5.1.4.2 Point-to-Multipoint Connections

The signaling procedures for point-to-multipoint call establishment are described in ATM Forum UNI 4.0 [3] signaling and ITU Q.2971 [25].

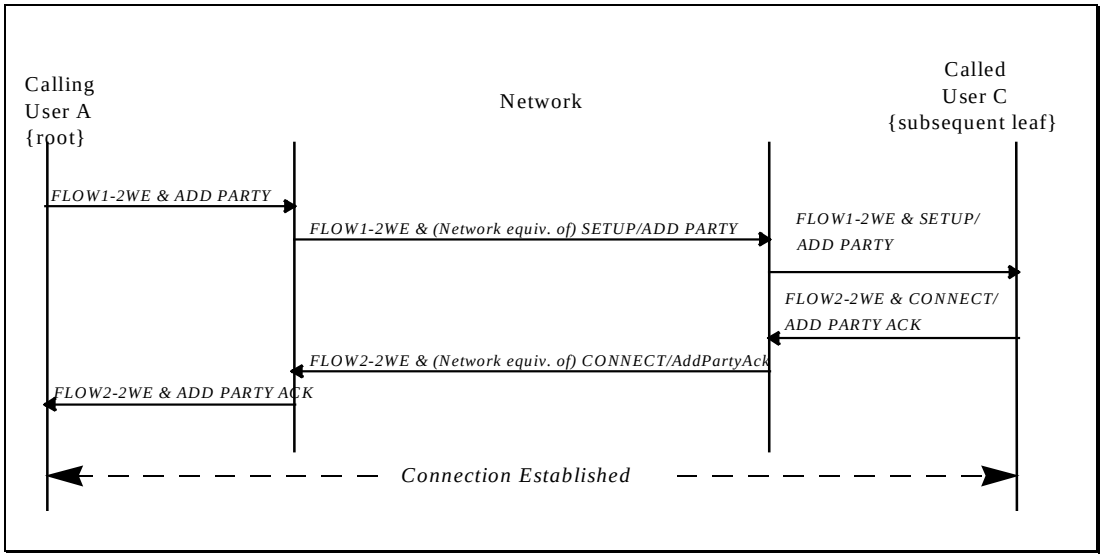


Figure 23: Point to Multipoint Signaling Support for Two-Way Security Message Exchange for Subsequent Leaf Setup.

The connection setup for the first party (leaf) in point-to-multipoint connections is the same as the connection setup in point-to-point connections. So, the two-way security message exchange protocol is supported the same way as in point-to-point connections.

The connection setup for the subsequent parties (leaves) is supported with the two-way security message exchange.

Figure 23 shows the signaling support for the two-way security message exchange protocol when setting up subsequent parties (leaves).

At the UNI interface on the calling side, FLOW1-2WE is carried in the ADD PARTY message and FLOW2-2WE is carried in the ADD PARTY ACK message.

At the UNI interface on the called side, FLOW1-2WE is carried in the SETUP message and FLOW2-2WE is carried in the CONNECT message.

At the PNNI and AINI interfaces, FLOW1-2WE is carried in the network equivalent of the UNI ADD PARTY message and FLOW2-2WE is carried in the network equivalent of the UNI CONNECT message.

5.1.4.3 Leaf Initiated Join Capability

The signaling procedures for leaf initiated join capability are described in Section 6.0 of ATM Forum UNI Signaling 4.0 [3].

There are two modes of operation associated with the leaf initiated join capability: root prompted join and leaf prompted join without root notification. The first SETUP message from the root will indicate whether this is the root prompted join or leaf prompted join without root notification.

5.1.4.3.1 Root Prompted Join

In this mode of operation, the root of the connection handles the LIJ request. The root adds leaves to or removes leaves from a new or established connection using the point-to-multipoint procedures. This type of connection is referred to as a root LIJ connection.

In this mode of operation, since the addition (or removal) of a leaf is handled by the root, the point-to-multipoint security procedures described above still apply and no additional enhancement is needed.

5.1.4.3.2 Leaf Prompted Join without Root Notification

In this mode of operation, if the leaf's request is for an existing connection, the network handles the request. The root is not notified when a leaf is added to or dropped from the connection. This type of connection is referred to as a network LIJ connection.

In this mode of operation, since the addition (or removal) of a leaf is not handled by the root, the current point-to-multipoint security procedures described above do not apply. Support for this mode of operation is outside the scope of this specification.

5.1.4.4 Security Agent Procedures for Signaling-Based Message Exchange

5.1.4.4.1 General Procedures

The general security procedures shall apply for all procedures defined in Section 5.1.4.4.

Refer to Section 1.3 for definition of "Security Agent," and to Section 2.3 for definitions of SA_{sme}, etc.

The SA_{sme} shall set the Pass Along indicator [5] to one, so those PNNI nodes that do not implement a SA along the path of the VC will pass the SSIE to the next node. The IE Action Indicator in the IE Instruction Field of the SSIE shall be set to 001 "Discard Information Element and Proceed." It is recommended that Security Agents be capable of handling the status report generated from the value 010 "Discard Information Element, Proceed and Report Status." Loss of the SSIE will be noted in the CONNECT message so that appropriate security policy actions can be invoked.

Security Association Sections (SASs) within the SSIE are processed as "atomic" entities, and so are processed to completion prior to processing of subsequent SASs.

Security agents, when modifying information elements in the signaled message, shall conform to the procedures that govern the format and behavior of the object information elements. Specifically, the relevant procedures described in UNI 4.0 [3], Q.2931 [24], and Q.2971 [25] shall apply.

In the case where errors occur during processing and the security service cannot be performed or established, the security agent shall notify signaling to clear the call, and provide a cause code and diagnostic.

The following procedures describe actions taken by security agents upon receipt of a message containing an SSIE. Version 1.1 Security Agents ignore SSIEs occurring in any other message.

5.1.4.4.2 Initiating Security Agent Procedures

5.1.4.4.2.1 Call/Connection Request

Upon receipt of a SETUP message by an initiating ATM security agent, all SSIE Security Association Sections that are present in the signaled message are parsed and the greatest Relative ID Security Association ID is noted. If there are no SSIE SASs present, the greatest Relative ID is zero.

Based on the security service that the security agent is to provide, the initiating security agent generates the appropriate Security Association Sections (SAS) for inclusion in the message, providing all mandatory fields that may be required. The initiating SA will ensure that:

1. The Version number is coded according to Section 5.1.3.2.3. All SASs generated by one security agent and intended for the same destination security agent shall be coded with the same Version number.
2. The transport method is chosen and indicated in the Transport Indicator field, using the guidelines specified in Section 5.1.3.2.4 of this document.
3. The Flow Indicator is set to zero. This indicates that this SAS contains information for FLOW1 of the two-way or three-way message exchange protocol.
4. If the SAS is intended for only one security agent, then the **Discard** bit is set to 1. Generally, label-based access control services can be intended for more than one target security agent, and so for these services the **Discard** bit may be set to zero.
5. If the security agent intends to use an explicit Target Security Agent Identifier to identify the intended target security agent, the **Explicit** Scope bit is set and an optional **Target Security Agent Identifier** is included in the SAS header.

   If the Target Security Agent Identifier is not used, then an appropriate **Scope** description is selected to identify the **Region** and **Role** of the intended target security agent. Details on the use of this field are specified in Section 5.1.3.2.7.
6. The security agent allocates a new **Security Association ID** value for the security services SAS, as described in Section 5.1.3.2.8. The Security Association ID is noted and is used to identify the corresponding SSIE SAS in the expected CONNECT message.
7. Each Security Association Section is given a **SAS Number** that specifies the precedence order for processing SASs within the same Security Association. SASs will be processed in descending order. The order of processing SASs with the same SAS Number is undetermined.

If an SSIE does not already exist in the SETUP message, an SSIE header is prepended to the SASs that are to be added to the message. The new SASs are then added to the signaled message accordingly.

If any error occurs in processing, the security agent should return the failure condition “Security Protocol Processing Error” (see Section 5.1.6), with an appropriate diagnostic for the condition that generated the error.

At this point, the message is returned to the signaling entity.

5.1.4.4.2.2 Call/Connection Acceptance

Upon receipt of a CONNECT message by an initiating ATM security agent, all SSIE Security Association Sections that are present in the signaled message are parsed and those SASs that have Relative ID Security Association IDs that match those being supported by this security agent are processed. If there are no SSIE SASs present that match any expected Relative ID Security Association IDs, then an error has occurred and the security agent will return the failure condition, “Missing Required Security Information

Element" (see Section 5.1.6). If only a partial set of expected Relative ID Security Association IDs is present in the CONNECT message, then the initiating SA shall determine if the call should be in error. This decision is based on the SASs received and the initiating SA's security policy.

If there is no SSIE present then the initiating SA shall determine if the call should be in error. This decision is based on the initiating SA's security policy. If the SASs are unresolved or partially resolved, the initiating SA can revert to in-band message exchange to establish the security service.

The initiating security agent processes all matching SASs, in descending order based on the Relative ID. If an error occurs during processing, the security agent will return the failure condition "Security Protocol Processing Failure."

For each SAS, the initiating security agent processes the contents of the SAS to completion. If the processing completes successfully, then the initiating security agent may perform additional processing, depending on the value of the Transport Indicator field. If the Transport Indicator is Signaling-Based messaging, then no additional processing is performed. If the Transport Indicator is In-Band Messaging, then the initiating security agent performs the In-Band Security Message Exchange as outlined in Section 5.1.5. If an error occurs during extended SME processing, the security agent will return the failure condition "Security Protocol Processing Failure." Upon successful completion of the extended SME, the initiating security agent processes the next appropriate SAS.

At this point, the message is returned to the signaling entity.

5.1.4.4.3 Responding Security Agent Procedures

5.1.4.4.3.1 Call/Connection Request

Upon receipt of a SETUP message by a security agent, if an SSIE is present, the SA follows the algorithm in Section 5.1.3.2.8 to determine which SASs it should process as a responding security agent. All other SASs are left unmodified.

If the SASs available for processing do not satisfy the responder's security policy, this responder may either revert to in-band message exchange to establish the security service or clear the call with the failure condition "Missing Required Information Element" (see Section 5.1.6).

If an error occurs during processing, the security agent will return the failure condition "Security Protocol Processing Failure."

For each new Security Association ID number encountered in the collection of appropriate SASs, a new security association is allocated and subsequently referenced by Security Association ID number. All SASs with the same Security Association ID are processed within the same security association context, and they are processed in descending order based on SAS number. SASs with identical 12-bit Relative ID numbers are processed in undetermined order.

Each SAS is processed to completion, before processing can proceed to the next SAS.

Any subsequent flows or responses to processed SASs are held, pending the arrival of the appropriate CONNECT message for this VC.

If the **Discard** bit in the Scope field is set (1), the security agent removes the SAS from the SSIE and adjusts the SSIE length. If no other SASs remain, the SSIE is removed from the signaled message. If the **Discard** bit is zero (0), the SAS is retained, unmodified, in the signaled message.

At this point, the message is returned to the signaling entity.

5.1.4.4.3.2 Call/Connection Acceptance

Upon receipt of a CONNECT message by a responding security agent, all SSIE Security Association Sections that are present in the signaled message are parsed and the greatest Relative ID Security Association ID is noted. If there are no SSIE SASs present, the greatest Relative ID is zero. The security agent determines that the Relative ID of any pending second (2^{nd}) flow or response SASs are not less than the greatest observed Relative ID in the current message. Once this is done, the security agent builds one or more SASs (with the Flow Indicator set to 1 to indicate a Flow-2 message), and adds or appends the pending SASs to the SSIE. If any processing errors occur, the security agent will return an appropriate error condition and the signaling entity will clear the call with the failure condition "Security Protocol Processing Failure" (see Section 5.1.6).

At this point, the message is returned to the signaling entity.

5.1.4.5 Endpoint Requests for Security Services

An endpoint or host that does not provide security services may (as an option) request security services from a downstream security agent as follows:

1. Insert a Security Services Information Element into the SETUP message on the signaling channel.
2. Indicate that the SME protocol type is not specified by the requestor by setting the Security Message Exchange Format Identifier (octet 5.9) to the "unspecified" codepoint ("0 0").
3. Insert any combination of the following optional fields, indicating the desired service(s) and/or algorithm(s):

    - Security service declaration (Section 7.2.1),
    - Data confidentiality algorithm (Section 7.2.3.1),
    - Data integrity algorithm (Section 7.2.3.2),
    - Hash algorithm (Section 7.2.3.3),
    - Signature algorithm (Section 7.2.3.4),
    - Key exchange algorithm (Section 7.2.3.5),
    - Session key update algorithm (Section 7.2.3.6),
    - Access control algorithm (Section 5.1.3.2.10.2).

    Multiple algorithms may be inserted in preference order for each requested security service.

Upon receipt of such a request, the security agent replaces the Security Services Information Element with one of its own choosing, based on its security policy. A security agent is under no obligation to use the options requested by the endpoint or host. It should be noted that this process is not secure, and that a trusted link between the endpoint and security agent is assumed.

5.1.4.6 Acknowledgements to Endpoints Requesting Security Services

A security agent shall acknowledge a security request received from an endpoint as follows:

1. Insert a Security Services Information Element into the CONNECT message on the signaling channel.
2. Indicate that the SME protocol type is not specified by the requestor by setting the Security Message Exchange Format Identifier to the unspecified codepoint (“0 0”).
3. Indicate which service(s) and/or algorithm(s) were negotiated by the security agents, only for those instances where a specific request was made.

The endpoint or host would then have the option of rejecting the call if it did not get the service(s) and/or algorithm(s) it desired. Note that protection of the path between the requestor and the SA is outside the scope of this discussion.

5.1.5 Message Exchange within the User Plane

This section defines the procedures for performing the security message exchange protocol within the user plane virtual circuit. These procedures apply for VCs that are established via signaling (SVCs), as well as VCs established via management (PVCs).

5.1.5.1 Security Message Exchange for Signaled Point-to-Point Connections

The in-band security message exchange protocol is a method that is suitable for exchanging security messages between ATM entities when signaling is not available either by policy or lack of support. After the user connection is completed successfully, the Security Agents (SAs) exchange security information in-band over the user traffic channel. (The SAs block the user traffic from passing between the users until after the SAs have completed the security exchange.)

Figure 24 presents point-to-point call setup and security exchange using the hosts’ user plane for a Switched Virtual Circuit (SVC) connection.

The ATM calling user transmitting an ordinary SETUP message requesting a point-to-point connection starts the process. The security agent determines the connection is established either by directly processing the signaling messages in a standalone implementation, or through an indication from the signaling function if the SA is hosted in a switch or end system. The method the security agent uses to determine whether a connection requires security services is a local issue and is not specified by this document. This applies to both the initiating and responding security agents. In some environments, the security services will be required for all connections. However, security could be applied selectively to connections between designated hosts. The source and destination ATM addresses could be used as a means of determining to which connections to apply security.

Once the ATM connection is established, the SAs perform certain security-related exchanges before either SA allows user traffic to pass. The security exchange occurs in-band on the user connection using a security exchange protocol and is used to perform such tasks as authentication and key exchange. In the case of a VPC connection request, the security exchange is performed over a well-known VCI within the VPC. This process is described in more detail below.

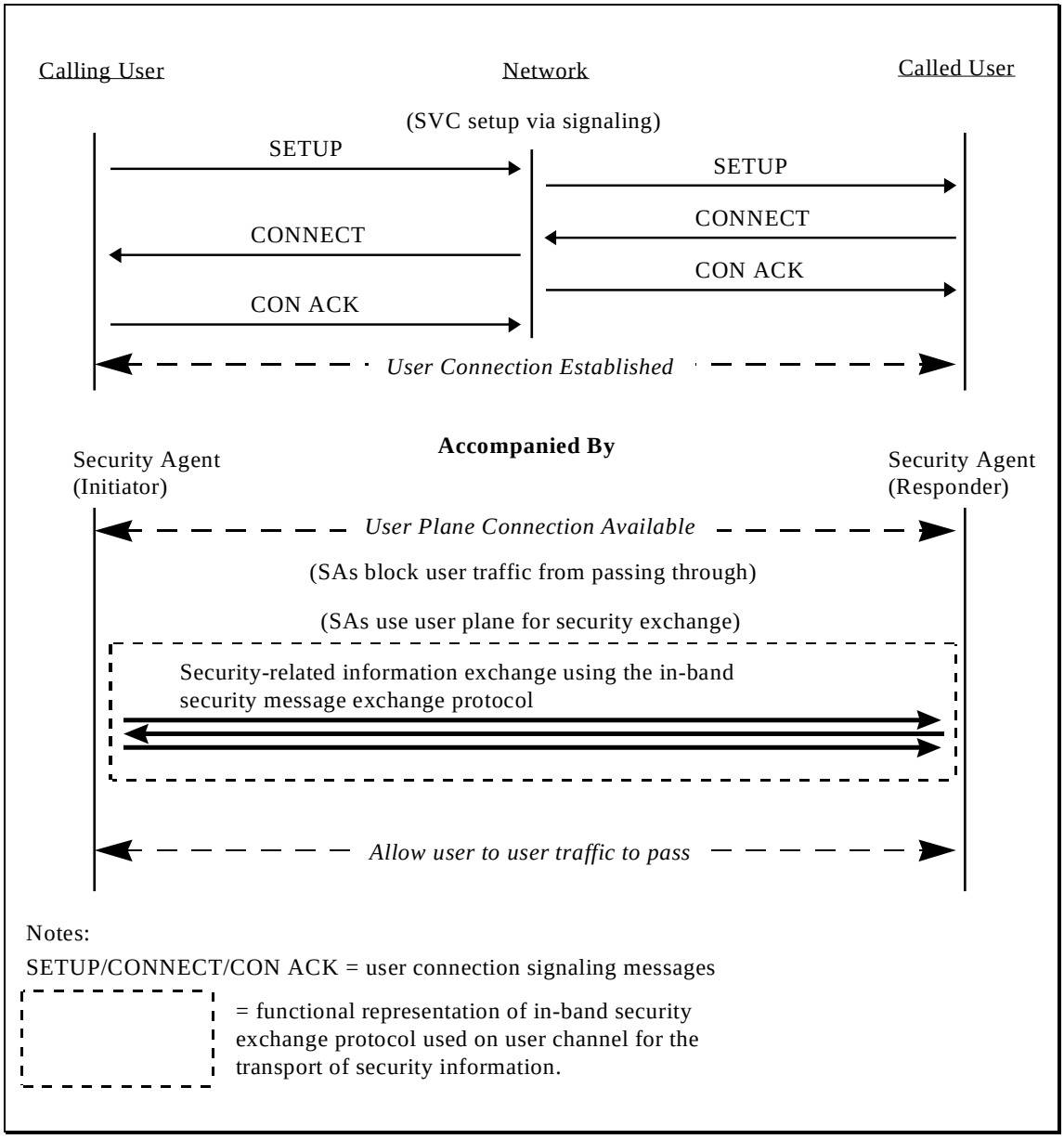


Figure 24: Point-to-Point Security Exchange Using the Hosts' User Plane for SVCs.

Once the in-band user connection is available for use by the SAs, the initiator SA sets up a session with the responder SA. This session is used to exchange security information.

The mechanisms used for security message exchange shall use the Security Message Exchange Protocols described in Section 5.1.5.3 for point-to-point connections. The in-band secure message exchange will only send those information elements that are required for the security exchange (e.g., Security Services IE, etc.), and not the entire signaling message (i.e., SETUP message).

The initiator and responder SAs block user traffic on the specified connection from passing until the SAs' peers have completed their security exchange.

Once the security protocol is complete (e.g., authentication, key exchange), the initiator and responder SAs allow user plane traffic to flow (i.e., unblock user traffic).

A SA can be collocated with the end user or at a switch. For example, the internal interface to the SA could be implemented as an application layer interface at the end user device or keyed off of signaling messages received at a switch.

5.1.5.1.1 Details of Security Call Establishment

Before In-Band Security Message Exchange can be invoked, a bi-directional connection between the initiating and responding users must be established. In-Band Security Messages flow over this connection. The underlying connection need not provide assured data delivery. The In-Band Security Message Exchange Protocol described in Section 5.1.5.3 has its own assured message exchange mechanism. The In-Band Security Message Exchange operation is independent of whether the underlying connection provides assured or non-assured data delivery. The underlying connection must allow messages of variable length to be sent. For these reasons, AAL5 shall be used as the data delivery service for in-band security message exchange.

5.1.5.1.1.1 Establish Point-to-Point on Calling Side

The initiating security agent shall support establishment of secure point-to-point Switched Virtual Circuit (SVC) connections initiated from the calling side as follows:

Upon receipt of a SETUP message arriving on the user side, the SA shall examine the traffic parameters contained within the message to determine whether the connection can support a full duplex SME.

If the SA determines that the requested connection is point-to-point and can support the SME, the SA shall forward the message toward the called user.

If the SA determines that the user requested point-to-point connection and the cell rates cannot support the SME or that the user requested a point-to-multipoint connection, the SA shall clear the call with the the procedures given in Section 5.1.6. under “Security Protocol Processing Error.”

Note: Alternatives to clearing the call if the connection does not support the bandwidth for in-band SME, such as out-of-band exchange or renegotiation of traffic parameters, are outside the scope of this specification.

Upon receipt of a CONNECT message from the called user accepting the connection (or some other indication) the SA shall invoke the in-band security exchange protocol as specified in Section 5.1.5.3 over the user connection and prevent the CONNECT message (or some internal indication) from being sent to the calling user until the security exchange completes. If the connection is a VPC connection request, the security exchange shall use the VPI assigned for the VPC and VCI=1 (i.e., well known VCI).

Note: The SA may elect to test the traffic parameters contained in the CONNECT message to ensure that in-band SME can be supported.

Upon completion of the in-band security exchange protocol indicating that the exchange completed successfully, the initiator SA shall unblock the ATM connection, allowing user cells to flow, and forward the CONNECT message over the user side interface. If the security exchange is deemed unsuccessful by the initiator SA, the SA shall request that the ATM connection be cleared. After the connection is cleared, the End User may attempt to retry the connection establishment.

5.1.5.1.1.2 Establish Point to Point on Called Side

The responding SA shall support establishment of secure point-to-point Switched Virtual Circuit (SVC) connections initiated from the called side as follows:

Upon indication that an inbound connection request has been received on the Network side, i.e., a SETUP message, the SA shall relay the SETUP message to the user side and wait for the associated CONNECT message.

The SA shall assure that any traffic received on the user side associated with the connection request will be blocked until the security exchange has completed successfully.

After receipt of an indication that the CONNECT message has been received from the called user accepting the connection, the SA shall allow the CONNECT message to be forwarded to the network side and wait for the in-band security exchange protocol to be invoked over the user connection. If this is a VPC connection request, the SA security exchange shall use the VPI for the VPC and VCI=1 (i.e., well known VCI).

Upon completion of the in-band security exchange protocol indicating that the exchange completed successfully, the responder SA shall unblock the ATM connection, allowing user cells to flow. If the security exchange is deemed unsuccessful by the responder SA, it shall request that the connection be cleared. After the connection is cleared, the End User may attempt to retry the connection establishment.

5.1.5.2 Security Message Exchange for Permanent Point-to-Point Connections

The basic premise of this approach is to simplify and strengthen “secure” PVC provisioning. After the user connection is completed successfully, the security agents exchange security information in-band over the user traffic channel. (The SAs block the user traffic from passing between the users until after the SAs have completed the security exchange.)

Figure 25 presents point-to-point call setup and security exchange using the hosts’ user plane for a PVC connection.

The process is started by an administrative (e.g., Network Manager) provisioning of a point-to-point connection. If the host requires security services, a security agent (SA) must be notified of the connection request. This can also be accomplished administratively. Each SA must also be told whether it is the initiator or responder of the security exchange.

The SAs perform certain security-related exchanges before either SA allows user traffic to pass. The security exchange occurs in-band on the user connection using a security exchange protocol and is used to perform such tasks as authentication and key exchange. In the case of a VPC connection request, the security exchange is performed over a well-known VCI within the VPC. This process is described in more detail below.

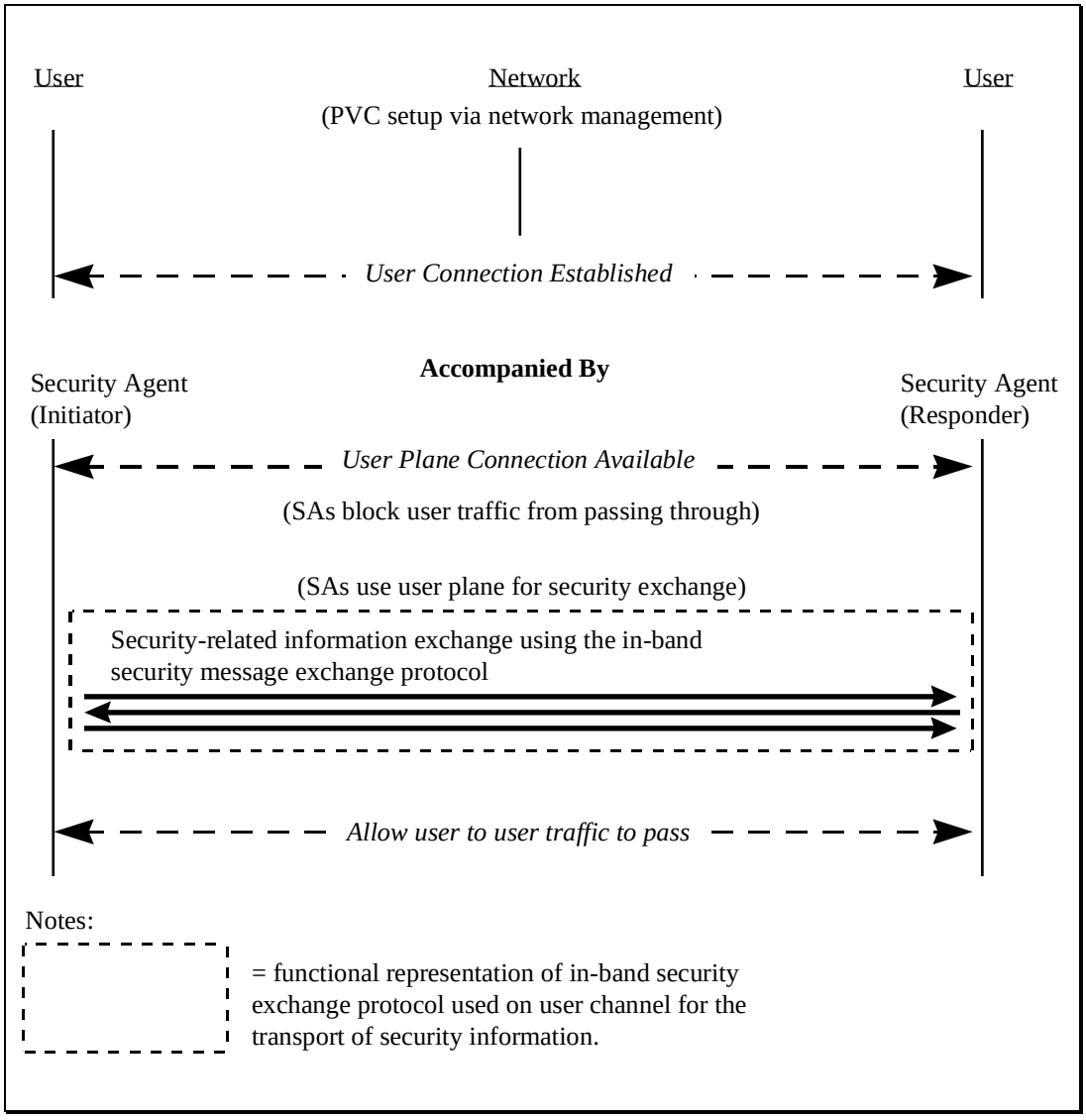


Figure 25: Point-to-Point Security Exchange using the Hosts' User Plane for PVCs.

Once the in-band user connection is available for use by the SAs, the initiator SA sets up a session with the responder SA. This session is used to exchange security information.

The mechanisms used for security message exchange shall use the Security Message Exchange Protocols described in Section 5.1.5.3 for point-to-point connections (the same as used for SVC in-band exchange). The in-band secure message exchange will only send those information elements that are required for the security exchange (e.g., Security Services IE, etc.), and not the entire signaling message (i.e. SETUP message).

The initiator and responder SA block user traffic on the specified connection from passing through it until the SA peers have completed their security exchange.

Once the security exchange is complete (e.g., authentication, key exchange), the initiator and responder SAs allow user plane traffic to flow (i.e., unblock user traffic).

A SA can be collocated with the end user or at a switch.

5.1.5.2.1 Details of Secure Call Provisioning for PVCs

Before the In-Band Security Message Exchange can be invoked, a bi-directional connection between the initiating and responding users must be established. In-Band Security Messages flow over this connection. The underlying connection need not provide assured data delivery. The In-Band Security Message Exchange Protocol described in Section 5.1.5.3 has its own assured message exchange mechanism. The In-Band Security Message Exchange operation is independent of whether the underlying connection provides assured or non-assured data delivery. The underlying connection must allow messages of variable length to be sent. For these reasons, AAL5 shall be used as the data delivery service for in-band security message exchange.

5.1.5.2.1.1 Establish Point-to-Point on Initiator Side

The initiating security agent shall support establishment of secure point-to-point Permanent Virtual Circuit (PVC) connections (initiator side) as follows:

Upon notification that a connection is requesting security services, the SA shall assure that any traffic received associated with the connection request will be blocked until the security exchange has completed successfully. The SA must also be notified that it is to function as the initiator.

Once the SA has been notified of the secure connection request and its SA function (i.e., Initiator) the SA shall invoke the in-band security exchange protocol over the user connection. If this is a VPC connection request, the security exchange shall use the VPI of the VPC requested and VCI=1.

If the protocol fails, the SA shall terminate its current attempt to secure the PVC (the user traffic will continue to be blocked).

Upon completion of the in-band security exchange protocol indicating that the exchange completed successfully, the initiator SA shall request that the traffic associated with the connection be unblocked. If the security exchange is deemed unsuccessful by the initiator SA, the SA shall terminate its current attempt to secure the PVC (the user traffic will continue to be blocked).

5.1.5.2.1.2 Establish Point-to-Point on Responder Side

The responding SA shall support establishment of secure point-to-point Permanent Virtual Circuit (PVC) connections as follows:

Upon notification that a connection is requesting security services, the SA shall assure that any traffic received associated with the connection request will be blocked until the security exchange has completed successfully. The SA must also be notified that it is to function as the responder.

Once the SA has been notified of the secure connection request and its SA function (i.e., Responder) the SA shall wait for the in-band security exchange protocol to be invoked by the Initiator over the user connection and start a PVC Wait timer (P_Wait). If this is a VPC connection request, the SA security exchange shall use the VPI of the VPC being requested and VCI=1. (Note that the use of VCI=1 for in-band security message exchange is temporary, and that VCI=1 is available to other functions once the in-band SME protocol successfully completes.)

If the P_Wait timer expires, or if the protocol fails, the SA shall terminate its current attempt to secure the PVC (the user traffic will continue to be blocked). This timer is canceled at completion of the security exchange, or if the connection is cleared. The value of P_Wait is defined in Section 5.1.5.3.5, Table 7.

Upon completion of the in-band security exchange protocol indicating that the exchange completed successfully, the responder SA shall request that the traffic associated with the connection be unblocked. If the security exchange is deemed unsuccessful by the responder SA, the SA shall terminate its current attempt to secure the PVC (the user traffic will continue to be blocked).

5.1.5.3 In-Band Security Message Exchange Protocol

When the three-way security message exchange protocol as described in Section 5.1.1.1 is used (only for in-band messaging), two messages (in addition to Flow-1, Flow-2, and Flow-3) are defined: CONFIRM-AP and FAULT. Note that these two messages can only be sent once and are not cryptographically secured.

CONFIRM-AP: The Responder sends this message to the Initiator in reply to a Flow-3 message. When the Initiator receives CONFIRM-AP, it concludes that the Responder received Flow-3 and the protocol completed successfully. This message is an integral part of the three-way security message exchange procedure because its purpose is to provide notification to the Initiator (i.e., the calling user) that the Responder received the Flow-3 and the Initiator may begin transmitting data.

FAULT: In error scenarios, this message is used to carry cause data (identifying the error) from the partner that detected the error to the other remote partner.

(The format of these messages is defined below in Section 5.1.5.3.2.)

5.1.5.3.1 Protocol Procedures

The following is a textual description of the in-band security message exchange protocol procedures contained in the finite state machine tables of Section 6. If any discrepancies exist between the following text and the FSM tables in Section 6, the FSM tables shall take precedence.

Figure 26 shows the normal processing at the Initiator.

AAL5 shall be used for transport of in-band security message exchange protocol messages.

The Initiator starts the message exchange process by sending a Flow-1 message, starting timer T100, and keeping track of the number of times Flow-1 has been sent by using variable I-Flow1-Retry-Count. If a Flow-2 message in reply to the Flow-1 message is not received before the expiry of T100, the Flow-1 message is retransmitted and timer T100 restarted.

The Initiator increases its retry counter, I-Flow1-Retry-Count, each time it sends (or resends) the Flow-1 message. If T100 expires when I-Flow1-Retry-Count is greater than I-MAX-FLOW1-RETRY the message exchange fails.

If the Initiator receives a Flow-2 message that is invalid, the message exchange fails.

If the Initiator receives a valid Flow-2 message, it stops timer T100, starts timer T101, and sends a Flow-3 message to the Responder.

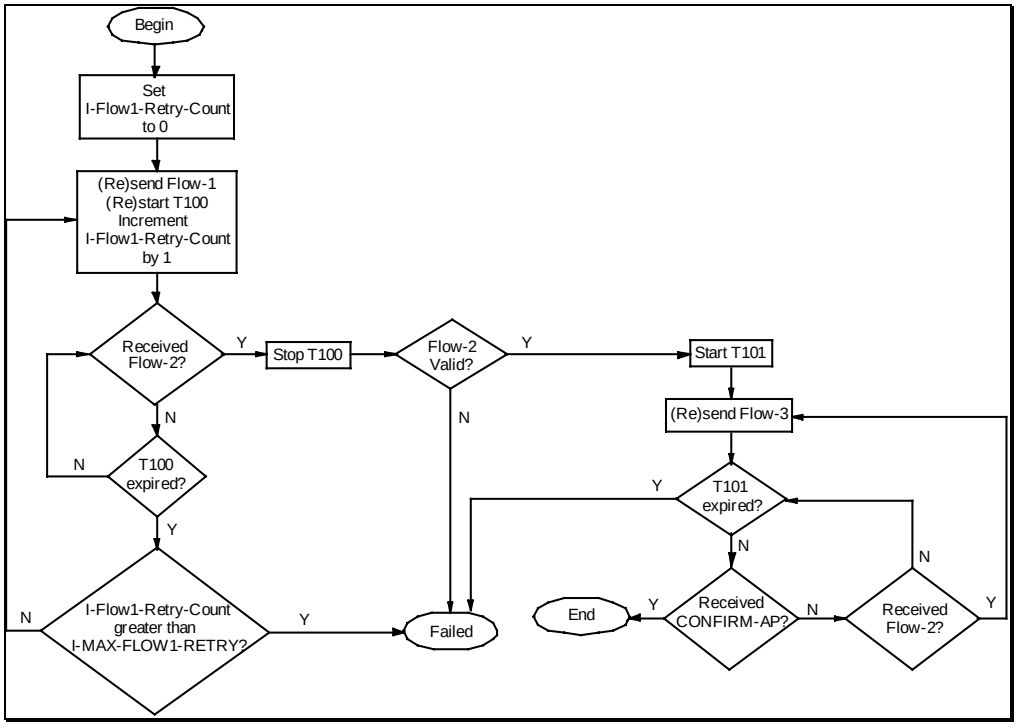


Figure 26: Protocol Procedure at the Initiator.

The Initiator assumes that the message exchange is successful when a CONFIRM-AP message is received. However, if a Flow-2 message is received before T101 expires or before a CONFIRM-AP message is received, it resends a Flow-3 message by concluding that the received Flow-2 message is an indication that the Flow-3 it sent earlier has not reached the Responder. The Initiator continues this behavior until T101 expires, or a CONFIRM-AP message is received, whichever is earlier.

The Initiator concludes that the protocol completed successfully as soon as a CONFIRM-AP message is received.

The Initiator concludes that the message exchange failed if T101 expires.

Figure 27 shows the normal processing at the Responder.

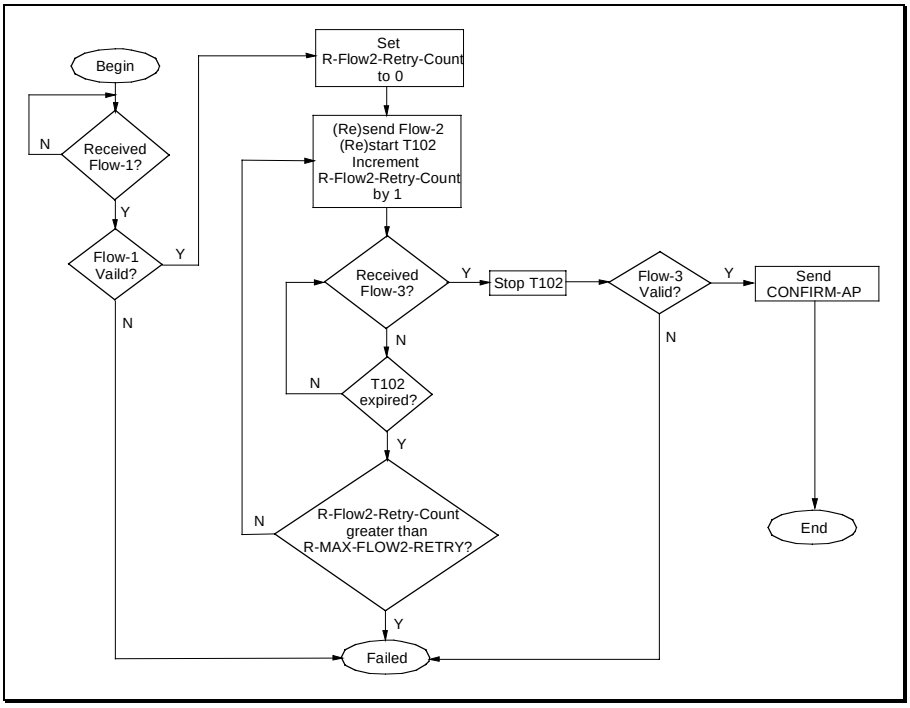


Figure 27: Protocol Procedure at the Responder.

The Responder waits until it receives a Flow-1 message. If the Flow-1 message is not valid, the message exchange fails.

If the Responder receives a valid Flow-1 message, it starts timer T102, sends a Flow-2 message, and keeps track of the number of times Flow-2 has been sent in variable R-Flow2-Retry-Count. If a Flow-3 message in reply to the Flow-2 message is not received before the expiry of T102, the Flow-2 message is retransmitted and timer T102 restarted.

The Responder increases its retry counter, R-Flow2-Retry-Count, each time it sends (or resends) the Flow-2 message. If T102 expires when R-Flow2-Retry-Count is greater than R-MAX-FLOW2-RETRY the message exchange fails.

If the Responder receives a Flow-3 message that is invalid, the message exchange fails.

If the Responder receives a valid Flow-3 message, the message exchange is successful. The Responder sends a CONFIRM-AP message to the Initiator so that the Initiator can conclude that the protocol concluded successfully.

5.1.5.3.2 General Message Format and Message Field Coding

Within the In-Band Security Message Exchange Protocol, every message shall consist of the following parts:

1. Message type,
2. Message length,
3. Variable length fields, as required.

Fields 1 and 2 are common to all of the messages and shall always be present, while field 3 is specific to each message type. This organization is illustrated in Figure 28.

Message type	1
Message length	2
Message length (continued)	3
Variable length information elements as required	4, etc.

Figure 28: General Message Organization.

5.1.5.3.2.1 Message Type

The purpose of the message type is to identify the function of the message being sent. The message type is the first part of every message. The message type is coded as shown in Figure 29.

8	7	6	5	4	3	2	1	Octets
Message Type								1

Figure 29: Message Type.

Message Type (Octet 1)

Bits								Meaning
8	7	6	5	4	3	2	1	
0	0	1	-	-	-	-	-	In-band security message
0	0	1	0	0	0	0	1	FLOW1-3WE
0	0	1	0	0	0	1	0	FLOW2-3WE
0	0	1	0	0	0	1	1	FLOW3-3WE
0	0	1	1	0	0	0	1	CONFIRM-AP
0	0	1	1	0	0	1	0	FAULT

Note - Although these message types are for in-band messages only, the codepoints were chosen so as not to overlap with the signaling codepoints for message type.

5.1.5.3.2.2 Message Length

The purpose of the message length is to identify the length of the contents of a message. It is the binary coding of the number of octets of the message contents, excluding the octets used for “message type” and for the message length indicator itself.

The message length is the second field of every message. The message length is a 16-bit value, coded as shown in Figure 30.

8	7	6	5	4	3	2	1	Octets
Message length								1
Message length (continued)								2

Figure 30: Message Length.

5.1.5.3.2.3 Variable Length Information Elements

5.1.5.3.2.3.1 Security Services Information Element

The Security Services Information Element (SSIE) is defined in Section 5.1.3 of this specification. When in-band messaging is used, the SME Flow Indicator in the SSIE, defined in section 5.1.3.2.5, shall be ignored.

5.1.5.3.2.3.2 Cause Information Element

The Cause information element format defined in Q.2931 [24] shall be used for transporting cause codes within the context of the In-Band Message Exchange Protocol. Refer to Section 5.1.5.3.6 for cause values.

5.1.5.3.3 Message Contents for In-Band SME Messages

5.1.5.3.3.1 Flow 1-3WE

This message is sent from the initiator to the responder to initiate the three-way security message exchange.

Message Type: Flow1-3WE

Field or Information Element	**Reference**	**Length**
Message Type	Section 5.1.5.3.2.1	1
Message Length	Section 5.1.5.3.2.2	2
Security Services Information Element	Section 5.1.3	12 - 65535

5.1.5.3.3.2 Flow2-3WE

This message is sent from the responder to the initiator in response to Flow1-3WE.

Message Type: Flow2-3WE

Field or Information Element	**Reference**	**Length**
Message Type	Section 5.1.5.3.2.1	1
Message Length	Section 5.1.5.3.2.2	2
Security Services Information Element	Section 5.1.3	12 - 65535

5.1.5.3.3.3 FLOW3-3WE

This message is sent from the initiator to the responder in response to FLOW2-3WE.

Message Type: FLOW3-3WE

Field or Information Element	Reference	Length
Message Type	Section 5.1.5.3.2.1	1
Message Length	Section 5.1.5.3.2.2	2
Security Services Information Element	Section 5.1.3	12 - 65535

5.1.5.3.3.4 CONFIRM-AP

This message is sent from the responder to the initiator in response to FLOW3-3WE. When the initiator receives the CONFIRM-AP message, it concludes that the responder received FLOW3-3WE and the protocol completed successfully. This message is an integral part of the three-way security message exchange procedure because its purpose is to provide notification to the initiator (i.e., calling user) that the responder received the Flow-3 and the initiator may begin transmitting data.

Message Type: CONFIRM-AP

Field or Information Element	Reference	Length
Message Type	Section 5.1.5.3.2.1	1
Message Length	Section 5.1.5.3.2.2	2

5.1.5.3.3.5 Fault

In error scenarios, this message is used to carry cause data (identifying the error) from the partner that detected the error to the other remote partner.

Message Type: FAULT

Field or Information Element	Reference	Length
Message Type	Section 5.1.5.3.2.1	1
Message Length	Section 5.1.5.3.2.2	2
Cause	Refer to Q.2931 [24]	4 - 34

5.1.5.3.4 Timer Definitions

The following is a description of the timers that are used for the in-band operation of the three-way security message exchange protocol. The values of these timers can be found in Section 5.1.5.3.5, Table 7.

1. T100: This timer is used by the Initiator of the protocol to determine whether it needs to resend Flow-1 to the Responder. The timer is started when the Initiator sends Flow-1. If the Initiator has not received Flow-2 before the timer expires, then the Initiator resends Flow-1 and starts the timer again. The timer is stopped when a Flow-2 message is received.
2. T101: This timer is used by the Initiator of the protocol to ensure that it is waiting as long as the Responder is present and is potentially resending Flow-2 to indicate that the partner has not received Flow-3 from the Initiator. The timer is started the first time the Initiator sends Flow-3. As long as this timer has not expired, the receipt of Flow-2 triggers the sending of Flow-3.
3. T102: This timer is used by the Responder in the protocol to determine whether it needs to resend Flow-2 to the Initiator. The timer is started when the Responder sends Flow-2. If the Responder has

not received Flow-3 before the timer expires, then the Responder resends Flow-2 to the Initiator and starts the timer again. The timer is stopped when a Flow-3 message is received.

The following variables (retry counters) are used in conjunction with the timers used in the protocol.

1. I-Flow1-Retry-Count: This variable is used in conjunction with timer T100 by the Initiator of the protocol and counts the number of times that Flow-1 has been sent. Flow-1 may be sent up to a maximum of I-MAX-FLOW1-RETRY times.
2. R-FLOW2-Retry-Count: This variable is used in conjunction with timer T102 by the Responder in the protocol and counts the number of times that Flow-2 has been sent. Flow-2 may be sent up to a maximum of R-MAX-FLOW2-RETRY times.

The following is a description of the constants that are used in conjunction with the retry counter variables used in the protocol. The values of these constants can be found in Section 5.1.5.3.5, Table 8.

1. I-MAX-FLOW1-RETRY: This constant indicates the maximum number of times that the Initiator may try to resend Flow-1 to the Responder.
2. R-MAX-FLOW2-RETRY: This constant indicates the maximum number of times that the Responder may try to resend Flow-2 to the Initiator.

5.1.5.3.5 Timer Values

The protocols for in-band (user plane-based) security message exchange use a number of timers in their procedures. These timers, and their values, are summarized in Table 7:

Table 7: Timers for In-Band Security Message Exchange.

Timer Name	Timer Value
P_Wait	600 seconds
T100	3 seconds
T101	9 seconds
T102	3 seconds

In addition, the in-band security message exchange protocols use a number of constants. These constants and their values are summarized in Table 8.

Table 8: Constant Values for In-Band Security Message Exchange.

Constant Name	Constant Value
I_MAX_FLOW1_RETRY	2
R_MAX_FLOW2_RETRY	2

5.1.5.3.6 Protocol Error Handling

Detailed error handling procedures are implementation dependent. However, capabilities facilitating the orderly treatment of error conditions provided for in this section shall be provided in each implementation.

When the Initiator or Responder detects an error, it sends a FAULT message to its partner to report the error, enters the failed state, and aborts. All errors are defined to be unrecoverable errors. The protocol aborts upon sending or receiving a FAULT message.

For SVC-initiated calls in the failed state, the security agent shall clear the call. Error recovery for PVC initiated calls is implementation specific.

A "Cause" information element describes the reason for an error and provides diagnostic information. This information element is carried in the FAULT message. The Cause information element may be repeated in a FAULT message.

The following cause codes are defined.

In-Band Message Exchange Cause Codes	
Number	**Meaning**
21	call rejected (Note 1)
47	resource unavailable
63	service or option not available
96	mandatory information element missing
97	message type non-existent or not implemented
100	invalid information element contents
102	recovery on timer expiry
111	protocol error, unspecified

Note 1:
An indication of the security protocol failure shall be included in the Diagnostics field of the Cause IE when the cause value = "#21, call rejected." This indication shall be the rejection reason "security exception" as defined in [4].

5.1.6 Security Information Exchange Error Processing

The following text applies when security message exchange occurs in signaling, in-band, or both.

When errors occur in establishing or maintaining a security service on a specific VC, the VC must be put into a state where User Data transport is not supported. For establishing or established VCs this is accomplished by clearing the call. When clearing a call based on failure of a security agent to establish or maintain a security service, an appropriate Cause code will be chosen by the security agent that is involved with the fault, and a diagnostic is provided that provides adequate information for the peer security agent to understand the nature of the fault condition.

Security diagnostics are specific to the types of error conditions that can happen within a security agent and are limited to 28 octets in length. The amount of information that is disclosed in a security agent diagnostic may have a security impact, and as such each diagnostic has a mandatory section and optional sections that provide more detail on the condition that generated the error.

1. Missing Required Security Information Element.
   When this error condition occurs, the call is cleared with Cause code # 96 "Mandatory Information Element Missing" (see Q.2931 [24]), and the diagnostic will be at most 28 octets of a valid SSIE. A 4-octet SSIE header is mandatory. Optionally, the diagnostic can contain valid SAS segments that will declare to the originator the type of security service that is required by the security agent. When providing SASs, the security agent can use existing fields to provide additional information, such as the security agent's region and role bits.

2. Security Protocol Processing Error.

   When this error condition occurs, the call is cleared with Cause code #21 "Call Rejected." See Q.2931 [24] for the Cause Information Element format. The diagnostic will be at most 28 octets of a valid SSIE. A 4-octet SSIE header is mandatory. Optionally, the diagnostic can contain valid SAS segments which will indicate which SAS was being acted on when the processing error occurred. The SAS may include the Relative ID of the SAS that generated the error.
3. Security Policy Violation.

   When this error condition occurs, the call is cleared with Cause code #21 "Call Rejected." See Q.2931 [24] for the Cause Information Element format. The diagnostic will be at most 28 octets of a valid SSIE. This diagnostic should contain valid SAS segments which indicate the service that is not allowable based on the security policy that was violated. The SAS may include the Relative ID of the SAS that generated the error.

Reporting this specific error condition is optional, as local policy may want to minimize the amount of information disclosed when a security error occurs. When reporting this specific error condition is not possible, a general "Security Protocol Processing Error" should be reported.

5.1.7 Security OAM Cells

5.1.7.1 Overview of ATM Layer OAM Cell Flows

At the ATM layer, two OAM flows are defined: F4 (virtual path level) and F5 (virtual channel level), which are used for the operation and maintenance of connections. F4 flow is for virtual path connections (VPCs) and F5 flow is for virtual channel connections (VCCs). F4 and F5 flows are for all types of ATM connections. At the ATM layer, the F4 and F5 flows are carried via OAM cells. F4 and F5 flows are bi-directional. In all cases, OAM cell flows must conform to the traffic contract for their respective VCC/VPCs. A detailed description of OAM flows and functions is given in [23].

Note: These mechanisms rely on sufficient bandwidth to sustain OAM cell flows. If sufficient bandwidth is not provided, loss or corruption of user data can occur, and errors may arise in the security mechanism itself.

Table 9: OAM Cell Type and Function Identifiers.

OAM Cell Type	Codepoint	Function Type	Codepoint
Fault management	**0001**	**AIS**	**0000**
		RDI	**0001**
		Continuity check	**0100**
		Loopback	**1000**
Performance management	**0010**	**Forward monitoring**	**0000**
		Backward monitoring	**0001**
		Monitoring & reporting	**0010**
Activation/Deactivation	**1000**	**Performance monitoring**	**0000**
		Continuity check	**0001**
System management	**1111**	**Security – non-real-time**	**0001**
		Security – real-time	**0010**

The OAM cell formats for ATM layer OAM flows are shown in Figure 31. The OAM cell type (4-bit) field indicates the type of management function performed by the OAM cell. Currently, four OAM types are defined: fault management, performance management, activation/deactivation, and system management. The function type (4-bit) field indicates the function performed by the OAM cell within

thecell type. Table 9 shows the codepoints assigned for the OAM cell type field and the function type field. The function specific field (45 octets) carries the information related to the actual function of the OAM flow. The reserved (6-bit) field is not used and left for future use. The error detection code (EDC) field carries a CRC-10 error detection code computed over the cell data payload.

5.1.7.1.1 F4 Flow of OAM Cells

The virtual path connection (VPC) operational information is carried via the F4 flow OAM cells. There are two types of F4 flows: end-to-end F4 flow and segment F4 flow. End-to-end F4 flows are terminated at the endpoints of a VPC and segment F4 flows are terminated at the connecting points terminating a VPC segment. A VPC segment is defined as either a single VPC link or a concatenation of multiple VPC links. Multiple VPC segments can be defined along a VPC path but they cannot overlap.

End-to-end and segment F4 flow OAM cells are passed unmodified by all intermediate nodes. Intermediate nodes can insert new F4 flow OAM cells. However, the end-to-end F4 flow OAM cells are removed only by the endpoints of the VPC, and the segment F4 flow OAM cells are removed only by the VPC segment terminating points.

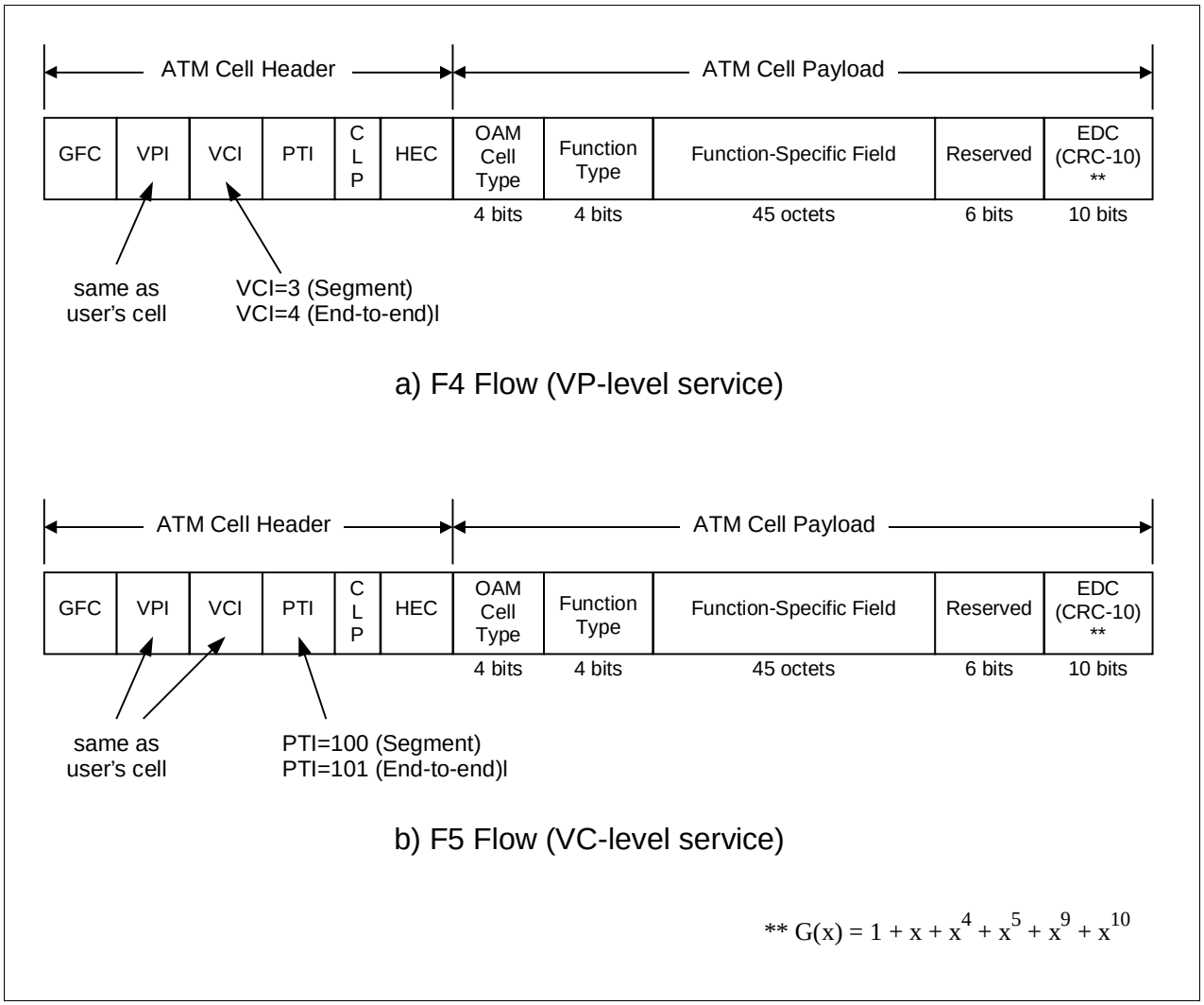


Figure 31: F4 and F5 OAM Cells.

F4 flow OAM cells follow exactly the same physical route as the user's data cells of the VPC. These OAM cells have the same VPI value as the user's data cells of the VPC and are identified by pre-assigned VCI values. The same pre-assigned VCI values are used for both directions of the F4 flows. Two unique VCI values are used for every VPC as shown in Figure 31. The VCI value = 4 is used to identify end-to-end F4 flows and the VCI value = 3 is used to identify segment F4 flows.

5.1.7.1.2 F5 Flow of OAM Cells

The virtual channel connection (VCC) operational information is carried via the F5 flow OAM cells. There are two types of F5 flows: end-to-end F5 flow and segment F5 flow. End-to-end F5 flows are terminated at the endpoints of a VCC and segment F5 flows are terminated at the connecting points terminating a VCC segment. A VCC segment is defined as either a single VCC link or a concatenation of multiple VCC links. Multiple VCC segments can be defined along a VCC path but they cannot overlap.

End-to-end and segment F5 flow OAM cells are passed unmodified by all intermediate nodes. Intermediate nodes can insert new F5 flow OAM cells. However, the end-to-end F5 flow OAM cells are

removed only by the endpoints of the VCC, and the segment F5 flow OAM cells are removed only by the VCC segment terminating points.

F5 flow OAM cells follow exactly the same physical route as the user's data cells of the VCC. These OAM cells have the same VPI/VCI values as the user's data cells of the VCC and are identified by pre-assigned codepoints of the payload type identifier (PTI). The same pre-assigned VCI values are used for both directions of the F5 flows. Two unique PTI values are used for every VCC as shown in Figure 31. The PTI value = 5 (101) is used to identify end-to-end F5 flows and the PTI value = 4 (100) is used to identify segment F5 flows.

5.1.7.2 Security OAM Cell Formats

Two Security OAM cell types are defined—one for non-time-critical processes (called non-real-time), and one for time-critical processes (called real-time). The distinction is to differentiate cells that can be processed independently of the user traffic from those that have direct impact on user traffic. The SKE and SKC cells, defined in sections 5.1.7.2.1.1 and 5.1.7.2.2.1, are examples of non-real-time and real-time security OAM cells, respectively. The generic format for security OAM cells is shown in Figure 32.

Bits								
8	7	6	5	4	3	2	1	Octets
GFC/VPI [11:8]				VPI [7:4]				1
VPI [3:0]				VCI [15:12]				2
VCI [11:4]								3
VCI [3:0]				PTI			CLP=0	4
HEC [7:0]								5
1	1	1	1	Function Type				6
Relative ID				Function ID				7
Security Function Specific								8-51
0	0	0	0	0	0	CRC [9:8]		52
CRC [7:0]								53

Figure 32: Generic Security OAM Cell Format.

Notes:

1) For VCCs the PTI field is set to 101 (binary).
2) For VPCs the VCI field is set to 0004 (hex).
3) The CLP bit is always set to 0.
4) For non-real-time security OAM cells, the Function Type field is set to 0001 (binary).
5) For real-time security OAM cells, the Function Type field is set to 0010 (binary).
6) The use of the Relative ID field is defined in Section 5.1.7.3.
7) The use of the Function ID field is described in Table 10 and Table 11.

5.1.7.2.1 Non-Real-Time Security OAM Cell Formats

Non-Real-Time (NRT) security OAM cells are defined as having an OAM function type of 0001 (binary). Up to 16 NRT cell types are possible, as defined by the Function ID field. The code points for the Function ID field for NRT security cells are defined in Table 10.

Table 10: Function ID Code Points for Non-Real-Time Security OAM Cells.

Function ID (binary)	Security Function
0001	Data Confidentiality Session Key Exchange (SKE)
0010	Data Integrity Session Key Exchange (SKE)
all others	not defined

5.1.7.2.1.1 Data Confidentiality SKE OAM Cell Format

The format of the Data Confidentiality SKE OAM Cell is defined in Figure 33.

Bits								
8	7	6	5	4	3	2	1	Octets
GFC/VPI [11:8]				VPI [7:4]				1
VPI [3:0]				VCI [15:12]				2
VCI [11:4]								3
VCI [3:0]				PTI			CLP=0	4
HEC [7:0]								5
1	1	1	1	Function Type = 0001				6
Relative ID				Function ID = 0001				7
Bank ID				Reserved				8
Reserved								9
Key Number (KN)								10-13
Encrypted Session Key (ESK)								14-45
Reserved								46-51
0	0	0	0	0	0	CRC [9:8]		52
CRC [7:0]								53

Figure 33: Session Key Exchange (SKE) OAM Cell Format.

Notes:

1) The use of the Relative ID field is defined in Section 5.1.7.3.

2) The Bank ID field is an alternating pattern of 0 hex or F hex, for successive key updates.

3) The key number (KN) field, a 32-bit field, indicates the key number associated with the new session key. Each session key is assigned a number. The first session key to be exchanged by the session key update protocol is assigned 1; the second session key is assigned 2, and so forth. The KN is a field which is used by the key update protocol to ensure freshness, uniqueness, and ordering of session key updates and to synchronize the initiator and responder to the same session key.

4) The Encrypted Session Key (ESK), a 256-bit field, contains the next session key encrypted using the master key for the connection. For cases when the session key being transported is less than 256 bits in length, it is contained in the least significant bits of the ESK field, with the most significant bits being padded with zeros (before encryption).

5) Reserved octets are set to 6A hex, reserved bit fields less than 1 octet in length are set to all zeros.

6) The reserved bits included after the 4-bit Bank ID field are provided so that the KN and ESK fields are aligned on 16 bit boundaries, to simplify high speed implementations.

5.1.7.2.1.2 Data Integrity SKE OAM Cell Format

The format of the Data Integrity SKE OAM Cell is defined in Figure 33, except that the Function ID field is set to 0010 (binary). When using HMAC, the next session key length is 256 bits or the length of the previous session key, whichever is less.

5.1.7.2.2 Real Time Security OAM Cell Formats

Real Time (RT) security OAM cells are defined as having an OAM function type of 0010 (binary). Up to 16 RT cell types are possible, as defined by the Function ID field. The code points for the Function ID field for RT security cells are defined in Table 11.

Table 11: Function ID Code Points for Real Time Security OAM Cells.

Function ID (binary)	Security Function
0001	Data Confidentiality Session Key Changeover (SKC)
0010	Data Integrity Session Key Changeover (SKC)
all others	not defined

5.1.7.2.2.1 Data Confidentiality SKC OAM Cell Format

The format of the Data Confidentiality SKC OAM Cell is defined in Figure 34.

Bits								
8	7	6	5	4	3	2	1	Octets
GFC/VPI [11:8]				VPI [7:4]				1
VPI [3:0]				VCI [15:12]				2
VCI [11:4]								3
VCI [3:0]				PTI			CLP=0	4
HEC [7:0]								5
1	1	1	1	Function Type = 0010				6
Relative ID				Function ID = 0001				7
Bank ID				Reserved				8
Reserved								9
Key Number (KN)								10-13
State Vector (SV)								14-21
Reserved								22-51
0	0	0	0	0	0	CRC [9:8]		52
CRC [7:0]								53

Figure 34: Session Key Changeover (SKC) OAM Cell Format.

Notes:

1) The use of the Relative ID field is defined in Section 5.1.7.3.
2) The Bank ID field is an alternating pattern of 0 hex or F hex for successive key updates.
3) The key number (KN) field, a 32-bit field, indicates the key number associated with the new session key. Each session key is assigned a number. The first session key to be exchanged by the session key update protocol is assigned 1, the second session key is assigned 2, and so forth.
4) The State Vector (SV) contains the new state vector when using the counter mode of the Data Confidentiality service, or it is set to all zeros otherwise.
5) Reserved octets are set to 6A hex, reserved fields less than 1 octet in length are set to all zeros.
6) The reserved bits included after the 4-bit Bank ID field are provided so that the KN and SV fields are aligned on 16 bit boundaries, to simplify high speed implementations.

5.1.7.2.2.2 Data Integrity SKC OAM Cell Format

The format of the Data Integrity SKC OAM Cell is defined in Figure 34, except that the Function ID field is set to 0010 (binary). The SV field shall be set to zero.

5.1.7.3 Use of the Security OAM Cell Relative ID Field

The security OAM cell's relative ID (or RID) field is used to support symmetric nesting of security agents and/or security services. Security OAM cells provide a means of communication between security agents throughout the lifetime of a connection. The relative ID field provides the mechanism to indicate which security agent a particular OAM cell applies to, when nesting is employed. Up to 16 layers of nesting are supported.

There are several potential uses for nested security agents. The primary one is to provide different security "domains" within a network, where an inner domain might provide different security characteristics than an outer domain. By allowing nesting, users in the outer domain can share the same network as the inner domain users. Nesting can also be used to combine security functions that happen to use separate security agents (e.g., privacy and integrity). Figure 35 shows an example of nested security agents and the effect on the relative id (RID) field.

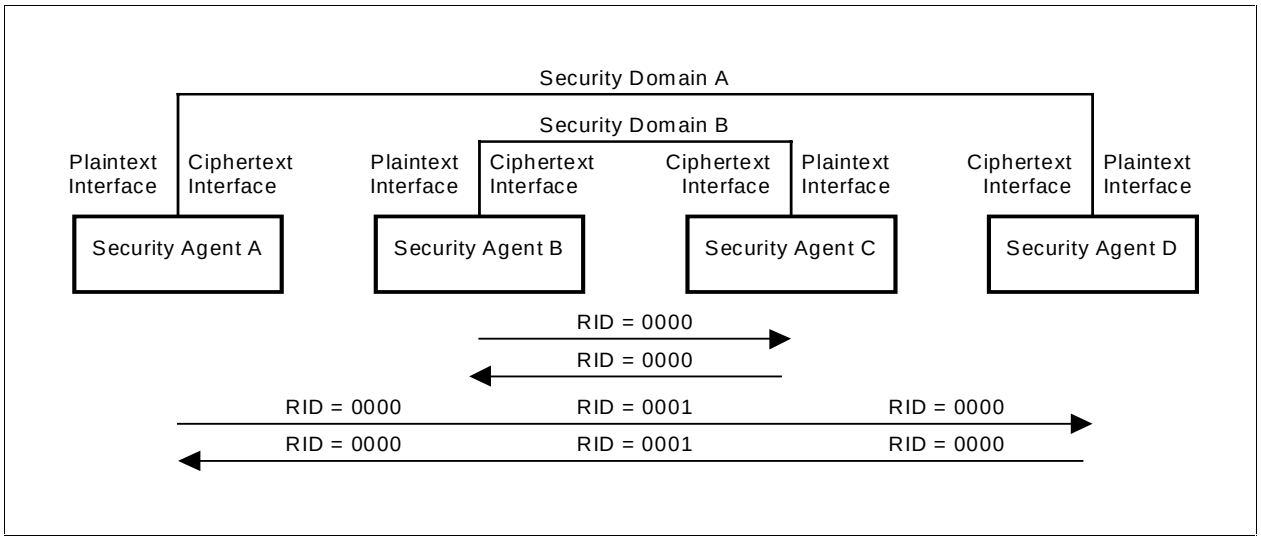


Figure 35: Example of Nested Security Agents.

The procedures for processing security OAM cells are described in Sections 5.1.7.3.1, 5.1.7.3.2, and 5.1.7.3.3. These procedures apply only to those security agents that insert or terminate security OAM cells for purposes of key update or cryptographic resynchronization. Security agents not performing these functions shall pass security OAM cells transparently.

Implementations containing multiple security services in a single physical device, e.g. integrity and encryption, shall treat each service as a separate logical entity with regards to RID processing.

A security agent contains two interfaces: plaintext and ciphertext. The plaintext interface is the interface over which the "unprotected" traffic is transmitted or received. A security agent receives "unprotected" ATM traffic on its plaintext interface, applies security services to the traffic, and forwards the "protected" traffic via the ciphertext interface. A security agent receives protected ATM traffic on its ciphertext interface, removes the security protection, and forwards the "unprotected" traffic over its plaintext interface. Security OAM cells flow in both the plaintext-to-ciphertext direction and ciphertext-to-plaintext direction. The procedures for processing the relative ID field depend on the direction of the Security OAM cell flow.

5.1.7.3.1 Initiation of Security OAM Cells

The following procedures apply to source security agents that insert security OAM cells.

Security OAM cells are introduced by security agents through the ciphertext interface. When a security OAM cell is injected into the cell stream by a security agent (for cryptographic resynchronization or key update purposes), the relative ID shall be set to zero.

5.1.7.3.2 Processing for Security OAM Cells Received on the Plaintext Interface

Security OAM cells may be received on the plaintext side of a security agent if there are two or more nested pairs of security agents providing confidentiality or integrity services on a given connection. A security agent which receives a Security OAM cell on its plaintext interface, with the Function ID matching the service the source SA is providing, shall increment the relative ID by one for each such matching Function ID, compute a new CRC-10 over the cell contents, circumvent the security function, and forward the cell to the ciphertext interface. The relative order of the security OAM cell and other cells on the connection shall not be perturbed. If the relative ID field of a received security OAM cell contains all ones, the cell is discarded.

5.1.7.3.3 Processing for Security OAM Cells Received on the Ciphertext Interface

A Security OAM cell received on the ciphertext interface is intended for the security agent if the relative ID field is set to zero. If the relative ID is set to zero the security agent shall remove the security OAM cell from the cell stream and use its contents to perform the security OAM function. If the relative ID is set to a value other than zero, the security agent shall decrement the relative ID by one for each service it terminates, compute a new CRC-10 over the cell contents, circumvent the security function, and forward the cell through the plaintext interface. The relative order of the security OAM cell and other cells on the connection shall not be perturbed.

5.2 Key Exchange

5.2.1 Key Exchange Infrastructure and Mechanisms

The ATM key exchange protocol is described in the context of "security message exchange protocol" in Section 5.1. Key exchange is performed by generating initial session keys for each direction in the VC and a shared master key. These keys are encrypted for exchange using an Initial Key Exchange Key. When using a public key encryption algorithm such as RSA for key exchange, the Initial Key Exchange Key is the public key of the recipient. When using a key development algorithm such as Diffie-Hellman, the Initial Key Exchange Key is a portion of the shared value developed by the algorithm from the users' public keys. When using a symmetric key algorithm, the Initial Key Exchange Key is a shared secret key established prior to key exchange.

5.2.2 Key Exchange Algorithms

Key exchange is performed using either symmetric (secret) key algorithms such as DES or asymmetric (public) key algorithms such as RSA. If a symmetric key algorithm is used, the two nodes must have already established a shared secret key. With asymmetric algorithms, on the other hand, each node need only know the public key of the other node.

Note that the generation, distribution, and storage of these (usually long-lived) secret, private, or public keys is outside the scope of this specification.

Associated with each algorithm is a codepoint that is used for identification when negotiating security options. These codepoints are listed in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

The following apply when performing key exchange:

- When performing user plane key exchange, one of the authentication and key exchange protocols described in Section 5.1 shall be used.
- When performing key exchange, an authentication algorithm (either listed in Section 3.1 or user defined) shall be used.

5.2.2.1 Asymmetric Algorithms for Key Exchange

The following asymmetric (public-key) algorithms are defined in this specification for key exchange.

Algorithm	Normative Reference
RSA	[27]
Diffie-Hellman	Section 8.6.4
ECKAS-DH	Section 8.7.5

For Diffie-Hellman Key Exchange, the size of the modulus (*p*) shall be one of the following: 512, 768, 1024, or 2048 bits.

5.2.2.2 Symmetric Algorithms for Key Exchange

The following symmetric (secret-key) algorithms are defined in this specification for key exchange.

Algorithm	Normative Reference
DES (in CBC mode)	[7], [8]
DES40* (in CBC mode)	Section 8.5
Triple DES (in CBC mode)	[7], [8]
FEAL (in CBC mode)	[28], [29], [8]

*Although a codepoint for this mode is assigned, this mode is deprecated.

5.2.3 Generation of Master Keys

A Master Key is a key used between security agents for encrypting and decrypting session keys after initial connection establishment. Master Keys are generated during the security message exchange protocol described in Section 5.1. A single Master Key is used for both full duplex and simplex (e.g., point-to-multipoint) calls. Master Keys can be developed with public key encryption algorithms, e.g., RSA, or with key development algorithms, e.g., Diffie-Hellman. The procedures for generating the Master Key with public key encryption algorithms and key development algorithms are slightly different. The maximum size of a Master Key is 256 bits.

5.2.3.1 Master Keys on Point-To-Point Connections

To develop the Master Key for point-to-point connections using a public key encryption algorithm, e.g., RSA, 128-bit random values are selected by both the initiator and responder. These 128-bit values are exchanged in the Master Key octet group of the Confidential Parameters (Section 7.3.1). The exchanged values are decrypted and concatenated to form the Master Key. The concatenation is performed as follows: the initiator value forms the most significant or leftmost half, and the responder value forms the least significant or rightmost half.

To develop the Master Key for point-to-point connections using a key development algorithm, e.g., Diffie-Hellman, the low-order 256 bits of the resultant shared secret value is the Master Key. The Master Key

octet group is not required, and will not be included in the Confidential Parameters, and will be ignored if received. To accommodate this procedure, and also for security reasons, the modulus size for the Diffie-Hellman algorithm shall be at least 512 bits, and the modulus size for the Elliptic Curve Key Agreement Scheme-Diffie Hellman algorithm shall be at least 150 bits. The Initial Key Exchange Key is then set equal to the Master Key value and used as input to the Zmask algorithm for encryption of the Confidential Parameters.

5.2.3.2 Master Keys on Point-To-Multipoint Connections

For the case of point-to-multipoint calls, the addition of leaf nodes is handled differently from the initial call setup. This is because the Master Key for the connection has already been established (as described above), and need only be distributed to the new leaves.

When using public key encryption algorithms (e.g., RSA) the Master Key is encrypted in the responder's public key by the initiator and sent to the leaf as described in Section 5.1.

If the Master Key for the point-multipoint connection is encrypted using the Zmask algorithm defined in Section 8.6.4.1, then the initial key exchange key used in the encryption algorithm (as an input to the hash) for subsequent leaves after the initial call setup must be pre-established. The pre-establishment of this key can be performed either through manual configuration or through prior key exchange. In both cases the encrypted Master Key for the connection is sent in the *ConfPar* token, along with the encrypted initial session keys.

5.2.4 Generation of Initial Session Keys

Session keys are the keys used by the encryption algorithm for the data confidentiality service, or the integrity algorithm for the data integrity service. The two security agents involved in a security exchange randomly create session keys, and they are encrypted and transferred using the security message exchange protocol. The method used to encrypt the initial session keys when using public or secret key encryption algorithms is different from the one used with key development algorithms.

When using public or secret key encryption algorithms or key development algorithms, Initial Session Keys (ISKs) for confidentiality and integrity are created using a random number generator, and are exchanged in the session key octet group of the Confidential Parameters octet group. The Confidential Parameters octet group is encrypted in the other party's public key or the shared secret key. If using a key development algorithm, the Confidential Parameters octet group containing the ISKs is encrypted in the shared Initial Key Exchange Key. This is accomplished by performing the Zmask operation, as specified in Section 8.6.4.1, on the Initial Key Exchange Key and using the Zmask value to encrypt the Confidential Parameters.

For simplex calls (e.g., point-to-multipoint) only a single session key per service is needed. This key is always provided by the SA providing security for the root on point-to-multipoint calls, and by the SA providing security for the node which is generating the traffic on the simplex connection., i.e., the node which has bandwidth allocated in the forward direction. The *ConfPar* token is sent in both directions for simplex connections, but only one value is used; the other discarded. For full duplex calls, separate initial session keys and initialization vectors shall be used in each direction.

5.2.5 Error Processing

Error processing for the key exchange service is described in the context of the security message exchange protocol in Section 5.1.

5.3 Session Key Update

5.3.1 Session Key Update Protocol

When either party wants to use a new session key, it sends key update OAM cells within the user data stream to exchange the new session key with the remote partner and to indicate to the remote partner when to start using the new session key. The key update OAM flows are end-to-end F4 flows for VPCs and end-to-end F5 flows for VCCs, respectively.

The session key update protocol involves two processes: exchanging a new session key between the initiator and responder, and changing over from the old session key to the new session key. The first process is referred to as "session key exchange" (SKE) and the second process is referred to as "session key changeover" (SKC). The format for these OAM cells is defined in Section 5.1.7.

In order to change keys at high speeds, without disrupting service to the end user, two session keys are required: a current-key and a next-key. The next-key is delivered from the source to the destination using the SKE cell. The destination stores the next-key in a separate memory location until needed. The Bank ID or key number fields in the SKE cell are used to identify the next-key (with respect to the current key). The actual changeover occurs when the SKC cell is sent.

The process of performing key updates is independent in each direction of data flow for full duplex connections. It is the responsibility of the source (e.g., the encrypting side of the data confidentiality service) of each data flow to initiate the key update in its direction. In point-to-multipoint connections there are one source and multiple destinations. Since point-to-multipoint connections are one-directional (from the source to destinations), only the root updates the session keys, and the same session keys are used by the root as well as all the leaves.

5.3.1.1 Session Key Exchange (SKE) Process

The SKE OAM cell is used to securely transfer the next session key from the source to the destination(s). Each key update uses a sequential key number for synchronization between the source and destination(s), as well as for cryptographic protection. A 32-bit numbering scheme is used, which means that $2^{32} - 1$ session key updates can be performed on a connection before the key number wraps around.

The next session key is encrypted using the master key obtained during secure call establishment. This is a 32-octet (256-bit) field that provides sufficient length for all currently defined algorithms. The actual length of the information in this field is dependent on the session key length of the algorithm being used.

The SKE process is derived from the method described in [31]. The process is defined using both the MD5 and SHA-1 hash functions. The determination of which to use is negotiated during secure call establishment.

5.3.1.1.1 SKE Processing at the Source (or Key Update Initiator)

Given a shared secret "master key" that is exchanged using the authentication/key exchange protocol at connection establishment time, the source can inform the destination(s) of a new session key that will be used for subsequent data traffic. When the source wants to send a new session key to the destination(s), it invokes the SKE process.

The format of the SKE OAM cell is defined in Section 5.1.7.2.1.1. The Bank ID is a 4-bit binary indication, coded as all zeros or all ones, which indicates the bank associated with the next session key. The key number (KN) is a 4-octet field, which indicates the key number associated with the new session key. Each session key is assigned a number. The first session key to be exchanged by the session key update protocol is assigned 1; the second session key is assigned 2, and so forth (using binary unsigned coding).

The key number field is used to maintain key update synchronization between the source and destination (i.e., to ensure both ends are using the same session key).

The following procedure is used to generate the SKE OAM cell. It is assumed that the source *A* shares a secret master key, $K_{m,AB}$, with the destination *B*. In a point-to-multipoint connection, it is assumed that the same master key is shared by the source and all the destinations.

A generates the new Bank ID = current Bank ID $\oplus$ 0F hex.

A increments its key number (i.e., KN_A) by one. KN_A is set to 0 at the time the connection is established.

A generates a new session key $K_{s,AB}$. This session key is generated randomly, and is checked to ensure it is not "weak" (with respect to the data confidentiality algorithm or the data integrity algorithm).

A encrypts the session key under the master key as defined in Section 8.6.5 or 8.6.6.

Each source shall insure that the combination of the master key and the key number are locally unique for each key update, to maintain the strength of the security. This does not include the extremely improbable case when randomly generated master keys might happen to be identical.

A sends the Bank ID, key number (i.e., KN_A), and the encrypted session key (i.e., $Enc_{K_{m,AB}}(K_{s,AB})$) to *B* in the SKE OAM cell. The session key, $K_{s,AB}$, can have any length up to 256 bits (which is the length of the encrypted session key field of the SKE OAM cell). For cases when it is less than 256 bits long, the key shall reside in the low-order bits and be prepended with zeroes. For Triple DES with keying option 2, the *k*2 key shall use the low order 64 bits, and the *k*1 key the next higher 64 bits.

Note that the old session key remains "active" at the source and destination(s) until session key changeover (SKC) is performed. The SKE OAM cell may get lost and the source will not be able to detect that (since there is no acknowledgment). To improve the probability that the session key exchange is successful, the source shall transmit the SKE OAM cell at least three (3) times with a fixed interval between transmissions. The interval is an implementation parameter and need not be specified.

5.3.1.1.2 SKE Processing at the Destination (or Key Update Responder)

Upon receipt of an SKE OAM cell, the destination *B* extracts the Bank ID, key number KN_A, and the encrypted session key *E*, and performs the following steps:

Verifies the 10-bit OAM cell CRC is correct, and discards the cell if it is not.

Checks the received KN_A. If this is the first session key received from *A* in a SKE OAM cell, the key number is valid. if it is greater than or equal to one. If this is not the first session key received from *A* in a SKE OAM cell, the key number is valid only if it is greater than the key number associated with the most

recent (i.e., the previous) session key received from *A*. If these tests fail, then the SKE OAM cell is discarded and no further action is taken.

If the key number is valid, then *B* recovers the new session key by:

$$K_{s,AB}=E \oplus Mask$$

The mask is computed as defined in section 8.6.5 using MD5, or section 8.6.6 for SHA-1.

The recovered key (or next-key) is stored in memory, until the corresponding SKC cell is received. The Bank ID, the KN, or both can be used to access the next-key.

5.3.1.2 Session Key Changeover (SKC) Process

After the SKE process is completed from the source point of view (i.e., after the SKE OAM cell is transmitted multiple times), the source invokes the session key changeover process to indicate to the destination(s) when to start using the new session key. The format of the SKC cell shall be as shown Section 5.1.7.2.2.1.

The source sends the SKC OAM cell that instructs the destination(s) to start using the new session key on the cells following the SKC OAM cell. The SKC OAM cell carries the key number associated with the new session key to which the destination(s) shall switch. The SKC OAM cell is sent multiple times to increase the probability of receipt at the destination(s) in the presence of cell loss. The SKC OAM cell is not cryptographically protected (since it does not carry any confidential information).

5.3.1.2.1 SKC Processing at the Source (or Key Update Initiator)

The source performs the following steps:

1. Wait at least 1 second after sending the last SKE OAM cell before sending the corresponding SKC OAM cell, to allow the destination sufficient time to complete the SKE processing.

2. Set the Bank ID and the *KN* of the SKC OAM cell to the most recent values sent in the SKE OAM cell.

3. Set the State Vector (SV) of the SKC cell to all zeros, unless the counter mode of the data confidentiality service is being used, in which case the SV is initialized as described in Section 8.2.

4. Inject the SKC OAM cell into the connection undergoing key changeover in such a manner that the session key(s) negotiated by the SKE process and the state vector (if applicable) are used on the next user cell transmitted on that connection for the confidentiality service, and the next SDU for the integrity service.

5. Transmit the SKC OAM cell at least three (3) times with a fixed interval between transmissions. The interval is an implementation parameter and need not be specified. For the counter mode of the confidentiality service, the state vector will be different each time the SKC OAM cell is sent if any user cells occur in the interim.

In the case of the Integrity service, the SKC OAM cell is repeated three times, and each cell shall be inserted between SDUs.

Note that in counter mode for the confidentiality service, the SKC OAM cell is also used to perform a cryptographic resynchronization as well as a key changeover. It is permissible to send an SKC OAM cell expressly for this purpose, without any key changeover. This is accomplished by setting the Bank ID and key number to the values currently in use.

5.3.1.2.2 SKC Processing at the Destination (or Key Update Responder)

Upon receipt of an SKC OAM cell, the destination shall perform the following steps:

1. Extract the Bank ID, key number, and state vector (if applicable).

2. Verify that the 10-bit OAM cell CRC is correct, and discard the cell if it is not.

3. Use either the Bank ID or the key number to access the session key negotiated by the SKE process.

4. Initialize the state vector as described in Section 8.2.4.3, if the counter mode of the data confidentiality service is being used.

5. Use the session key and state vector (if applicable) for the next user data cell received on the connection in the case of the confidentiality service or the next SDU received in the case of the integrity service.

6. When the confidentiality service is used with resynchronization, treat further SKC OAM cells received for the same key update as resyncs; otherwise ignore them.

Note that the SKC OAM cell is also used to perform a cryptographic resynchronization in the counter mode case.

5.3.1.3 Session Key Exchange Algorithms

Associated with each algorithm is a codepoint that is used for identification when negotiating security options. These codepoints are listed in Section 7. Procedures for using user-defined algorithm codepoints are also described in Section 7.

The following algorithms are defined in this specification for session key exchange.

Algorithm	**Normative Reference**
MD5	Section 8.6.5
SHA-1	Section 8.6.6
RIPEMD-160	Section 8.6.6, [21]

5.4 Certificates

The security message exchange protocol described in Section 5.1 also provides for the exchange of public key certificates.

The X.509 v1 certificate shall be used when certificate exchange is performed in the signaling channel. When certificate exchange is performed in-band (in the user data channel), one of the X.509 v1, v2, and v3 certificates shall be used.

6 In-Band Security Message Exchange Finite State Machine (FSM)

The Finite State Machine (FSM) described in this section specifies the intended behavior for the in-band security message exchange protocol. This FSM corresponds to the textual procedures described in Section 5.1.5.3 of this specification. If there are any discrepancies between the textual procedures and the FSM description, the FSM description shall take precedence.

The FSM covers the procedures for the Initiator and the Responder of the security message exchange.

The FSM is described in five sections:

1. An overview of the message sequence is given in Section 6.1.
2. The FSM States are described in Section 6.2.
3. The FSM Events are described in Section 6.3.
4. The timers and constants needed to control the FSM are described in Section 6.4.
5. The FSM Specification and Description Language (SDL) diagrams are contained in Section 6.5.

6.1 Message Sequence Chart

An overview of the sequence of messages (Flow-1, Flow-2, etc.) and the use of timers for the normal case is shown in Figure 36.

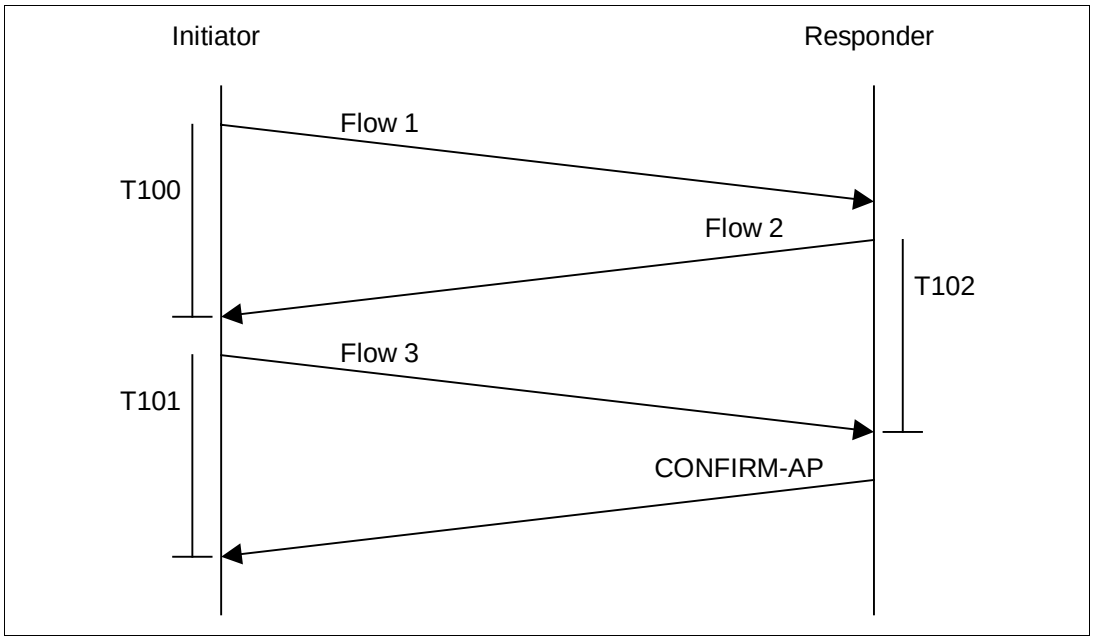


Figure 36: Basic Message Exchange Sequence.

6.2 FSM States

The FSM states for the Initiator and Responder sides are as follows. (It should be noted that the Initiator and Responder Idle states are really one and the same state.)

Initiator States:

- Idle: No requests for a secure connection are outstanding.
- Setup initiated: A secure connection has been initiated by sending a Flow-1, and Flow-2 is expected.
- Waiting for Confirmation: A Flow-3 has been sent and waiting for a CONFIRM-AP to indicate that the Responder has completed the message exchange.
- Operating at Initiator: The connection has been made available to the user.
- Failed: Errors have been detected.

Responder States:

- Idle: No requests for a secure connection are outstanding.
- Exchanging Parameters: A Flow-2 has been sent and waiting for a Flow-3.
- Operating at Responder: The connection has been made available to the user.
- Failed: Errors have been detected.

6.3 FSM Events

The FSM events which may be received by the Initiator and the Responder are as follows:

Events at Initiator:

- Secure request: The initiator has been requested to secure a connection.

- Valid Flow-2 received: A message was received which passed all the format requirements, was recognized as a Flow-2, and contains all required parameters.
- Confirm-AP received: A message was received which passed all the format requirements and was recognized as a CONFIRM-AP.
- T100 expires: The set time as shown in Table 7 is exceeded without receipt of a Flow-2.
- T101 expires: The set time as shown in Table 7 is exceeded without receipt of CONFIRM-AP.
- Fault received: The initiator has received a fault message from the Responder
- Invalid Flow-2 received: A Flow-2 has been received with errors.

Events at Responder:

- Valid Flow-1 received: A message was received which passed all the format requirements, was recognized as a Flow-1, and contains all required parameters.
- Valid Flow-3 received: A message was received which passed all the format requirements, was recognized as a Flow-3, and contains all required parameters.
- T102 expires: The set time as shown in Table 7 is exceeded without receipt of Flow-3.
- Fault received: The responder has received a fault message from the Initiator
- Invalid Flow-1 received: A Flow-1 has been received with errors.
- Invalid Flow-3 received: A Flow-3 has been received with errors.

6.4 Timers and Constants

The control of the FSM uses the following timers as defined in Sections 5.1.5.3.4 and 5.1.5.3.5:

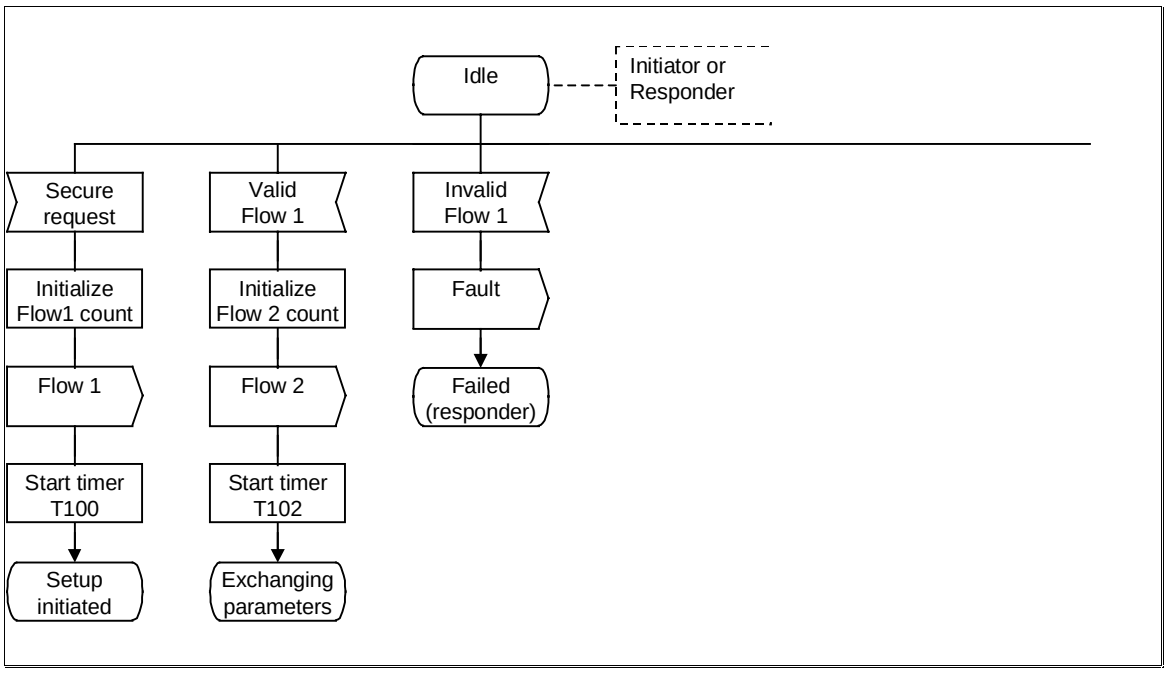
- T100, started each time Flow-1 is sent or resent.
- T101, started when Flow-3 is sent (the first time).
- T102, started each time Flow-2 is sent or resent.

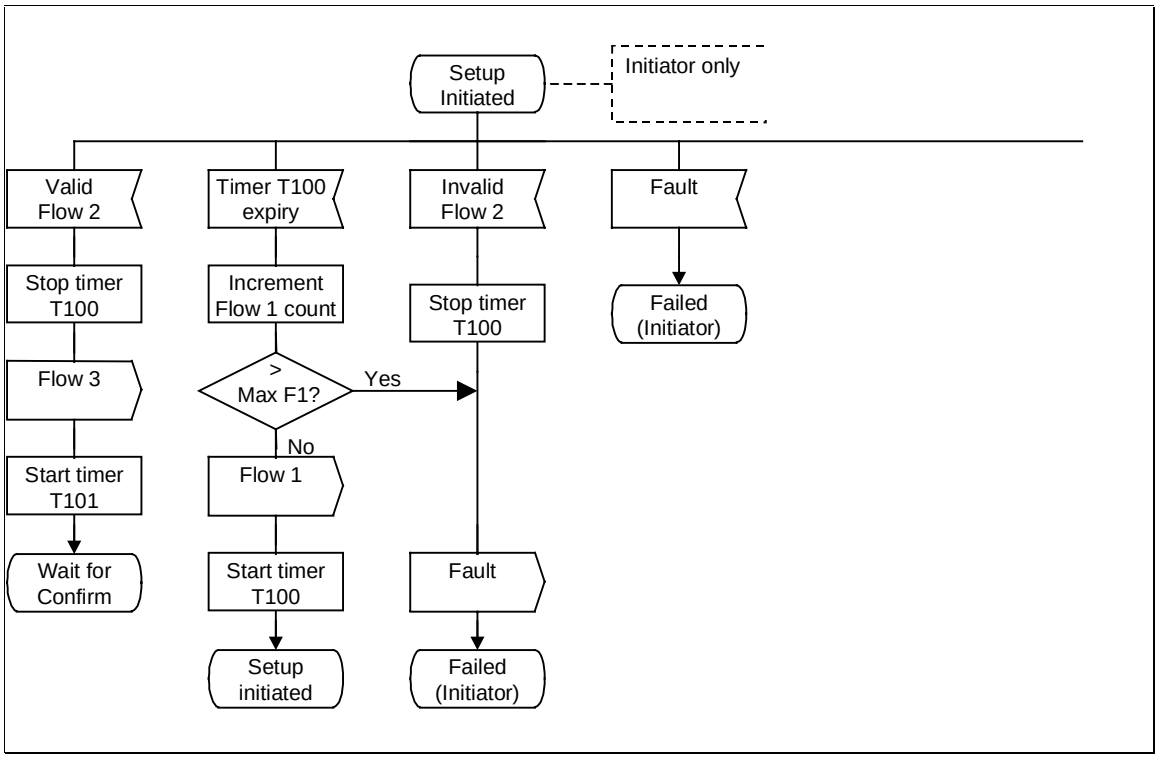
The control of the FSM uses the following constants as defined in Sections 5.1.5.3.4 and 5.1.5.3.5:

- I-Max-Flow1-Retry, which limits the number of times that Flow-1 is resent.
- R-Max-Flow2-Retry, which limits the number of times that Flow-2 is resent.

6.5 SDL

The detailed SDL for the Initiator and Responder is given in Figure 37.


Idle
Initiator or Responder
Secure request
Valid Flow 1
Invalid Flow 1
Initialize Flow1 count
Initialize Flow 2 count
Fault
Flow 1
Flow 2
Failed (responder)
Start timer T100
Start timer T102
Setup initiated
Exchanging parameters


Setup Initiated
Initiator only
Valid Flow 2
Timer T100 expiry
Invalid Flow 2
Fault
Stop timer T100
Increment Flow 1 count
Stop timer T100
Failed (Initiator)
Flow 3
> Max F1?
Yes
No
Start timer T101
Flow 1
Wait for Confirm
Start timer T100
Fault
Setup initiated
Failed (Initiator)

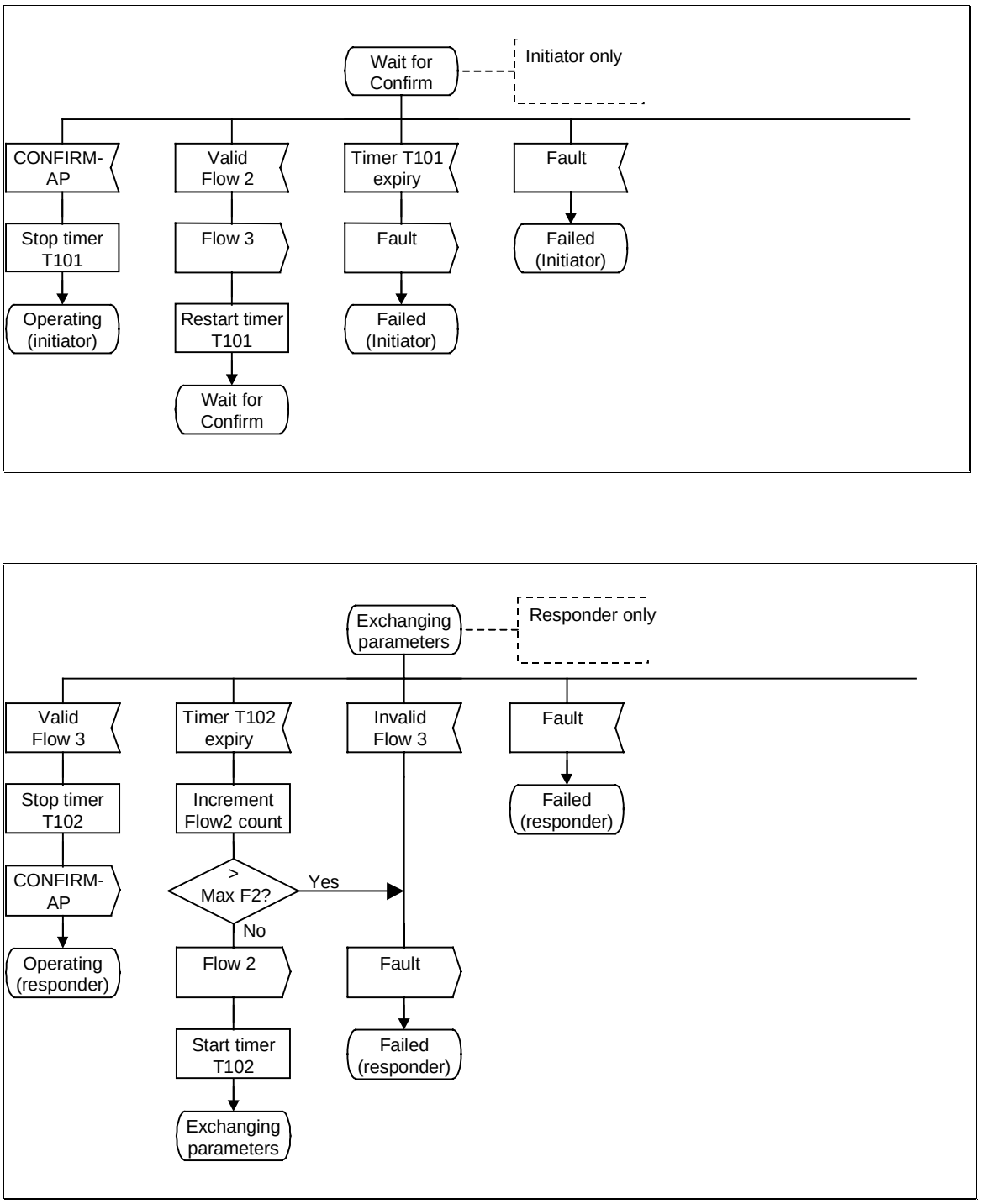


Figure 37: Detailed SDL for Three-Way SME Initiator and Responder Procedures.

7 Security Service Data Structures

This section defines the various data sections and octet groups which are used to construct the Security Service Data Section.

7.1 Security Agent Identifiers

This section specifies the use of “distinguished names” for initiating, responding, and explicitly targeting security agents. There are two distinguished name formats specified here: the X.509 distinguished name and ATM address of the ATM network element that hosts the security agent.

7.1.1 Initiator Distinguished Name

This octet group is part of the Security Agent Identification Section shown in Section 5.1.3.2.10.1. This octet group contains the Distinguished Name (ID) of the initiating security agent in a Security Message Exchange.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	0	0	0	1	0	
Initiator Distinguished Name Identifier								x.1
Initiator Distinguished Name Length								x.2
Initiator Distinguished Name Type								x.3
Initiator Distinguished Name Value								x.4 etc.

Initiator Distinguished Name Length (Octet x.2)

A binary number indicating the length in octets of the Initiator distinguished name type and value fields, contained in octets x.3, x.4, etc.

Initiator Distinguished Name Type (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	X.509 Distinguished Name
0	0	0	0	0	0	1	0	ATM End System Address

Initiator Distinguished Name Value (Octet x.4 etc.)

This octet group contains the value of the distinguished name (ID) of the Initiator of the Security Message Exchange Protocol.

X.509 Distinguished Name

This document does not specify naming conventions for security agents. The coding and length of this field shall be determined by the coding and length of the same names when carried in X.509 certificates–that is, according to the Basic Encoding Rules (BER, ISO 8825),with the restrictions imposed by X.509 to make BER deterministic.

ATM End System Address (AESA)

This field contains the ATM address associated with the Initiator. The address is coded as described in ISO 8348, Addendum 2, using the preferred binary encoding. For further details on using this field, consult Section 3.0 of [3]. When these addresses need to be used in X.509 certificates, the following ASN.1 production shall be used to define the attribute used for the distinguished name:

```
aTMAddress ATTRIBUTE    ::= {
      WITH SYNTAX                 OCTET STRING
      EQUALITY MATCHING RULE      octetStringMatch
      SUBSTRINGS MATCHING RULE    octetSubstringsMatch
      ID                          ...aTMAddress }
```

7.1.2 Responder Distinguished Name

This octet group is part of the Security Agent Identification Section shown in Section 5.1.3.2.10.1. This octet group contains the Distinguished Name (ID) of the responding security agent in a Security Message Exchange.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	0	0	0	1	1	
Responder Distinguished Name Identifier								x.1
Responder Distinguished Name Length								x.2
Responder Distinguished Name Type								x.3
Responder Distinguished Name Value								x.4 etc.

Responder Distinguished Name Length (Octet x.2)

A binary number indicating the length in octets of the Responder distinguished name type and value fields, contained in octets x.3, x.4, etc.

Responder Distinguished Name Type (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	X.509 Distinguished Name
0	0	0	0	0	0	1	0	ATM End System Address

Responder Distinguished Name Value (Octet x.4 etc.)

This octet group contains the value of the distinguished name (ID) of the Responder of the Security Message Exchange Protocol.

X.509 Distinguished Name

This document does not specify naming conventions for security agents. The coding and length of this field shall be determined by the coding and length of the same names when carried in X.509 certificates–that is, according to the Basic Encoding Rules (BER, ISO 8825),with the restrictions imposed by X.509 to make BER deterministic.

ATM End System Address (AESA)

This field contains the ATM address associated with the Responder. The address is coded as described in ISO 8348, Addendum 2, using the preferred binary encoding. For further details on using this field, consult Section 3.0 of [3]. When these addresses need to be used in X.509 certificates, the following ASN.1 production shall be used to define the attribute used for the distinguished name:

```
aTMAddress ATTRIBUTE    ::= {
      WITH SYNTAX                 OCTET STRING
      EQUALITY MATCHING RULE      octetStringMatch
      SUBSTRINGS MATCHING RULE    octetSubstringsMatch
      ID                          ...aTMAddress }
```

7.1.3 Security Agent Distinguished Name

This octet group contains the distinguished name (ID) of the explicitly targeted security agent in a Security Message Exchange, as shown in Section 5.1.3.2.9.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	0	0	1	0	0	
Security Agent Distinguished Name Identifier								x.1
Security Agent Distinguished Name Length								x.2
Security Agent Distinguished Name Type								x.3
Security Agent Distinguished Name Value								x.4 etc.

Security Agent Distinguished Name Length (Octet x.2)

A binary number indicating the length in octets of the Security Agent distinguished name type and value fields, contained in octets x.3, x.4, etc.

Security Agent Distinguished Name Type (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	X.509 Distinguished Name
0	0	0	0	0	0	1	0	ATM End System Address

Security Agent Distinguished Name Value (Octet x.4 etc.)

This octet group contains the value of the distinguished name (ID) of the Security Agent of the Security Message Exchange Protocol.

X.509 Distinguished Name

This document does not specify naming conventions for security agents. The coding and length of this field shall be determined by the coding and length of the same names when carried in X.509 certificates–that is, according to the Basic Encoding Rules (BER, ISO 8825),with the restrictions imposed by X.509 to make BER deterministic.

ATM End System Address (AESA)

This field contains the ATM address associated with the security agent. The address is coded as described in ISO 8348, Addendum 2, using the preferred binary encoding. For further details on using this field, consult Section 3.0 of [3]. When these addresses need to be used in X.509 certificates, the following ASN.1 production shall be used to define the attribute used for the distinguished name:

```
aTMAddress ATTRIBUTE    ::= {
      WITH SYNTAX                OCTET STRING
      EQUALITY MATCHING RULE     octetStringMatch
      SUBSTRINGS MATCHING RULE   octetSubstringsMatch
      ID                         ...aTMAddress }
```

7.2 Security Service Specification Section

The Security Service Specification Section provides a description of the security services that are requested or supported for a particular security association. This section is optional in Flow-1 and Flow-2. It may not be used in Flow-3. If this section is used, services that are requested or supported shall be specified in one of two ways, either using a Security Service Declaration, or using a list of specific Security Service Options. The Security Service Declaration is provided as a concise method of declaring to a peer or proxy security agent the services that are supported or requested on the VC. The Security Service Option Section is designed for detailed security service declaration and negotiation. The Option is used to specify the supported or required security service. The Declaration may be used with the 2-way and the Options may be used with the 2-way or 3-way message exchange.

Following the Security Service Options (described in Section 7.2.2), the Algorithm Description (described in Section 7.2.3) may be used to specify in detail the specific services.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier								x.1
Security Service Declaration Section								x.2 etc*
Security Service Option Section								x.3 etc*
Security Service Algorithm Section								x.4 etc*

Security Service Declaration Section (Octet Group x.2)

This optional octet group declares the specific security services that are requested for a VC. Details are found below.

Security Service Option Section (Octet Group x.3)

This optional octet group indicates specific options for the indicated security service. Details are found below.

Security Service Algorithm Section (Octet Group x.4)]

This octet group describes the details of security service algorithms for the indicated security service. Details are found in section 7.2.3.

7.2.1 Security Service Declaration

The Security Service Declaration Section provides a minimal description of the security services that are requested or supported by a security agent.

The Security Service Declaration shall only be contained in the SSIEs within a 2-way signaling-based exchange. It shall not be generated in 3-way and shall be ignored if received in 3-way.

The Security Service Declaration Section is employed when communicating a security service request to a proxy security agent, or when declaring security capabilities to a peer SA.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	0	1	0	1	0	
Security Service Declaration Identifier								x.1
Security Service Declaration								
x	x	x	x	x	x	x	x	x.2

Security Service Declaration (Octet x.2, bits 8-1)

Bit	Meaning in Flow-1 from Initiator SA and in Flow-2 from Responder SA	Meaning in Flow-1 from end system	Meaning in Flow-2 from proxy
1			
0	Confidentiality Service not supported	not requested	not provided
1	Confidentiality Service supported	requested	provided
2			
0	Integrity Service not supported	not requested	not provided
1	Integrity Service supported	requested	provided
3			
0	Authentication Service not supported	not requested	not provided
1	Authentication Service supported	requested	provided
4			
0	Key Exchange Service not supported	not requested	not provided
1	Key Exchange Service supported	requested	provided
5			
0	Certificate Exchange Service not supported	not requested	not provided
1	Certificate Exchange Service supported	requested	provided
6			
0	Session Key Update Service not supported	not requested	not provided
1	Session Key Update Service supported	requested	provided
7			
0	Access Control Service not supported	not requested	not provided
1	Access Control Service supported	requested	provided
8			
-	Not used		

7.2.2 Security Service Options Section

The Security Service Options Section contains one or more octet groups, each used during security service negotiation to indicate whether a specific security service is required or supported. The following octet groups are all optional and may be included in any order, but each not more than once.

In the 2-way exchange, the initiator shall indicate which security services are required for the connection. The responder shall examine the security services specification, and accept the call if it is suitable, or reject it if not.

In the 3-way exchange, the initiator shall indicate which security services are required, which security services can be supported if the responder requires them, and which security services are not supported for the connection. For each service supported by the initiator, the responder may indicate if this service is required or not supported. For each service not supported by the initiator, the responder shall not include any response.

When an octet group for a specific service is omitted, it shall be interpreted to mean that the corresponding service is not required or not supported.

7.2.2.1 Data Confidentiality Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	0	0	0	
Data Confidentiality Service Option Identifier								x.1
Data Confidentiality Service Options								
x	x	x	x	x	x	x	x	x.2

Data Confidentiality Service Options (Octet x.2)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Not Supported
0	0	0	0	0	0	0	1	Supported at ATM Cell Level (Note)
1	0	0	0	0	0	0	1	Required at ATM Cell Level

Note: This codepoint applies only when used by the initiator in FLOW1-3WE.

7.2.2.2 Data Integrity Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	0	1	0	
Data Integrity Service Options Identifier								x.1
Data Integrity Service Options								
x	x	x	x	x	x	x	x	x.2

Data Integrity Service Options (Octet x.2)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**

0 0 0 0 0 0 0 0	Not supported
0 0 0 0 0 0 0 1	Supported, with Replay / Reordering Protection (Note)
0 0 0 0 0 0 1 0	Supported, without Replay / Reordering Protection (Note)
1 0 0 0 0 0 0 1	Required, with Replay/Reordering Protection
1 0 0 0 0 0 1 0	Required, without Replay/Reordering Protection
1 0 0 0 0 1 0 0	Required, with or without Replay/Reordering Protection (Note)

Note: This codepoint applies only when used by the initiator in FLOW1-3WE.

7.2.2.3 Authentication Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	0	1	1	
Authentication Service Options Identifier								x.1
Authentication Service Options								
x	x	x	x	x	x	x	x	x.2

Authentication Service Options (Octet x.2)

8 7 6 5 4 3 2 1	**Meaning**
0 0 0 0 0 0 0 0	Not supported
0 0 0 0 0 0 0 1	Supports Authentication (Note)
1 0 0 0 0 0 0 1	Requires Authentication

Note: This codepoint applies only when used by the initiator in FLOW1-3WE.

7.2.2.4 Key Exchange Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	1	0	0	
Key Exchange Service Options Identifier								x.1
Key Exchange Service Options								
x	x	x	x	x	x	x	x	x.2

Key Exchange Service Options (Octet x.2)

8 7 6 5 4 3 2 1	**Meaning**
0 0 0 0 0 0 0 0	Not supported
0 0 0 0 0 0 0 1	Supports Key Exchange (Note)
0 1 0 0 0 0 0 1	Requires Key Exchange

Note: This codepoint applies only when used by the initiator in FLOW1-3WE.

7.2.2.5 Session Key Update Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	1	0	1	
Session Key Update Service Options Identifier								x.1
Session Key Update Service Options								
x	x	x	x	x	x	x	x	x.2

Session Key Update Service Options (Octet x.2)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Not supported
0	0	0	0	0	0	0	1	Supports Session Key Update (Note 1)
1	0	0	0	0	0	0	1	Requires Session Key Update

Note 1: This codepoint applies only when used by the initiator in FLOW1-3WE.
Note 2: The result of SKU negotiation applies to both the confidentiality and integrity services.

7.2.2.6 Access Control Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	1	1	0	
Access Control Service Options Identifier								x.1
Access Control Service Options								
x	x	x	x	x	x	x	x	x.2

Access Control Service Options (Octet x.2)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Not supported
0	0	0	0	0	0	0	1	Supports Access Control (Note)
1	0	0	0	0	0	0	1	Requires Access Control

Note: This codepoint applies only when used by the initiator in FLOW1-3WE to indicate that it supports access control.

7.2.2.7 Certificate Exchange Service Options

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	0	1	0	1	1	1	
Certificate Exchange Service Options Identifier								x.1
Certificate Exchange Service Options								
x	x	x	x	x	x	x	x	x.2

Certificate Exchange Service Options (Octet x.2)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Not supported
0	0	0	0	0	0	0	1	Supports Certificate Exchange (Note)
1	0	0	0	0	0	0	1	Requires Certificate Exchange

Note :This codepoint applies only when used by the initiator in FLOW1-3WE.

7.2.3 Security Service Algorithm Description Section

The security algorithm section is used during negotiation for proposing and specifying algorithms to be used for the indicated security services. This also includes the algorithm's mode of operation, when appropriate. In addition, the parameters associated with each algorithm are also included.

This section may include:

- One or more octet groups for Data Confidentiality, Data Integrity, Hash, Signature, Key Exchange, and Session Key Update algorithms. Octet groups for the same service may be included multiple times in the order of preference selected by the initiator. Octet groups for different services may be in any order.
- One or more octet groups for the Authentication, Integrity, and Confidentiality Algorithm Profile Groups. Octet groups for the same Algorithm Profile Group may be included multiple times in the order of preference selected by the initiator. Octet groups for different Algorithm Profile Groups may be in any order.

Only one of the above methods shall be used for each security service. Different methods may be used for different security services.

This specification allows for the use of user (or vendor) specified algorithms. If a user (or vendor) specified algorithm is used, then the optional octet group containing the user's (or vendor's) Organizationally Unique Identifier (OUI) shall be used. The value of the OUI is unique to the user (or vendor), and is assigned by the Institute for Electrical and Electronics Engineers (IEEE).

As defined in IEEE Std 802-1990, the OUI is a 6-hex character identifier which is also represented as a 24-bit value. These 24 bits are placed in the octet groups defined in this section as follows:

- The first 8 bits of the OUI are mapped to the first octet, and so on.
- The most significant bit of the OUI is mapped to bit 8 of that first octet and the least significant bit of the OUI is mapped to bit 1 of the third octet.
- Because of the coding defined by IEEE, bit 7 of the first octet is always set to "0."

As an example, for an OUI of ACDE48, the contents of the three octets in the security message would be as follows:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	1	1	0	0	1st
1	1	0	1	1	1	1	0	2nd
0	1	0	0	1	0	0	0	3rd

7.2.3.1 Data Confidentiality Algorithm

This octet group indicates an algorithm for the data confidentiality service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	0	0	0	0	
Data Confidentiality Algorithm Identifier								x.1
Length of Data Confidentiality Algorithm Contents								x.2
Data Confidentiality Algorithm								x.3
OUI								x.4 (Note 1)
OUI (continued)								x.5 (Note 1)
OUI (continued)								x.6 (Note 1)
Data Confidentiality Mode of Operation								x.7
OUI								x.8 (Note 2)
OUI (continued)								x.9 (Note 2)
OUI (continued)								x.10 (Note 2)
Data Confidentiality Algorithm Details								x.11 etc.*
Data Confidentiality Mode Details								x.12 etc.*

Length of Data Confidentiality Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the data confidentiality algorithm/mode fields, contained in octets x.3, x.4, x.5 etc.

Data Confidentiality Algorithm (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	DES with 56 bits effective key
0	0	0	0	0	0	1	0	DES with 40 bits effective key
0	0	0	0	0	0	1	1	Triple-DES with keying option 2 [7]
0	0	0	0	0	1	0	0	FEAL, N=32, 64 bit key, no key block parity
1	x	x	x	x	x	x	x	User-defined data confidentiality algorithm (the value of bits 1-7 is user-defined)

OUI (Octets x.4 - x.6)

Note 1: if the data confidentiality algorithm is “user defined,” then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Data Confidentiality Mode of Operation (Octet x.7)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	0	Mode not applicable
0	0	0	0	0	0	0	1	CBC
0	0	0	0	0	0	1	0	Counter Mode
0	0	0	0	0	0	1	1	ECB
1	x	x	x	x	x	x	x	User-defined data confidentiality mode of operation (the value of bits 1-7 is user-defined)

OUI (Octets x.8 - x.10)

Note 2: if the data confidentiality mode of operation is "user defined," then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Data Confidentiality Algorithm Details (Octet x.11 etc.)

These octets indicate coding details for each data confidentiality algorithm. These details are found below:

⇒ DES coding details
- No further detail required

⇒ DES40 coding details
Two eight-octet fields are added to the data confidentiality algorithm information element details. The first eight octets contain a binary encoded 64-bit random number. The second eight octets contain the binary encoding of that random number encrypted under the DES40 key in the ECB mode.
[Note: these details originally were included to satisfy certain export requirements.]

⇒ Triple DES coding details
- No further detail required

⇒ FEAL coding details
- No further detail required

⇒ User-defined algorithm details
- Format of details specified by user

Data Confidentiality Mode Details (Octet x.12 etc.)

These octets indicate coding details for each data confidentiality mode of operation. These details are found below:

⇒ CBC mode coding details
A 64-bit (8-octet) binary encoded value. This is the initialization vector (IV) for the CBC mode.

⇒ Counter mode coding details
- No further detail required

⇒ ECB mode coding details
- No further detail required

⇒ User-defined mode details
- Format of details specified by user

7.2.3.2 Data Integrity Algorithm

This octet group indicates an algorithm for the data integrity service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	0	0	1	0	
Data Integrity Algorithm Identifier								x.1
Length of Data Integrity Algorithm Contents								x.2
User	Replay	Algorithm						
Data Integrity Algorithm								x.3
OUI								x.4 (Note)
OUI (continued)								x.5 (Note)
OUI (continued)								x.6 (Note)
Data Integrity Algorithm Details								x.7 etc.*

Length of Data Integrity Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the data integrity algorithm fields, contained in octets x.3, x.4, etc.

User Defined Indicator (Octet x.3 Bit 8)

8	**Meaning**
0	ATM Forum Defined Algorithm
1	User Defined Algorithm

When a User Defined Algorithm is indicated, Bits 7-1 are user defined. The following definitions of Replay/Reordering protection and Data Integrity Algorithm apply only when Bit 8 indicates “ATM Forum Defined Algorithm”.

Replay/Reordering Protection Indicator (Octet x.3 Bit 7)

7	**Meaning**
0	No replay/reordering protection provided.
1	Replay/reordering protection provided.

Data Integrity Algorithm (Octet x.3 Bits 6 - 1)

6	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	1	HMAC-MD5
0	0	0	0	1	0	HMAC-SHA-1
0	0	0	0	1	1	HMAC-RIPEMD-160
0	0	0	1	0	0	DES/CBC MAC
0	0	0	1	0	1	DES40/CBC MAC
0	0	0	1	1	0	Triple DES/CBC MAC
0	0	0	1	1	1	FEAL/CBC MAC

OUI (Octets x.4 - x.6)

Note: if the data integrity algorithm is “user defined,” then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Data Integrity Algorithm Details (Octet x.7 etc.)

These octets indicate coding details for each data integrity algorithm. These details are found below:

⇒ HMAC-MD5 coding details
- No further detail required

⇒ HMAC-SHA-1 coding details
- No further detail required

⇒ HMAC-RIPEMD-160 coding details
- No further detail required

⇒ DES in CBC mode MAC details
- No further detail required

⇒ DES-40 in CBC mode MAC details
- No further detail required

⇒ Triple DES in CBC mode MAC details
- No further detail required

⇒ FEAL in CBC mode MAC details
- No further detail required

⇒ User-defined algorithm details
- Format of details specified by user

7.2.3.3 Hash Algorithm

This octet group indicates a hashing algorithm for the authentication service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	0	1	0	0	
Hash Algorithm Identifier								x.1
Length of Hash Algorithm Contents								x.2
Hash Algorithm								x.3
OUI								x.4 (Note)
OUI (continued)								x.5 (Note)
OUI (continued)								x.6 (Note)
Hash Algorithm Details								x.7 etc.*

Length of Hash Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the hash algorithm fields contained in octets x.3, x.4, etc.

Hash Algorithm (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	MD5
0	0	0	0	0	0	1	0	SHA-1
0	0	0	0	0	0	1	1	RIPEMD-160

1 x x x x x x x	User-defined hash algorithm (the value of bits 1-7 is user-defined)

OUI (Octets x.4 - x.6)

Note: if the hash algorithm is "user defined," then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Hash Algorithm Details (Octet x.7 etc.)

These octets indicate coding details for each hash algorithm. These details are found below:

⇒ MD5 coding details
- No further detail required

⇒ SHA-1 coding details
- No further detail required

⇒ RIPEMD-160 coding details
- No further detail required

⇒ User-defined algorithm details
- Format of details specified by user

7.2.3.4 Signature Algorithm

This octet group indicates a signature algorithm or MAC for the Authentication Service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	0	1	1	0	
Signature Algorithm Identifier								x.1
Length of Signature Algorithm Contents								x.2
Signature Algorithm								x.3
OUI								x.4 (Note)
OUI (continued)								x.5 (Note)
OUI (continued)								x.6 (Note)
Signature Algorithm Details								x.7 etc*.

Length of Signature Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the signature algorithm fields contained in octets x.3, x.4, etc.

Signature Algorithm (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	RSA
0	0	0	0	0	0	1	0	DSA
0	0	0	0	0	0	1	1	EC-GDSA
0	0	0	0	0	1	0	0	ESIGN

0 0 0 0 0 1 0 1	DES/CBC MAC
0 0 0 0 0 1 1 0	DES40/CBC MAC
0 0 0 0 0 1 1 1	Triple DES/CBC MAC
0 0 0 0 1 0 0 0	FEAL/CBC MAC
1 x x x x x x x	User-defined algorithm (the value of bits 1-7 is user-defined)

OUI (Octets x.4 - x.6)

Note: If the signature algorithm is "user defined," then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Signature Algorithm Details (Octet x.7 etc.)

These optional octets indicate coding details for each signature algorithm. These details are found below:

⇒ RSA coding details
- No further detail required

⇒ DSA coding details
- No further detail required

⇒ EC-GDSA coding details
- No further detail required (cf. Section 8.7)

⇒ ESIGN coding details

The order of *k*:
This octet contains the binary encoding of the order of *k* (i.e., *X*, in the relation $k = 2^X$)

⇒ DES/CBC MAC coding details
- No further detail required

⇒ DES40/CBC MAC coding details
- No further detail required

⇒ Triple DES/CBC MAC coding details
- No further detail required

⇒ FEAL/CBC MAC coding details
- No further detail required

⇒ User-defined algorithm details
- Format of details specified by user

7.2.3.5 Key Exchange Algorithm

This octet group indicates the algorithm used for key exchange.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	1	0	0	0	
Key Exchange Algorithm Identifier								x.1
Length of Key Exchange Algorithm Contents								x.2
Key Exchange Algorithm								x.3
OUI								x.4 (Note)
OUI (continued)								x.5 (Note)
OUI (continued)								x.6 (Note)
Key Exchange Algorithm Details								x.7 etc.*

Length of Key Exchange Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the key exchange algorithm fields contained in octets x.3, x.4, etc.

Key Exchange Algorithm (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	RSA
0	0	0	0	0	0	1	0	Diffie-Hellman
0	0	0	0	0	0	1	1	ECKAS-DH (prime field)
0	0	0	0	0	1	0	0	ECKAS-DH (characteristic 2 field)
0	0	0	0	0	1	0	1	DES/CBC
0	0	0	0	0	1	1	0	DES40/CBC
0	0	0	0	0	1	1	1	Triple DES/CBC
0	0	0	0	1	0	0	0	FEAL/CBC
1	x	x	x	x	x	x	x	User-defined key exchange algorithm (the value of bits 1-7 is user-defined)

OUI (Octets x.4 - x.6)

Note: If the key exchange algorithm is “user defined,” then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Key Exchange Algorithm Details (Octet x.7 etc.)

These octets indicate coding details for each key exchange algorithm. These details are found below:

⇒ RSA coding details

- No further detail required

⇒ Diffie-Hellman coding details

Diffie-Hellman public key identifier (Octet x.7a):

This octet is the identifier for the Diffie-Hellman public key.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	Diffie-Hellman public key

Diffie-Hellman public key length (Octet x.7b):

This octet specifies the length of the Diffie-Hellman public key in octets.

Diffie-Hellman public key value (Octet x.7c etc.):

This field contains the octet string representation of the Diffie-Hellman public key value. This field contains the initiator's Diffie-Hellman public key value (*X*) when this information element is sent in FLOW1-3WE. This field contains the responder's Diffie-Hellman public key value (*Y*) when this information element is sent in FLOW2-3WE.

Diffie-Hellman modulus identifier (Octet x.8a):

This octet is the identifier for the Diffie-Hellman public modulus.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	0	Diffie-Hellman public modulus

Diffie-Hellman modulus length (Octet x.8b):

This octet specifies the length of the Diffie-Hellman public modulus in octets.

Diffie-Hellman modulus value (Octet x.8c etc.):

This field contains the octet string representation of the Diffie-Hellman public modulus value (*P*).

Diffie-Hellman base identifier (Octet x.9a):

This octet is the identifier for the Diffie-Hellman public base.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	1	Diffie-Hellman public base

Diffie-Hellman base length (Octet x.9b):

This octet specifies the length of the Diffie-Hellman public base in octets.

Diffie-Hellman base value (Octet x.9c etc.):

This field contains the octet string representation of the Diffie-Hellman public base value (*G*).

⇒ Elliptic Curve Key Agreement Scheme-Diffie Hellman Analogue (ECKAS-DH) coding details for prime fields (cf. Section 8.7.5):

ECKAS-DHp public key identifier (Octet x.7a):

This octet is the identifier for the ECKAS-DHp public key.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	ECKAS-DHp public key

ECKAS-DHp public key length (Octet x.7b):

This octet specifies the length of the ECKAS-DHp public key in octets.

ECKAS-DHp public key value (Octet x.7c etc.):

This field contains the octet string representation of the ECKAS-DHp public key value. This field contains the initiator's ECKAS-DHp public key value (*aP*) when this information element is sent in FLOW1-3WE. This field contains the responder's ECKAS-DHp public key value (*bP*) when this information element is sent in FLOW2-3WE.

ECKAS-DHp modulus identifier (Octet x.8a):

This octet is the identifier for the ECKAS-DHp public modulus (*p*).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	0	ECKAS-DHp public modulus

ECKAS-DHp modulus length (Octet x.8b):

This octet specifies the length of the ECKAS-DHp public modulus in octets.

ECKAS-DHp modulus value (Octet x.8c etc.):

This field contains the octet string representation of the ECKAS-DHp public modulus value (*p*).

ECKAS-DHp base identifier (Octet x.9a):

This octet is the identifier for the ECKAS-DHp public base (*P*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	1	ECKAS-DHp public base

ECKAS-DHp base length (Octet x.9b):

This octet specifies the length of the ECKAS-DHp public base in octets.

ECKAS-DHp base value (Octet x.9c etc.):

This field contains the octet string representation of the ECKAS-DHp public base.

ECKAS-DHp Weierstrass coefficient identifier (Octet x.10a):

This octet is the identifier for the ECKAS-DHp Weierstrass coefficient (*a*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	1	0	0	ECKAS-DHp Weierstrass coefficient

ECKAS-DHp Weierstrass coefficient length (Octet x.10b):

This octet specifies the length of the ECKAS-DHp Weierstrass coefficient (*a*) in octets.

ECKAS-DHp Weierstrass coefficient value (Octet x.10c etc.):

This field contains the octet string representation of the ECKAS-DHp Weierstrass coefficient (*a*).

ECKAS-DHp Weierstrass coefficient identifier (Octet x.11a):

This octet is the identifier for the ECKAS-DHp Weierstrass coefficient (*b*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	1	0	1	ECKAS-DHp Weierstrass coefficient

ECKAS-DHp Weierstrass coefficient length (Octet x.11b):

This octet specifies the length of the ECKAS-DHp Weierstrass coefficient (*b*) in octets.

ECKAS-DHp Weierstrass coefficient value (Octet x.11c etc.):

This field contains the octet string representation of the ECKAS-DHp Weierstrass coefficient (*b*).

⇒ Elliptic Curve Key Agreement Scheme-Diffie Hellman Analogue (ECKAS-DH) coding details for characteristic 2 (cf. Section 8.7.5):

ECKAS-DH2 public key identifier (Octet x.7a):

This octet is the identifier for the ECKAS-DH2 public key.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	ECKAS-DH2 public key

ECKAS-DH2 public key length (Octet x.7b):

This octet specifies the length of the ECKAS-DH2 public key in octets.

ECKAS-DH2 public key value (Octet x.7c etc.):

This field contains the octet string representation of the ECKAS-DH2 public key value. This field contains the initiator's ECKAS-DH2 public key value (*aP*) when this information element is sent in FLOW1-3WE. This field contains the responder's ECKAS-DH2 public key value (*bP*) when this information element is sent in FLOW2-3WE.

ECKAS-DH2 field size identifier (Octet x.8a):

This octet is the identifier for the ECKAS-DH2 field size (*m*).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	0	ECKAS-DH2 field size

ECKAS-DH2 field size length (Octet x.8b):

This octet specifies the length of the ECKAS-DH2 field size (*m*) in octets.

ECKAS-DH2 field size value (Octet x.8c etc.):

This field contains the octet string representation of the ECKAS-DH2 field size value (*m*).

ECKAS-DH2 base identifier (Octet x.9a):

This octet is the identifier for the ECKAS-DH2 public base (*P*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	1	ECKAS-DH2 public base

ECKAS-DH2 base length (Octet x.9b):

This octet specifies the length of the ECKAS-DH2 public base in octets.

ECKAS-DH2 base value (Octet x.9c etc.):

This field contains the octet string representation of the ECKAS-DH2 public base.

ECKAS-DH2 Weierstrass coefficient (*a*) identifier (Octet x.10a):

This octet is the identifier for the ECKAS-DH2 Weierstrass coefficient (*a*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	1	0	0	ECKAS-DH2 Weierstrass coefficient (*a*)

ECKAS-DH2 Weierstrass coefficient (*a*) length (Octet x.10b):

This octet specifies the length of the ECKAS-DH2 Weierstrass coefficient (*a*) in octets.

ECKAS-DH2 Weierstrass coefficient (*a*) value (Octet x.10c etc.):

This field contains the octet string representation of the ECKAS-DH2 Weierstrass coefficient (*a*).

ECKAS-DH2 Weierstrass coefficient (*b*) identifier (Octet x.11a):

This octet is the identifier for the ECKAS-DH2 Weierstrass coefficient (*b*) (cf. Section 8.7).

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	1	0	1	ECKAS-DH2 Weierstrass coefficient (*b*)

ECKAS-DH2 Weierstrass coefficient (*b*) length (Octet x.11b):

This octet specifies the length of the ECKAS-DH2 Weierstrass coefficient (*b*) in octets.

ECKAS-DH2 Weierstrass coefficient (*b*) value (Octet x.11c etc.):

This field contains the octet string representation of the ECKAS-DH2 Weierstrass coefficient (*b*).

⇒ DES/CBC coding details

- No further detail required

⇒ DES40/CBC coding details

- No further detail required

⇒ Triple DES/CBC coding details

- No further detail required

⇒ FEAL/CBC coding details

- No further detail required

⇒ User-defined algorithm details

- Format of details specified by user

7.2.3.6 Session Key Update Algorithm

This octet group indicates a session key update algorithm for updating the data confidentiality and data integrity session keys.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	1	0	1	0	
Session Key Update Algorithm Identifier								x.1
Length of Session Key Update Algorithm Contents								x.2
Session Key Update Algorithm								x.3
OUI								x.4 (Note)
OUI (continued)								x.5 (Note)
OUI (continued)								x.6 (Note)
Session Key Update Algorithm Details								x.7 etc.*

Length of Session Key Update Algorithm Contents (Octet x.2)

A binary number indicating the length in octets of the key exchange algorithm fields, contained in octets x.3, x.4, etc.

Session Key Update Algorithm (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	SKE with MD5
0	0	0	0	0	0	1	0	SKE with SHA-1
0	0	0	0	0	0	1	1	SKE with RIPEMD-160
1	x	x	x	x	x	x	x	User-defined key exchange algorithm (the value of bits 1-7 is user-defined)

OUI (Octets x.4 - x.6)

Note: if the session key update algorithm is "user defined," then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Session Key Update Algorithm Details (Octet x.7 etc.)

These octets indicate coding details for each session key update algorithm. These details are found below:

⇒ SKE with MD5 coding details
- No further detail is required.

⇒ SKE with SHA-1 coding details
- No further detail is required.

⇒ SKE with RIPEMD-160 coding details
- No further detail is required.

⇒ User-defined algorithm details
- Format of details specified by user

7.2.3.7 Authentication Algorithm Profile Group

This octet group indicates a set of algorithms supporting the authentication service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	1	1	0	0	
Authentication Algorithm Group Identifier								x.1
Length of Authentication Algorithm Group Contents								x.2
Authentication Algorithm Group								x.3
OUI								x.4* (Note)
OUI (continued)								x.5* (Note)
OUI (continued)								x.6* (Note)
1	0	1	1	0	0	1	0	
Signature Algorithm Details Identifier								x.7*
Length of Signature Algorithm Details								x.8*
Signature Algorithm Details								x.9 etc.*
1	0	1	1	0	1	0	0	
Hash Algorithm Details Identifier								x.10*
Length of Hash Algorithm Details								x.11*
Hash Algorithm Details								x.12 etc.*

Length of Authentication Algorithm Group Contents (Octet x.2)

A binary number indicating the length in octets of the authentication algorithm group fields contained in x.3, x.4, etc.

Authentication Algorithm Group (Octet x.3)

8	7	6	5	4	3	2	1	**Meaning**
0	0	0	0	0	0	0	1	AUTH-1 Signature=DES/CBC MAC Hash=Not Applicable
0	0	0	0	0	0	1	0	AUTH-2 Signature=DSA Hash=SHA-1
0	0	0	0	0	0	1	1	AUTH-3 Signature=EC-GDSA Hash=SHA-1
0	0	0	0	0	1	0	0	AUTH-4 Signature=ESIGN Hash=MD5
0	0	0	0	0	1	0	1	AUTH-5 Signature=FEAL/CBC MAC Hash=Not Applicable
0	0	0	0	0	1	1	0	AUTH-6 Signature=RSA Hash=MD5
1	x	x	x	x	x	x	x	User-defined Authentication Algorithm Group (the value of bits 1-7 is user defined)

OUI (Octets x.4-x.6)

Note: If the authentication algorithm group is “user defined,” then the IEEE OUI of the vendor or user that assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Signature Algorithm Details (Octets x.7 through x.9 etc.)

This optional octet group is formatted the same as the Signature Algorithm Details of the Signature Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.4.

This octet group may be included once in each Authentication Algorithm Profile Group.

Hash Algorithm Details (Octets x.10 through x.12 etc.)

This optional octet group is formatted the same as the Hash Algorithm Details of the Hash Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.3.

This octet group may be included once in each Authentication Algorithm Profile Group.

7.2.3.8 Integrity Algorithm Profile Group

This octet group indicates a set of algorithms supporting integrity service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	0	1	1	1	0	
Integrity Algorithm Group Identifier								x.1
Length of Integrity Algorithm Group Contents								x.2
Integrity Algorithm Group								x.3
OUI								x.4* (Note)
OUI (continued)								x.5* (Note)
OUI (continued)								x.6* (Note)
1	0	1	1	0	1	1	0	
MAC Algorithm Details Identifier								x.7*
Length of MAC Algorithm Details								x.8*
MAC Algorithm Details								x.9 etc.*
1	0	1	1	0	0	1	0	
Signature Algorithm Details Identifier								x.10*
Length of Signature Algorithm Details								x.11*
Signature Algorithm Details								x.12 etc.*
1	0	1	1	1	0	0	0	
Key Exchange Algorithm Details Identifier								x.13*
Length of Key Exchange Algorithm Details								x.14*
Key Exchange Algorithm Details								x.15 etc.*
1	0	1	1	1	0	1	0	
Key Update Algorithm Details Identifier								x.16*
Length of Key Update Algorithm Details								x.17*
Key Update Algorithm Details								x.18 etc.*
1	0	1	1	0	1	0	0	
Hash Algorithm Details Identifier								x.19*
Length of Hash Algorithm Details								x.20*
Hash Algorithm Details								x.21 etc.*

Length of Integrity Algorithm Group Contents (Octet x.2)

A binary number indicating the length in octets of the integrity algorithm group fields contained in x.3, x.4, etc.

Integrity Algorithm Group (Octet x.3)

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	INTEG-1 MAC=DES/CBC Signature=RSA

	Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 0 0 1 0	INTEG-2 MAC=DES/CBC Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 0 0 1 1	INTEG-3 MAC=DES/CBC Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 0 1 0 0	INTEG-4 MAC=DES/CBC Signature=DES/CBC Key Exchange=DES/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 0 0 1 0 1	INTEG-5 MAC=HMD5 Signature=RSA Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 0 1 1 0	INTEG-6 MAC=HMD5 Signature=DES/CBC Key Exchange=DES/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 0 0 1 1 1	INTEG-7 MAC=HSHA-1 Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1

0 0 0 0 1 0 0 0	INTEG-8 MAC=HSHA-1 Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 1 0 0 1	INTEG-9 MAC=HSHA-1 Signature=DES/CBC Key Exchange=DES/CBC Key Update=SHA-1 Hash=Not Applicable
0 0 0 0 1 0 1 0	INTEG-10 MAC=FEAL/CBC Signature=ESIGN Key Exchange=DH Key Update=MD5 Hash=MD5
0 0 0 0 1 0 1 1	INTEG-11 MAC=FEAL/CBC Signature=FEAL/CBC Key Exchange=FEAL/CBC Key Update=MD5 Hash=Not Applicable
1 x x x x x x x	User-defined Authentication Algorithm Group (the value of bits 1-7 is user defined)

OUI (Octets x.4-x.6)

Note: If the integrity algorithm group is “user defined,” then the IEEE OUI of the vendor or user which assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

MAC Algorithm Details (Octet x.7 through x.9 etc.)

This optional octet group is formatted the same as the Data Integrity Algorithm Details of the Data Integrity Algorithm octet groups defined in octet x.7 etc. in Section 7.2.3.2.

This octet group may be included once in each Integrity Algorithm Profile Group.

Signature Algorithm Details (Octets x.10 through x.12 etc.)

This optional octet group is formatted the same as the Signature Algorithm Details of the Signature Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.4.

This octet group may be included once in each Integrity Algorithm Profile Group.

Key Exchange Algorithm Details (Octets x.13 through x.15 etc.)

This optional octet group is formatted the same as the Key Exchange Algorithm Details of the Key Exchange Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.5.

This octet group may be included once in each Integrity Algorithm Profile Group.

Key Update Algorithm Details (Octets x.16 through x.18 etc.)

This optional octet group is formatted the same as the Session Key Update Algorithm Details of the Session Key Update Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.6.

This octet group may be included once in each Integrity Algorithm Profile Group.

Hash Algorithm Details (Octets x.19 through x.21etc.)

This optional octet group is formatted the same as the Hash Algorithm Details of the Hash Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.3.

This octet group may be included once in each Integrity Algorithm Profile Group.

7.2.3.9 Confidentiality Algorithm Profile Group

This octet group indicates a set of algorithms supporting confidentiality service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	0	1	1	0	0	0	0	
Confidentiality Algorithm Group Identifier								x.1
Length of Confidentiality Algorithm Group Contents								x.2
Confidentiality Algorithm Group								x.3
OUI								x.4* (Note)
OUI (continued)								x.5* (Note)
OUI (continued)								x.6* (Note)
1	0	1	1	1	1	1	0	
Encryption Algorithm Details Identifier								x.7*
Length of Encryption Algorithm Details								x.8*
Encryption Algorithm Details								x.9 etc.*
1	0	1	1	0	0	1	0	
Signature Algorithm Details Identifier								x.10*
Length of Signature Algorithm Details								x.11*
Signature Algorithm Details								x.12 etc.*
1	0	1	1	1	0	0	0	
Key Exchange Algorithm Details Identifier								x.13*
Length of Key Exchange Algorithm Details								x.14*
Key Exchange Algorithm Details								x.15 etc.*
1	0	1	1	1	0	1	0	
Key Update Algorithm Details Identifier								x.16*
Length of Key Update Algorithm Details								x.17*
Key Update Algorithm Details								x.18 etc.*
1	0	1	1	0	1	0	0	
Hash Algorithm Details Identifier								x.19*
Length of Hash Algorithm Details								x.20*
Hash Algorithm Details								x.21 etc.*

Length of Confidentiality Algorithm Group Contents (Octet x.2)

A binary number indicating the length in octets of the confidentiality algorithm group fields contained in x.3, x.4, etc.

Confidentiality Algorithm Group (Octet x.3)

8 7 6 5 4 3 2 1	**Meaning**
0 0 0 0 0 0 0 1	CONF-1 Encryption=DES/CBC Signature=RSA Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 0 0 1 0	CONF-2

	Encryption=DES/CBC Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 0 0 1 1	CONF-3 Encryption=DES/CBC Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 0 1 0 0	CONF-4 Encryption=DES/CBC Signature=DES/CBC Key Exchange=DES/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 0 0 1 0 1	CONF-5 Encryption=DES/Counter Signature=RSA Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 0 1 1 0	CONF-6 Encryption=DES/Counter Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 0 1 1 1	CONF-7 Encryption=DES/Counter Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 1 0 0 0	CONF-8 Encryption=DES/Counter Signature=DES /CBC Key Exchange=DES /CBC Key Update=MD5

	Hash=Not Applicable
0 0 0 0 1 0 0 1	CONF-9 Encryption=Triple-DES/CBC Signature=RSA Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 1 0 1 0	CONF-10 Encryption=Triple-DES/CBC Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 1 0 1 1	CONF-11 Encryption=Triple-DES/CBC Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 1 1 0 0	CONF-12 Encryption=Triple-DES/CBC Signature= Triple-DES/CBC Key Exchange= Triple-DES/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 0 1 1 0 1	CONF-13 Encryption=Triple-DES/Counter Signature=RSA Key Exchange=RSA Key Update=MD5 Hash=MD5
0 0 0 0 1 1 1 0	CONF-14 Encryption=Triple-DES/Counter Signature=DSA Key Exchange=DH Key Update=SHA-1 Hash=SHA-1
0 0 0 0 1 1 1 1	CONF-15 Encryption=Triple-DES/Counter

	Signature=EC/DSA Key Exchange=EC/DH Key Update=SHA-1 Hash=SHA-1
0 0 0 1 0 0 0 0	CONF-16 Encryption=Triple-DES/Counter Signature= Triple-DES/CBC Key Exchange= Triple-DES/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 1 0 0 0 1	CONF-17 Encryption=FEAL/CBC Signature=ESIGN Key Exchange=DH Key Update=MD5 Hash=MD5
0 0 0 1 0 0 1 0	CONF-18 Ecryption=FEAL/CBC Signature=FEAL/CBC Key Exchange=FEAL/CBC Key Update=MD5 Hash=Not Applicable
0 0 0 1 0 0 1 1	CONF-19 Encryption=FEAL/Counter Signature=ESIGN Key Exchange=DH Key Update=MD5 Hash=MD5
0 0 0 1 0 1 0 0	CONF-20 Encryption=FEAL/Counter Signature=FEAL/CBC Key Exchange=FEAL/CBC Key Update=MD5 Hash=Not Applicable
1 x x x x x x x	User-defined Authentication Algorithm Group (the value of bits 1-7 is user defined)

OUI (Octets x.4-x.6)

Note: If the confidentiality algorithm group is "user defined," then the IEEE OUI of the vendor or user which assigned the user-defined codepoint shall be included in these octets. Otherwise, these octets are not included.

Encryption Algorithm Details (Octets x.7 through x.9 etc.)

This optional octet group is formatted the same as the Data Confidentiality Algorithm Details and Data Confidentiality Mode Details of the Data Confidentiality Algorithm octet group defined in octets x.11 etc. and x.12 etc. in Section 7.2.3.1.

This octet group may be included once in each Confidentiality Algorithm Profile Group.

Signature Algorithm Details (Octets x.10 through x.12 etc.)

This optional octet group is formatted the same as the Signature Algorithm Details of the Signature Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.4.

This octet group may be included once in each Confidentiality Algorithm Profile Group.

Key Exchange Algorithm Details (Octets x.13 through x.15 etc.)

This optional octet group is formatted the same as the Key Exchange Algorithm Details of the Key Exchange Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.5.

This octet group may be included once in each Confidentiality Algorithm Profile Group.

Key Update Algorithm Details (Octets x.16 through x.18 etc.)

This optional octet group is formatted the same as the Session Key Update Algorithm Details of the Sesion Key Update Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.6.

This octet group may be included once in each Confidentiality Algorithm Profile Group.

Hash Algorithm Details (Octets x.19 through x.21 etc.)

This optional octet group is formatted the same as the Hash Algorithm Details of the Hash Algorithm octet group defined in octet x.7 etc. in Section 7.2.3.3.

This octet group may be included once in each Confidentiality Algorithm Profile Group.

7.3 Confidential Parameters Section

The confidential parameters section provides for the exchange of confidential information in the SME. This optional section provides an opportunity to include encrypted data in an SAS.

Bits								
8	7	6	5	4	3	2	1	Octets
1	1	0	0	0	0	0	0	
Confidential Parameters Section Identifier								x.1
Length of Confidential Parameters Section								x.2
Length of Confidential Parameters Section (cont.)								x.3
Confidential Data								x.4 etc

Length of Confidential Parameters Section (Octet x.2, x.3)

This 16-bit octet group provides the length of the Confidential ParametersSection. This is the length of the ciphertext, which may not be the same as the plaintext.

Confidential Data (Octet x.4 etc.)

This Octet group contains encrypted data that requires decryption in order to be meaningful to the security agent. In the SME, this is the encryption of the Confidential Parameters defined in Section 7.3.1, using the key exchange algorithm referenced by the SAS identifier.

7.3.1 Confidential Parameters

The Security Message Exchange Protocol supports the exchange of confidentiality parameters. This is the original confidential parameters section.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	0	0	1	0	0	
Confidential Parameters Identifier								x.1
Master Key								x.2 etc
First Data Confidentiality Session Key								x.3 etc
First Data Integrity Session Key								x.4 etc

Master Key (Octet x.2 etc. Optional)

This octet group provides the Master Key for the cryptographic services. It contains the identifier, length, and value as defined in octets x.1, x.2, and x.3 etc. in Section 7.3.2. Further details on the use of this key can be found in Section 0.

First Data Confidentiality Session Key (Octet x.3 etc. Optional)

This field contains the initial Data Confidentiality Session Key. It contains the identifier, length, and value as defined in octets x.1, x.2, and x.3 etc. in Section 7.3.3. Further details on the use of this key can be found in Section 5.2.4.

First Data Integrity Session Key (Octet x.4 etc. Optional)

This field contains the initial Data Integrity Session Key. It contains the identifier, length, and value as defined in octets x.1, x.2, and x.3 etc. in Section 7.3.4. Further details on the use of this key can be found in Section 5.2.4.

7.3.2 Master Key

This octet group contains one party's contribution to the key used to encrypt subsequent session keys.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	0	1	0	0	0	
Master Key Identifier								x.1
Length of Master Key								x.2
Master Key Value								x.3 etc.

Master Key Length (Octet x.2)

A binary number indicating the length in octets of the Master Key value contained in octets x.3, etc.

Master Key Value (Octet x.3 etc.)

This field contains the binary encoding of the Master Key value, with bit 8 of the first octet being the most significant bit, and bit 1 of the last octet being the least significant bit. The Master Key length must be an integer multiple of 8 bits.

7.3.3 First Data Confidentiality Session Key

This octet group contains the first session key to be used to provide the data confidentiality service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	0	1	0	1	0	
First Data Confidentiality Session Key Identifier								x.1
Length of First Data Confidentiality Session Key								x.2
First Data Confidentiality Session Key Value								x.3 etc.

First Data Confidentiality Session Key Length (Octet x.2)

A binary number indicating the length in octets of the First Data Confidentiality Session Key Value contained in octets x.3, etc.

First Data Confidentiality Session Key Value (Octet x.3 etc.)

This field contains the binary encoding of The First Data Confidentiality Session Key Value, with bit 8 of the first octet being the most significant bit, and bit 1 of the last octet being the least significant bit. The First Data

Confidentiality Session Key length must be an integer multiple of 8 bits. Algorithm-specific details for this field are as follows:

⇒ When the data confidentiality algorithm is DES with 56-bit effective key, the 64-bit (8-octet) key value (which includes parity) is encoded in binary in this field.

⇒ When the data confidentiality algorithm is Triple-DES with keying option 2 [7], the 128-bit (16-octet) key value (which includes parity) is encoded in binary in this field as follows: The "first key" is encoded in binary in octets x.3 through x.10 and the "second key" is encoded in binary in octets x.11 through x.18 of this field.

⇒ When the data confidentiality algorithm is FEAL with 64-bit effective key, the 64-bit (8-octet) key is encoded in binary in this field.

7.3.4 First Data Integrity Session Key

This octet group contains the first session key to be used to provide the data integrity service.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	0	1	1	0	0	
First Data Integrity Session Key Identifier								x.1
Length of First Data Integrity Session Key								x.2
First Data Integrity Session Key Value								x.3 etc.

First Data Integrity Session Key Length (Octet x.2)

A binary number indicating the length in octets of the First Data Integrity Session Key value contained in octets x.3, etc.

First Data Integrity Session Key Value (Octet x.3 etc.)

This field contains the binary encoding of the First Data Integrity Session Key value, with bit 8 of the first octet being the most significant bit, and bit 1 of the last octet being the least significant bit. The First Data Integrity Session Key length must be an integer multiple of 8 bits.

7.4 Authentication Section

This octet group specifies the SAS Authentication Section. This section is intended to support authentication as specified in the Security Message Exchange Protocol. However, the design provides a generic authentication service that can be applied to any part of the SSIE. All octet groups of this section are optional and may be included in any order, except that the SAS Digital Signature, if present, shall be last. Each octet group may be included no more than once.

The specified digital signature type determines the digital signature's scope. When used in the Security Message Exchange Protocol, the digital signature must be a Security Message Exchange Digital Signature.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	0	0	0	0	
Authentication Section Identifier								x.1
Initiator Random Number								x.2 etc
Responder Random Number								x.3 etc
Time Variant Time Stamp								x.4 etc
Credentials								x.5 etc
Security Message Exchange Digital Signature								x.6 etc
SAS Digital Signature								x.7 etc

Initiator Random Number (Octet x.2 etc Optional)

This section provides the initiator supplied nonce, if provided in the exchange. Further details on the format and use of this field are found below.

Responder Random Number (Octet x.3 etc Optional)

This section provides the responder supplied nonce, if provided in the exchange. Further details on the format and use of this field are found below.

Time Variant Time Stamp (Octet x.4 etc Optional)

This section specifies a unique time stamp/sequence number that will provide replay protection. Further details on the format and use of this field are found below.

Credentials (Octet x.5 etc Optional.)

This section is employed when credential presentation or exchange is required in the Security Message Exchange. Further details on using this field are found below.

Security Message Exchange Digital Signature (Octet x.6 etc optional)

This section contains the Security Message Exchange Digital Signature as described in Section 7.4.5.

SAS Digital Signature (Octet x.7 etc optional)

This section contains the SAS Digital Signature as described in Section 7.4.6.

7.4.1 Initiator Random Number (Nonce)

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	0	1	0	0	
Initiator Random Number Identifier								x.1
Initiator Random Number Value								x.2
Initiator Random Number Value (cont.)								x.3
Initiator Random Number Value (cont.)								x.4
Initiator Random Number Value (cont.)								x.5

Initiator Random Number Value(Octet x.2-5)

This field is a 32-bit binary random number.

7.4.2 Responder Random Number (Nonce)

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	0	1	0	1	
Responder Random Number Identifier								x.1
Responder Random Number Value								x.2
Responder Random Number Value (cont.)								x.3
Responder Random Number Value (cont.)								x.4
Responder Random Number Value (cont.)								x.5

Responder Random Number Value (Octet x.2-5)

This field is a 32-bit binary random number.

7.4.3 Time-Variant Time Stamp

This field, combined with the identity of the assigning security agent, provides a label that can be used as a unique identifier for a given SAS used in an authentication exchange. This field consists of two 32-bit (four octet) integers, one for the time stamp (with one second resolution), and the other for a sequence number that within each time interval starts at zero and is increased by one each time it is used. The time stamp shall be encoded in Octets x.2 - x.5, and the sequence number shall be encoded in Octets x.6 - x.9. Each of these integers are encoded as 32-bit unsigned binary integers, with bit 8 of the first octet being the most significant bit, and bit 1 of the fourth octet being the least significant bit. For further details on using this field, consult Sections 5.1 and 5.1.1.2.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	0	1	1	0	
Time-Variant Time Stamp Identifier								x.1
Time Stamp Value								x.2
Time Stamp Value (cont.)								x.3
Time Stamp Value (cont.)								x.4
Time Stamp Value (cont.)								x.5
Sequence Number								x.6
Sequence Number (cont.)								x.7
Sequence Number (cont.)								x.8
Sequence Number (cont.)								x.9

Time Stamp Value (Octet x.2-5)

The time stamp value is a 4-octet coordinated universal time, the Greenwich Mean Time (GMT) at which the signature was generated. This value is the binary encoding of the number of seconds since 00:00:00 GMT on January 1, 1970 (same as UNIX time). This is encoded in binary in octets x.2 through x.5.

Sequence Number (Octet x.6-9)

The sequence number is a 4-octet binary number that is incremented with each authentication flow that is sent to the same destination with the same time stamp value. When the time stamp value changes, the sequence number is reset to 0. The sequence number value is encoded in binary in octets x.6 through x.9.

7.4.4 Credentials

Certificate exchange is an optional feature of the Security Message Exchange Protocol, and is in general, a credential presentation feature. User defined credential types may contain a complete set of security services, and as such, additional authentication sections, such as time stamps, random numbers, and signatures, may not be required in the authentication process.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	1	0	0	0	
Credential Identifier								x.1
Length of Credential Contents								x.2
Length of Credential Contents (cont.)								x.3
Credential Type								x.4
Credential Value								x.5 etc.

Length of Credential Contents (Octets x.2 - 3):

The overall length of the SSIE limits maximum length of the credential, when signaling channel is used for certificate exchange

Credential Type (Octet x.3):

8	7	6	5	4	3	2	1	**Meaning**
0	0	0	0	0	0	0	1	X.509 Certificate V1
0	0	0	0	0	0	1	0	X.509 Certificate V2
0	0	0	0	0	0	1	1	X.509 Certificate V3
1	x	x	x	x	x	x	x	User defined credential type. (the value of bits 1-7 is user-defined)

Credential Value (Octet x.4 etc.):

This field contains the binary encoding of the credentials value, the format of which conforms to the type specified in Octet x.3.

7.4.5 Security Message Exchange Digital Signature

This octet group contains the signature value computed over the objects required by the Security Message Exchange Protocol. The signature algorithm is specified in other sections of the SSIE SAS. The length is the length of the entire octet group, excluding the identifier and the length octets.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	1	0	1	0	
Security Message Exchange Digital Signature Identifier								x.1
Security Message Exchange Digital Signature Length								x.2
Digital Signature Value								x.3 etc.

Security Message Exchange Digital Signature Length (Octet x.2)

A binary number indicating the length in octets of the digital signature value contained in octets x.3 etc.

Security Message Exchange Digital Signature Value (Octet x.3 etc.)

This field contains the binary encoding of the signature value. This is signature algorithm specific and both security agents in the SME must know the signature algorithm used. Further details on constructing the digital signature buffer and calculating this field are found in the following sections.

Algorithm-specific details for the signature are described below:

⇒ When the signature algorithm is RSA, this field contains the octet string representation of the digital signature.

⇒ When the signature algorithm is DSA, the two digital signature components R and S are encoded as octet strings in this field as follows:

DSA "R" parameter identifier (Octet x.3a):

This octet is the identifier for the R component of the DSA digital signature.

8 7 6 5 4 3 2 1 **Meaning**

0	0	0	0	0	0	0	1	R Parameter

DSA "R" parameter length (Octet x.3b):

This octet specifies the length of R in octets.

DSA "R" parameter value (Octet x.3c etc.):

This field contains the octet string representation of R.

DSA "S" parameter identifier (Octet x.4a):

This octet is the identifier for the S component of the DSA digital signature.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	0	S Parameter

DSA "S" parameter length (Octet x.4b):

This octet specifies the length of S in octets.

DSA "S" parameter value (Octet x.4c etc.):

This field contains the octet string representation of S.

⇒ When the signature algorithm is ESIGN, the digital signature component *S* is encoded as octet strings in this field as follows:

ESIGN "S" parameter identifier (Octet x.3a):

This octet is the identifier for the ESIGN digital signature S.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	S Parameter

ESIGN "S" parameter length (Octet x.3b):

This octet specifies the length of S in octets.

ESIGN "S" parameter value (Octet x.3c etc.):

This field contains the octet string representation of S.

⇒ When the signature algorithm is Elliptic Curve Digital Signature Algorithm (EC-GDSA), the two integers *r* and *s* are encoded as octet strings in this field as follows (cf. Section 8.7.3):

EC-GDSA "*r*" parameter identifier (Octet x.3a):

This octet is the identifier for the *r* component of the EC-GDSA digital signature.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	0	1	*r* Parameter

EC-GDSA "*r*" parameter length (Octet x.3b):

This octet specifies the length of *r* in octets.

EC-GDSA "*r*" parameter value (Octet x.3c etc.):

This field contains the octet string representation of *r*.

EC-GDSA "*s*" parameter identifier (Octet x.4a):

This octet is the identifier for the *s* component of the EC-GDSA digital signature.

8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Meaning**
0	0	0	0	0	0	1	0	*s* Parameter

EC-GDSA "*s*" parameter length (Octet x.4b):

This octet specifies the length of *s* in octets.

EC-GDSA "*s*" parameter value (Octet x.4c etc.):

This field contains the octet string representation of *s*.

7.4.5.1 Digital Signature Calculation–Two-Way Exchange Protocol

The contents and structure of the data to be hashed for the Digital Signature for Flow-1 and Flow-2 of the Two-Way Security Message Exchange Protocol are defined below.

7.4.5.1.1 FLOW1-2WE

For FLOW1-2WE, the SME Digital Signature octet group contains the digital signature as defined in Section 5.1.1.2, and reproduced below:

$$Sig_{Ka}(Hash(A, B, T_a, R_a, SecOpt, \{ConfPar_a\}))$$

In order to calculate this signature, the hash value is calculated across the octet groups shown in Table 12 in the order listed. Bit ordering within each octet is identical to the bit ordering within the respective octets of the Security Services Information Element. In addition, this buffer is padded according to the appropriate hash algorithm procedures.

Table 12: Digital Signature Buffer for FLOW1-2WE.

Symbol	Description of Octet Group	Octets	Refer to Section
A	Initiator Distinguished Name	X.1 - X.4, etc.	7.1.1
B	Responder Distinguished Name	X.1 - X.4, etc	7.1.2
T_a	Time-Variant Time Stamp	X.1 - X.9	7.4.3
R_a	Initiator Random Number	X.1 - X.5	7.4.1
SecOpt	Security Service Specification Section	X.1, X.2, etc., X.3, etc.	7.2
{$ConfPar_a$}	Confidential Parameters (Note)	X.1, X.2, etc., X.3, etc., X.4, etc	7.3.1

Note: If this octet group is present, the hash function operates on the *plaintext* data. That is, the confidential parameters as they exist either before encryption without any padding (if the digital signature is generated by the sending agent), or after decryption after removal of any padding (if the digital signature is validated by the receiving agent).

7.4.5.1.2 FLOW2-2WE

For FLOW2-2WE, the SME Digital Signature octet group contains the digital signature as defined in Section 5.1.1.2, and reproduced below:

$$Sig_{Kb}(Hash(A, B, R_a, \{ConfPar_b\}))$$

In order to calculate this signature, the hash value is calculated across the octet groups shown in Table 13 in the order listed. Bit ordering within each octet is identical to the bit ordering within the respective octet of the Security Services Information Element. In addition, this buffer is padded according to the appropriate hash algorithm procedures.

Table 13: Digital Signature Buffer for FLOW2-2WE.

Symbol	Description of Octet Group	Octets	Refer to Section
A	Initiator Distinguished Name	X.1 - X.4, etc.	7.1.1
B	Responder Distinguished Name	X.1 - X.4, etc	7.1.2
R_a	Initiator Random Number	X.1 - X.5	7.4.1 (Note 1)
{$ConfPar_b$}	Confidential Parameters (Note 2)	X.1, X.2, etc., X.3, etc., X.4, etc	7.3.1

Note 1: These octets are received from the initiator in FLOW1-2WE.

Note 2: If this octet group is present, the hash function operates on the *plaintext* data. That is, the confidential parameters as they exist either before encryption without any padding (if the digital signature is generated by the sending agent), or after decryption after removal of any padding (if the digital signature is validated by the receiving agent).

7.4.5.2 Digital Signature Buffer–Three-Way Exchange Protocol

The contents and structure of the data to be hashed for the Digital Signature for Flow-2 and Flow-3 of the Three-Way Security Message Exchange Protocol are defined below.

7.4.5.2.1 FLOW2-3WE

For FLOW2-3WE, the SME Digital Signature octet group contains the digital signature as defined in Section 5.1.1.1, and reproduced below:

$$Sig_{Kb}(Hash(A, B, R_a, R_b, SecNeg_a, SecNeg_b, \{ConfPar_b\}))$$

In order to calculate this signature, the hash value is calculated across the octet groups shown in Table 14 in the order listed. Bit ordering within each octet is identical to the bit ordering within the respective octet of the Security Services Information Element. In addition, this buffer is padded according to the appropriate hash algorithm procedures.

Table 14: Digital Signature Buffer for FLOW2-3WE.

Symbol	Description of Octet Group	Octets	Refer to Section
A	Initiator Distinguished Name	X.1 - X.4, etc.	7.1.1
B	Responder Distinguished Name	X.1 - X.4, etc	7.1.2
R_a	Initiator Random Number	X.1 - X.5	7.4.1 (Note 1)
R_b	Responder Random Number	X.1 - X.5	7.4.2
$SecNeg_a$	Security Service Specification Section	X.1, X.2, etc., X.3, etc.	7.2 (Note 2)
$SecNeg_b$	Security Service Specification Section	X.1, X.2, etc., X.3, etc.	7.2
{$ConfPar_b$}	Confidential Parameters (Note 3)	X.1, X.2, etc., X.3, etc., X.4, etc	7.3.1

Note 1: These octets are received from the initiator in FLOW1-3WE.

Note 2: These octets are received from the initiator in FLOW1-3WE, and are not sent in FLOW2-3WE.

Note 3: If this octet group is present, the hash function operates on the *plaintext* data. That is, the confidential parameters as they exist either before encryption without any padding (if the digital signature is generated by the sending agent), or after decryption after removal of any padding (if the digital signature is validated by the receiving agent).

7.4.5.2.2 FLOW3-3WE

For FLOW3-3WE, the SME Digital Signature octet group contains the SME digital signature as defined in Section 5.1.1.1, and reproduced below:

$$Sig_{Ka}(Hash(A, B, R_b, \{ConfPar_a\}))$$

In order to calculate this signature, the hash value is calculated across the octet groups shown in Table 15 in the order listed. Bit ordering within each octet is identical to the bit ordering within the respective octet of the Security Services Information Element. In addition, this buffer is padded according to the appropriate hash algorithm procedures.

Table 15: Digital Signature Buffer for FLOW3-3WE.

Symbol	Description of Octet Group	Octets	Refer to Section
A	Initiator Distinguished Name	X.1 - X.4, etc.	7.1.1
B	Responder Distinguished Name	X.1 - X.4, etc	7.1.2
R_b	Responder Random Number	X.1 - X.5	7.4.2 (Note 1)
{$ConfPar_a$}	Confidential Parameters (Note 2)	X.1, X.2, etc., X.3, etc., X.4, etc	7.3.1

Note 1: These octets are received from the responder in FLOW2-3WE.

Note 2: If this octet group is present, the hash function operates on the *plaintext* field. That is, the confidential parameters as they exist either before encryption without any padding (if the digital signature is generated by the sending agent), or after decryption after removal of any padding (if the digital signature is validated by the receiving agent).

7.4.6 SAS Digital Signature

This octet group contains a digital signature computed over an SAS, using a value of '00' in the transport indicator field for the purpose of this signature calculation. The digital signature value is computed over the entire contents of the SAS, up to, but not including, the signature itself. An SAS can contain at most one SAS digital signature.

Bits								
8	7	6	5	4	3	2	1	Octet(s)
1	1	0	1	1	1	0	0	
SAS Digital Signature Identifier								x.1
Length of Digital Signature Contents								x.2
Length of Digital Signature Contents (cont.)								x.3
Digital Signature Value								x.4 etc.

Digital Signature Length (Octet x.2-3)

A binary number indicating the length in octets of the digital signature value contained in octet group x.4, etc.

Digital Signature Value (Octet x.4 etc.)

This field contains the binary encoding of the signature value. The signature is computed over the encoded contents of this Security Association Section (excluding this digital signature octet group). The contents of this SAS must remain intact as this SSIE (and SAS) travels through the network. That is, the network must not change or reorder the contents of this SAS.

The algorithm-specific details for the SAS Digital Signature Value are identical to those for the SME Digital Signature Value, found in Section 7.4.5.

8 Cryptographic Procedures

8.1 Symmetric Encryption Bit Ordering

8.1.1 Bit Ordering for Data

The ATM layer encryption process is used to encrypt the 48 payload octets contained in user cells. The 48 payload octets are numbered 6 to 53, and within an octet the bits are numbered 8 to 1 (from high to low order) with bit 8 transmitted first, as defined in the ITU-T I.361 [35]. The DES and triple DES standard [7] and FEAL standard [28], [29], define 64 bit input and output data blocks, with the bits numbered 1 to 64 (from high order to low order). Each ATM cell payload contains 384 bits, and hence must be divided into 6 equal blocks of 64 bits to perform the encryption.

The mapping of the bits from the cell payload into the encryption algorithm and the mapping of the encrypted data back into the cell payload shall be as follows: The first 8 octets of the cell payload (cell octets 6-13) form the first block for encryption with bit 8 of octet 6 becoming bit 1 of the first encryption block. The result of the block encryption is mapped back into the same octets 6-13 of the cell. This is shown in Figure 38. This process continues with each successive 8 octets of the cell.

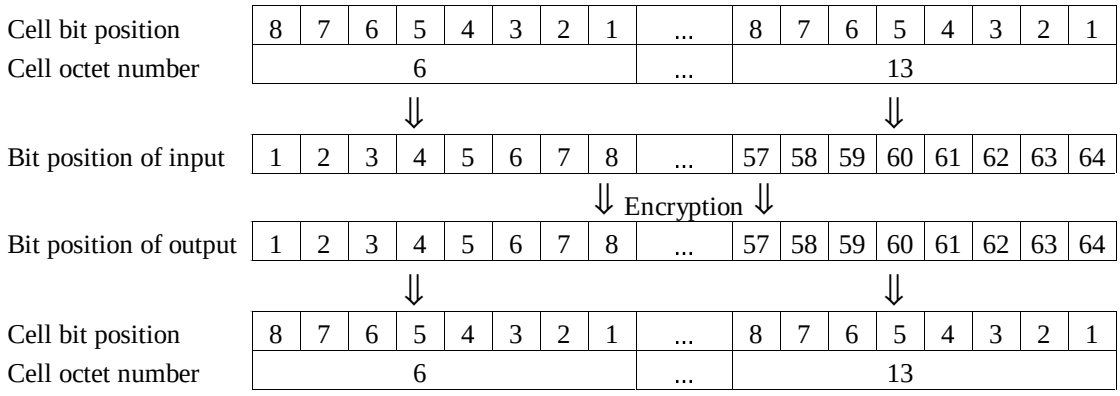


Figure 38: SymmetricEncryption Algorithm Data Bit Ordering.

8.1.1.1 The Effect of the Mode of Operation

The mapping indicated above applies directly to the ECB mode of operation. For CBC mode it is intended that the first ciphertext output bit (Bit position 1) be *xor*ed with the highest-order payload bit (bit 8 of payload octets 1, 9, ... 41). The result is sent back into the first input bit position (Bit position 1), and so on.

For the Counter Mode it is intended that the first output bit from the symmetric algorithm (Bit position 1) be *xor*ed with the highest-order payload bit (bit 8 of payload octets 1, 9, ... 41), with the result put back in the first payload bit, and so on. In addition, bit 63 of the state vector is input into bit position 1, bit 62 of the state vector into the bit position 2, and so on.

8.1.2 Bit Ordering for Keys

Encrypted session keys are transported in the Confidential Parameters Section during secure call setup, and in Session Key Exchange OAM cells for key updates. When using DES or FEAL, this key is 64 bits. When using triple DES, this key is 128 bits. The use of the DES parity bits after transport is implementation specific, and is not defined here.

The mapping of keys from either an Information Element, or an SKE OAM cell, shall be as shown in Figure 39.

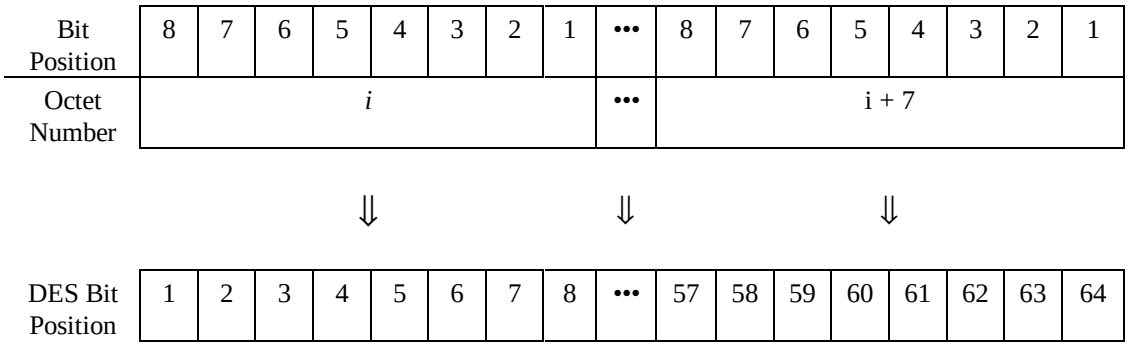


Figure 39: Symmetric Encryption Algorithm Key Bit Ordering.

Note: Octet number *i* represents the first octet of the key in either an information element or OAM cell.

8.2 The Counter Mode of Operation

8.2.1 Purpose

This version of the counter mode is intended for use with any 64-bit block encryption algorithm.

Block (or codebook) encryption algorithms are rarely used in a stand-alone fashion because they have several security weaknesses. The most serious is that patterns in the plaintext are not adequately concealed in the ciphertext. In addition it is possible to remove, duplicate, and interchange ciphertext without detection. Typically some form of a feedback mechanism, along with an exclusive OR operation, is used to overcome these problems. The feedback information must be retained in memory at both the encryptor and decryptor, on a per connection basis.

The counter mode is well suited for use with ATM encryption. It provides an efficient implementation allowing it to scale to higher data rates than other modes, such as cipher block chaining. With the counter mode the feedback information can be updated and restored to memory in parallel with the encryption algorithm processing. Second, and perhaps more important, it allows multiple blocks of plaintext to be encrypted in parallel. For example, an entire 48-octet cell payload can be encrypted in one operation using 6 copies of the encryption algorithm (with a 64-bit block size). Because each of the 6 payload blocks is given a unique segment number, implementations that use the parallel encryption approach are completely interoperable with those that don't.

8.2.2 Description

In counter mode both the encryptor and decryptor are synchronously producing identical key stream, based on each end having identical State Vectors (SVs) feeding like-keyed encryption algorithms. This state vector, which is described in more detail in Section 8.2.6, consists of several fields that contain the

results from various counters and a Linear Recurring Sequence. This ensures that unique key stream values are used for each block that is encrypted.

Once the key stream value is determined, the encryptor XORs the key stream with the plaintext to produce ciphertext. Similarly, the decryptor XORs the key stream with the ciphertext to recover the original plaintext. A block diagram of this process is shown in Figure 40. Note that both the encryptor and decryptor use the encryption algorithm to "encrypt" the SV.

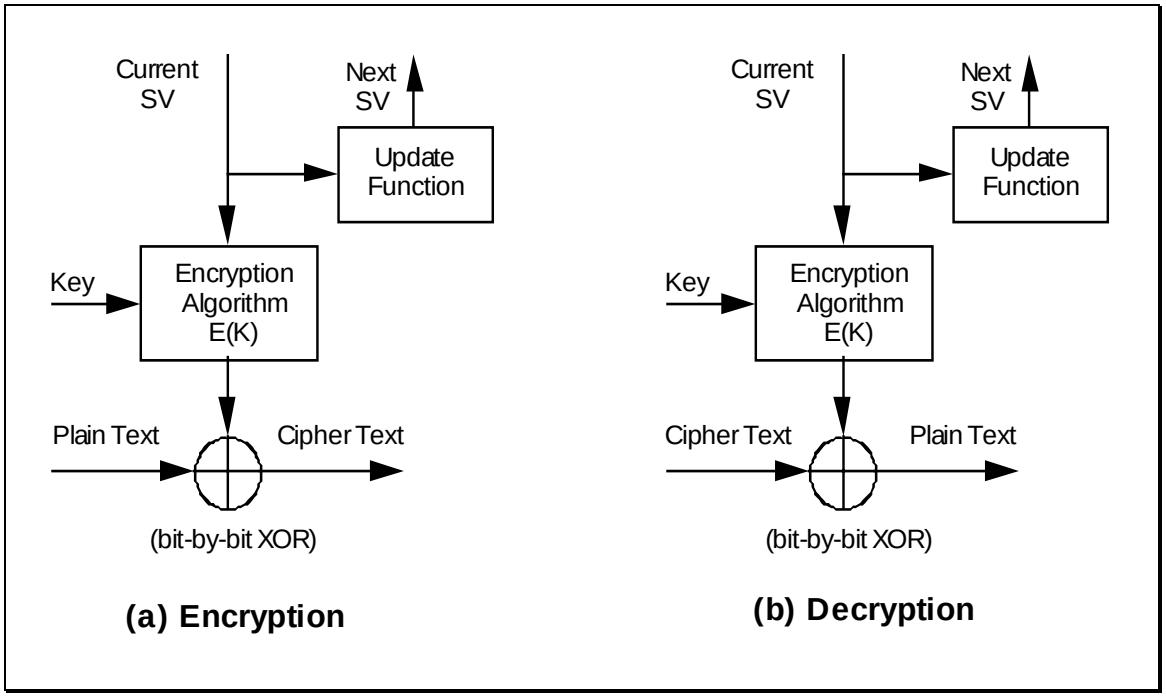


Figure 40: Counter Mode Block Diagram.

The SV must be changed on every new encryption; otherwise the generator will produce identical key streams. The definition of the SV, and the associated processing to update it, are described in later sections.

8.2.3 Properties

With the counter mode, cell loss in the ATM network causes the decryptor to lose cryptographic synchronization. The mechanisms for recovering synchronization are described in the following sections. The counter mode exhibits no error extension however, as a bit error in the ciphertext produces only a single bit error in the plaintext.

8.2.4 Cryptographic Synchronization

Cryptographic synchronization is maintained on a per connection basis. To recover from synchronization loss the decryptor must be provided with the same State Vector (SV) that the encryptor is using, for a particular connection. To accomplish this the encryptor transmits a resync message containing the new SV. The encryptor begins using the new SV on the very next cell to occur on that connection. The decryptor, upon receipt of the resync message, loads the new SV into its internal memory. Cell sequence integrity ensures that the next cell to arrive at the decryptor, on the connection in question, will correspond with the new SV.

8.2.4.1 SKC OAM Cell

The session key changeover cell defined in Section 5.1.7.2.2 shall be used for both key changeover and resynchronization. A key changeover occurs when the Bank ID and key number fields in the SKC OAM cell are different from those currently in use. For a resync cell they are the same. For the counter mode, it is permissible simply to change the Bank ID of the periodic resync SKC OAM cell processing to perform a key changeover (after the corresponding SKE processing is completed). If this approach is taken, no additional SKC OAM cells are required.

8.2.4.2 Encryptor Processing of SKC OAM Cells

It is the job of the encryptor to insert the SKC OAM cells periodically, at the rate sufficient to ensure required Quality of Service. A description of one method for determining the desired rate is given in Appendix I. This applies to both ends of a full duplex connection. A new SV is computed as follows (see Section 8.2.6 for a definition of the fields in the SV): the jump number is incremented, the I/R is set accordingly, the SEQ and SEG fields are set to all zeros. The LFSR is set to the default preset value, 05A5A hex. The new SV is loaded into internal memory and may also be loaded into the payload of the SKC OAM cell, although only the jump number is required. The encryptor shall set the other fields in the SV either to their default preset values or to all zeros. The CRC-10 is computed and inserted at the end of the cell. The new SV is used to encrypt the next incoming cell on that connection.

For the case of a key changeover, the encryptor may reset the jump number to any value, although zero is recommended. If multiple key changeover SKC OAM cells are transmitted, the jump number is reset for the first copy, and then incremented thereafter.

8.2.4.3 Decryptor Processing of SKC OAM Cells

Upon receipt of a SKC OAM cell the decryptor verifies that the CRC-10 is correct, and discards the cell if it is not. It also verifies that the jump number (see Section 8.2.6 for a definition of the fields in the SV) is greater than the current jump number in use on that connection, and discards the cell if it is not. An exception to this rule is made in the case of a key changeover. When the Bank ID and key number of an SKC OAM cell are different from those currently in use, any jump number is acceptable. If either the CRC-10 or jump number test fails, the decryptor discontinues processing the OAM cell. If both tests pass, it continues as follows. The decryptor sets the LFSR to the default preset value, 05A5A HEX. The I/R bit is unchanged, and the SEQ and SEG fields are set to all zeros. The decryptor loads the new jump number into its internal memory and begins using the new SV on the next incoming cell of that connection. The decryptor discards the SKC OAM cell, removing it from the cell stream.

8.2.5 Cell Loss Insensitivity

In some applications the performance of secure connections, in the presence of cell loss, may not be satisfactory. Depending on the AAL type information may be used to improve this performance. The AAL type of the connection is obtained during call establishment.

8.2.5.1 AAL1 and AAL3/4 Connections

Cells on AAL1 or AAL3/4 connections contain a 3 or 4 bit cell sequence number, respectively. This information is extracted from the cell payload and used as part of the SV. The LFSR is only updated when the sequence number of the received cell is less than or equal to the sequence number of the previous cell on that connection (i.e., the sequence number has wrapped around). It is held constant otherwise. Other than those cells where the sequence number wraps around, the only part of the SV that

changes is the sequence number extracted from the cell. This gives immunity to cell loss (up to the maximum size provided by the sequence number minus one, i.e., 7 for AAL1 and 15 for AAL3/4) by maintaining SV synchronization in the event of dropped cells.

The sequence number must be available from the ciphertext cell for this scheme to work. Therefore, this field is masked (i.e. excluded) from the XOR function that otherwise encrypts or decrypts the payload with key stream.

8.2.5.2 AAL5 Connections

AAL5 uses two specific values in the PTI field (i.e., PTI = 001 or 011) of the ATM cell header to indicate end-of-message cells. After encrypting or decrypting an end-of-message cell, the LFSR is preset to 05A5A hex, and the jump number is incremented. Thus, the process automatically resynchronizes at the beginning of each new packet, provided the end-of-message cell itself is not lost. Even though the cells after the lost cell(s) are decrypted incorrectly, no additional negative effects are seen by the user, since the AAL5 receive processing discards the entire packet anyway. This process improves the performance of the counter mode to be roughly identical to the self-synchronizing modes. If an end-of-message cell is lost, the SKC OAM cell will eventually resynchronize the decryptor.

8.2.6 State Vector (SV) Definition

The format of the 64 bit SV is shown in Figure 41. The definition of each of the fields follows.

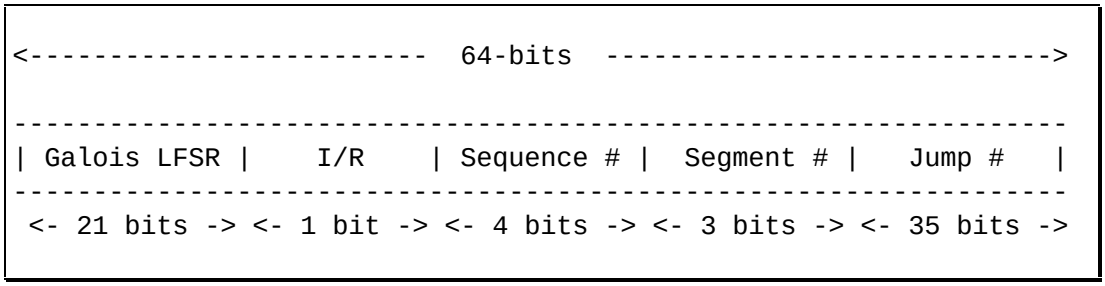


Figure 41: 64-Bit State Vector (SV) Definition.

8.2.6.1 Galois Linear Feedback Shift Register (LFSR)

The LFSR is a linear non-repeating sequence that is stepped once per cell or once per sequence of cells depending on AAL type. The LFSR is preset back to its starting value each time the connection is resynchronized. The maximum resync interval and the cell rate determine the 21-bit size of the LFSR. At 622 Mbps the maximum interval between resyncs should be 1 second. A full bandwidth connection at 622 Mbps produces roughly 1.4 million cells/sec. The LFSR, when clocked at the cell rate, must produce a non-repeating sequence longer than this. A 21-bit LFSR produces 2E21-1 = 2,097,151 unique values, satisfying this condition. The LFSR on a full bandwidth 622 Mbps connection would not repeat for 1.48 sec. To prevent LFSR wrap-around on higher bandwidth connections, the resync period should be proportionally shortened such that the number of cells sent during the maximum resync period is less than 2,097,151.

An LFSR must implement a primitive polynomial mod 2 in order to maximize its non-repeating sequence. Non-primitive polynomials will cause the LFSR to repeat at shorter intervals. From Schneier [37] Table 16.2, the polynomial xE21 + xE2 + 1 is selected and a Galois implementation of this polynomial is specified.

The Galois implementation is as shown in Figure 42. Bit 0 is the leftmost bit and the shift is to the left.

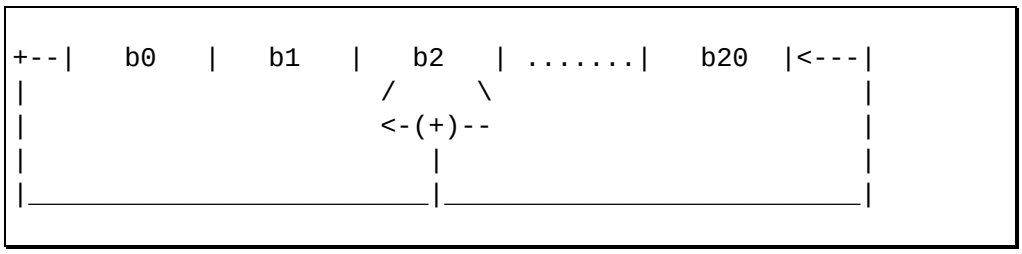


Figure 42: Galois LFSR.

The update algorithm for the Galois LFSR is defined as follows:

```
If b0 = 1 (SV negative):
  then
    flip b2 (XOR with pre-defined mask word)
    rotate left (shift left 1 bit) and set b20 to 1
  else
    rotate left (shift left 1 bit) and set b20 to 0
endif
```

8.2.6.1.1 LFSR Format in SV

The 21-bit LFSR field of the SV is the first 21 bits of the SV as shown in Figure 43.

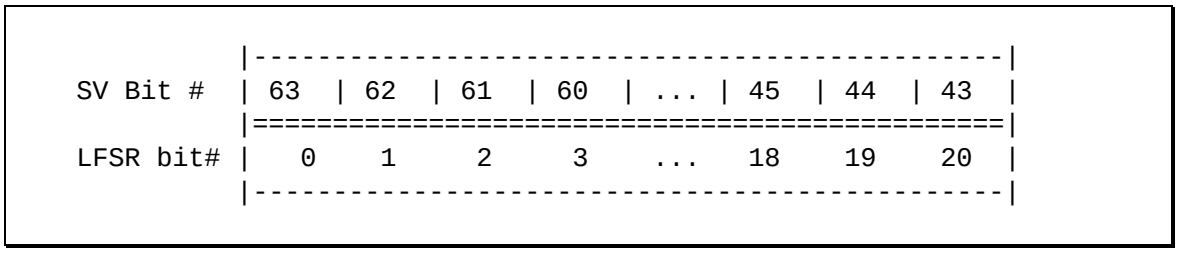


Figure 43: 21-Bit LFSR Format.

8.2.6.1.2 LFSR Processing

For AAL5 connection types the LFSR is updated (or clocked) once per cell, after the cell is encrypted or decrypted.

For AAL1 and AAL3/4 connections, the LFSR is updated (or clocked) each time the incoming cell sequence number (read from the cell) is less than or equal to the previous cell sequence number (stored in SV memory), on that connection. That is, each time a new cell sequence is detected. For this case the LFSR is updated (or clocked) before the cell is encrypted or decrypted.

The LFSR is initialized to a fixed value (0x05A5A) at the beginning of a connection (i.e., during call setup), and preset to that fixed value when a Secure Key Changeover (SKC) OAM cell is received. (SKC cells are sent to resync the connection.) For AAL5 connections the LFSR is also preset to 0x05A5A when an end-of-message cell is received.

Note that the preset value 0x05A5A is used to encrypt/decrypt the first cell in all cases. On AAL1 and AAL3/4 the "previous" sequence number is initialized to zero (in SV memory) so that the first incoming cell (with seq# = 1) does not update the LFSR.

In all cases, no action need be taken if the receiver's LFSR wraps-around. Because the encryptor's LFSR is always reset before it wraps, the receiver will experience an out-of-sync condition before its LFSR ever wraps around, and, once out-of-sync, LFSR wrap-around is of no significance to the receiver.

8.2.6.2 Initiator/Responder bit

Duplex connections may use the same key for traffic encryption in both directions. If both directions use the same SV then a response that enclosed the original message would have part of the ciphertext identical to the original message's ciphertext. To prevent such an occurrence, an initiator/responder bit is used in the SV. This forces the responder's key stream to be different so enclosing the original plaintext would produce different ciphertext. The I/R bit is set to one for cells flowing away from the calling party (initiator) toward the called party (responder), and set to zero in the opposite direction.

The I/R bit field of the SV is bit 42 as shown in Figure 44. Initiator = 1; Responder = 0.

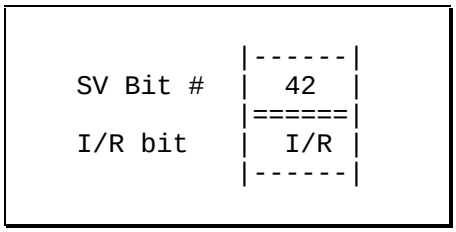


Figure 44: I/R Bit Format.

8.2.6.3 Sequence number

For AAL1 connections the most significant bit of the sequence number (bit 41) is set to zero. The remaining three bits are extracted from the sequence number within the payload of the cell.

For AAL3/4 connections the sequence number is extracted from the four bit sequence number in the payload of the cell. For all other connection types these four bits are set to all zeros.

The 4-bit sequence number field of the SV is bits 41-38 as shown in Figure 45. The MSB is the leftmost bit.

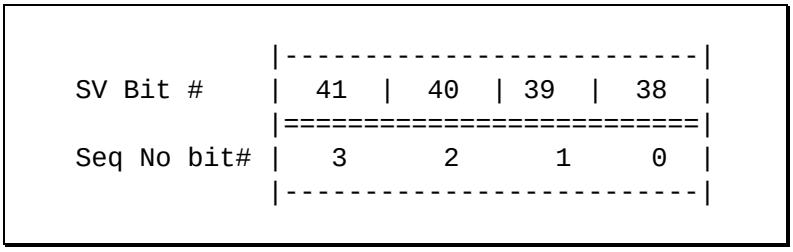


Figure 45: Sequence Number Bit Format.

8.2.6.4 Segment number

The 384-bit ATM cell payload is segmented into six 64-bit segments for encryption or decryption. The LFSR is held constant for the entire cell payload. The segment number is a 3-bit field that defines which 64-bit segment within the payload is being encrypted or decrypted. The segment number for the first 64 bit segment (i.e., octets 1-8 of the payload) is 000, followed by 001, and so on using a binary count through 101. The values 110 and 111 are not used. The format of the segment number in the SV is shown in Figure 46. The MSB is the leftmost bit.

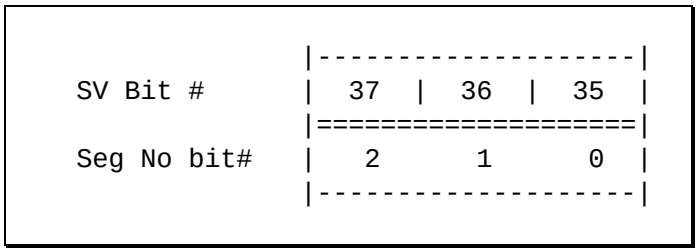


Figure 46: Segment Number Bit Format.

8.2.6.5 Jump Number

The jump number is initialized to all zeros at call setup time and incremented each time a resync SKC OAM cell is sent or, on AAL5 connections, with each end-of-message cell. A 35-bit jump number allows 2E35-1 or 3.44x10E+10 resyncs without repeating.

This ensures the SV is always unique so that repeating patterns in the plaintext will not show through in the ciphertext.

For example, a full bandwidth 622 Mbps connection (1,416,907 cells/sec), with a cell loss ratio of 10E-4, requires 1417 resyncs per second (10x the expected number of cells lost per second). At this rate the jump number won't repeat for 2.42x10E+07 seconds, about 280 days or 9 months. At this point in time, key stream will start to repeat. To avoid reusing key stream, the session key should be changed prior to the expiration of this period. The implementation should prevent Jump number wrap-around. A Jump number of all ones should be considered an error condition.

The format of the Jump number is shown in Figure 47. The MSB is on the left. The jump number is incremented as a binary count.

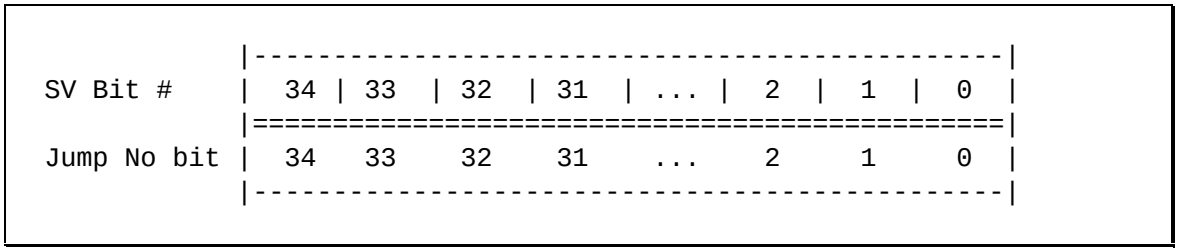


Figure 47: 35-Bit Jump Number Format.

Of the 64-bit SV, the jump number is the only field required to be transmitted to the receiver during a resync or key changeover. The other fields in the SV are preset to their default values.

When an SKC OAM cell is transmitted, the sender places its current Jump number in Octets 17-21 as shown below in Figure 48. The remaining bits (bits 4-8 in Octet 17 and Octets 14-16) are set to zero.

The receiver copies the Jump number from the SKC OAM cell into the SV for that connection only if the new Jump number is greater than the previous Jump number. SKC OAM cells containing Jump numbers less than or equal to the previous Jump number are rejected and this should be treated as an error condition.

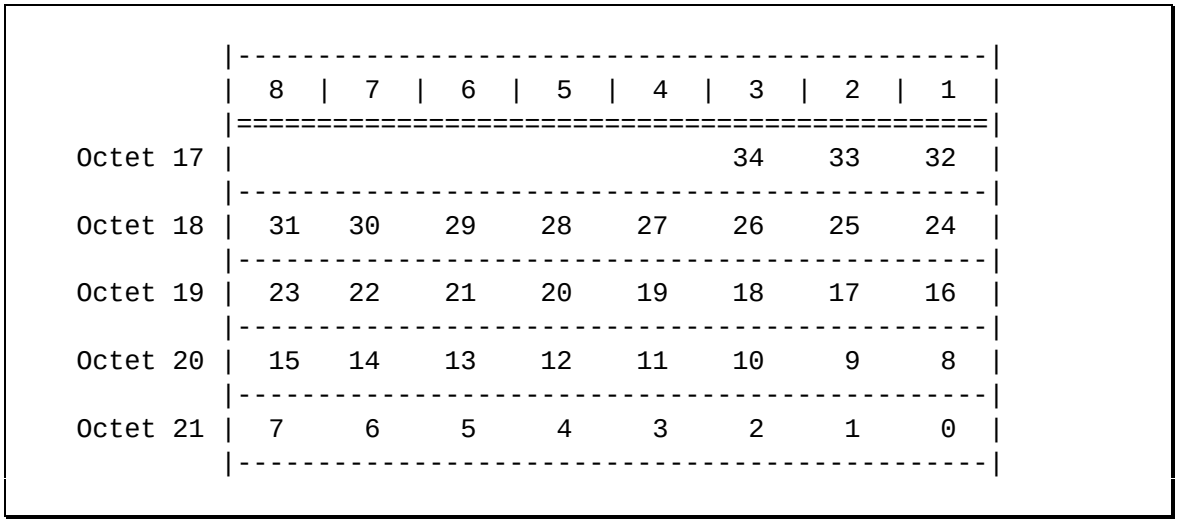


Figure 48: Jump Number Position within SKC OAM Cell.

8.2.7 Using the Counter Mode with Triple DES

When using Triple DES, or multiples of any encryption algorithm, the application of the counter mode must be clarified. It is intended that the counter be applied as follows:

Ciphertext = $E_{k1}(D_{k2}(E_{k1}(SV)))$ XOR plaintext

Plaintext = $E_{k1}(D_{k2}(E_{k1}(SV)))$ XOR ciphertext

8.3 Asymmetric Authentication Using ESIGN

8.3.1 Basic Procedure

Private Key:

p; a large prime number,

q; a large prime number ($p > q$).

Public Key:

$n = p^2 q$.

k; an integer ($4 \leq k$),

Signature Generating:

x; chosen at random ($0 \le x \le pq-1$),
d; the least integer that is larger or equal to
$|n|/3$ where $|n|$ is a bit length of n,
m; a input data to be signed ($m < n/2^{2d}$),
w; the least integer that is larger or equal to $(m\ 2^{2d} - (x^k \bmod n))/(pq)$,
$y = w/(k\ x^{k-1}) \bmod p$,
$S = x + ypq$,
$ESIGN_{(p, q)}(m)$ is defined by a value S.

Verifying:
$ESIGN_{(n, k)}(S)$ is defined as the upper d-bit value of $S^k \bmod n$. When $m' = ESIGN_{(n, k)}(S)$, accept (m', S) as valid if m' contains information which a verifier wants to verify.

Note : In normal case, accept (M, S) if $H' = H''$ where m' contains a hash value H' = Hash(M), and H'' = Hash(M) is newly generated from an original message M by a verifier.

8.3.2 Precomputation Procedure

ESIGN's basic procedure can be accelerated if the Signature Generating process is divided into two parts:

Signature Generating:
a) Precomputation
x; chosen at random ($0 \le x \le pq-1$),
$u = x^k \bmod n$,
$v = 1/(k\ x^{k-1}) \bmod p$.

b) Signing (accelerated)
w; the least integer that is larger or equal to $(m\ 2^{2d} - u)/(pq)$,
$y = wv \bmod p$,
$S = x + ypq$.

Even if one cannot determine an input data m, parameters u and v related to x can be computed separately. Just after selecting m, only the remaining part b) is calculated by using u and v. ESIGN can be accelerated to about ten times faster than the non-precomputation procedure. For example, if one uses a typical 8-bit microprocessor (f=5 MHz), a signature generation delay time can be reduced from about 0.4 s to 0.05 s where its precomputation delay is about 0.4 s.

8.3.3 Example

A small example for ESIGN is presented. Although the size of private keys (p, q) of ESIGN should be more than 170 bits, the example is useful to understand.

Private Key :(Note[1])

[1] Private key candidates for p, q can be easily checked by division by all prime numbers from 2 to their square roots, respectively. However, since the real candidates are larger than 100 bits, one must check them by using more efficient primality testing methods such as the Rabin method.

p = 1000033,
q = 1000003.

Public Key:
n = 1000069001287003267.

Signature Generating:
x = 878087808780,
k = 1024,
m = 641219,
w = 172197; the least integer that is larger or equal to
(641216 x 1099511627776 - (878087808780^{1024} *mod* 1000069001287003267))/10403
y = 172197/(1024 x 878087808780^{1023}) *mod* 1000033 = 49898, (Note[2])
S = 878087808780 + 49898 x 1000033 x 1000003 = 49900674420748682,
d = 20; the least integer that is larger or equal to $|n|/3$ where $|n|$
is a bit length 60.

Verifying:
Accept (m', S) as valid because the upper 20-bit value of $m' = S^k \bmod n$
= 49900674420748682^{1024} *mod* 1000069001287003267 = 705028336500982591
(= 10011100100011000011100010010110000110111001110000110011111 in binary representation) equals 641219 (= 10011100100011000011 in binary representation) = m''
where m'' contains information which a verifier wants to verify.

8.4 Block Cipher/CBC Mode Message Authentication Code

Another method for providing the MAC for AAL SDU data integrity is to use a block cipher in the cipher block chaining (CBC) mode of operation, which is described in detail in ISO/IEC 9797 [20]. Note that when this method is used for data integrity protection, the block cipher is responsible for generating a MAC, **not** for encrypting data.

8.4.1 Padding and Blocking

This method first requires that the AAL SDU data be padded. The SDU may be appended with as few (possibly none) "0" bits as necessary to obtain a data string whose length (in bits) is an integer multiple of n (the block size of the algorithm).

The resulting data is divided into n-bit blocks (D_1,D_2,...,D_q). This padded data is only used for calculating and verifying the MAC. Consequently, the padding bits (if any) are not stored or transmitted with the data.

---

[2] The equation of y is modified to:
y = 172197 x 878087808780 / (1024 x 878087808780^{1024}) *mod* 1000033.
After 1024 x 878087808780^{1024} *mod* 1000033 is computed, one can compute its inverse modulo, (1024 x 878087808780^{1024})$^{-1}$ *mod* 1000033. This is carried out by using the extended Euclidian algorithm.

8.4.2 The Cryptographic Key

The key should be randomly or pseudo-randomly generated. If the same algorithm is used for encipherment of the message, the key used for the calculation of the MAC should be different from that used for encipherment.

8.4.3 The Initial Stage

The MAC is calculated as illustrated in Figure 49.

The input register is initialized with the first block (D_1).This input data (I_1) is passed through the algorithm (A), which uses a key (K) to produce *n* bits in the output register (O_1).

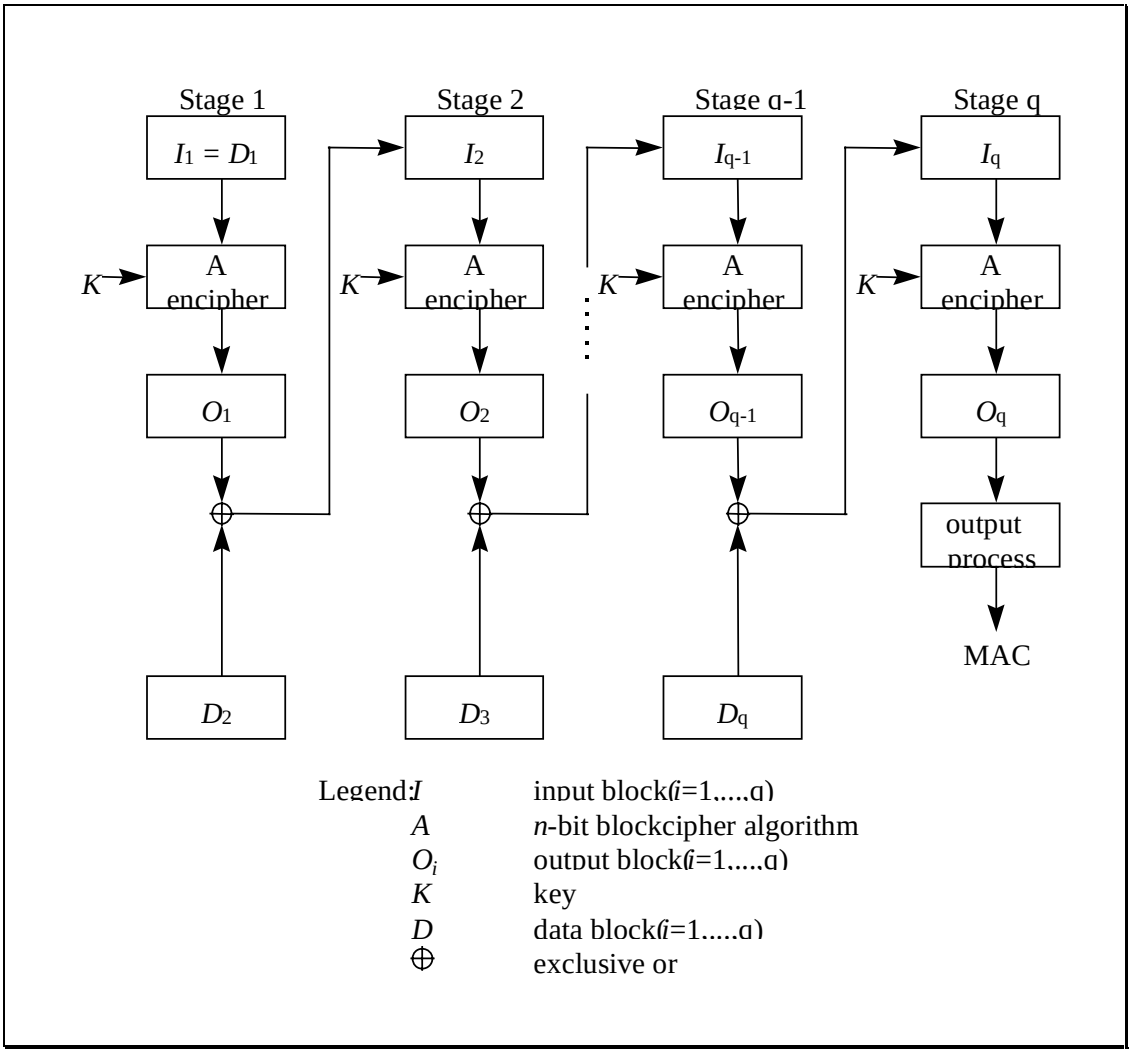


Figure 49: CBC-MAC Calculation.

8.4.4 Subsequent Stages

The next *n* bits of data (D_2) are bitwise exclusive or'ed with the *n* bits of the output register (O_1) and the result is loaded into the input register of the next stage (I_2). The contents of the input register (I_2) is passed through the algorithm (A), which uses the key (K) to produce *n* bits in the output register (O_2).

This operation continues until all blocks have been processed. The result will be the output block (O_q).

8.4.5 Output Process

To increase the strength of the CBC MAC, the output block O_q is subjected to an output process. This process uses an additional key, K1, which is the bitwise complement of the key original key K (as shown in the examples in Sections 8.4.6.1 and 8.4.6.2).

The n-bit block (O_q) is first generated using key (K) in the procedure specified in Sections 8.4.3 and 8.4.4. After O_q is generated, two additional steps shall then be performed (see Figure 50):

a) decipher the output (O_q) using key (K1) to obtain (O'_q):
b) encipher (O'_q) using key (K) to obtain (O''_q).

This completes the output process, and the resulting *n* bits is the MAC.

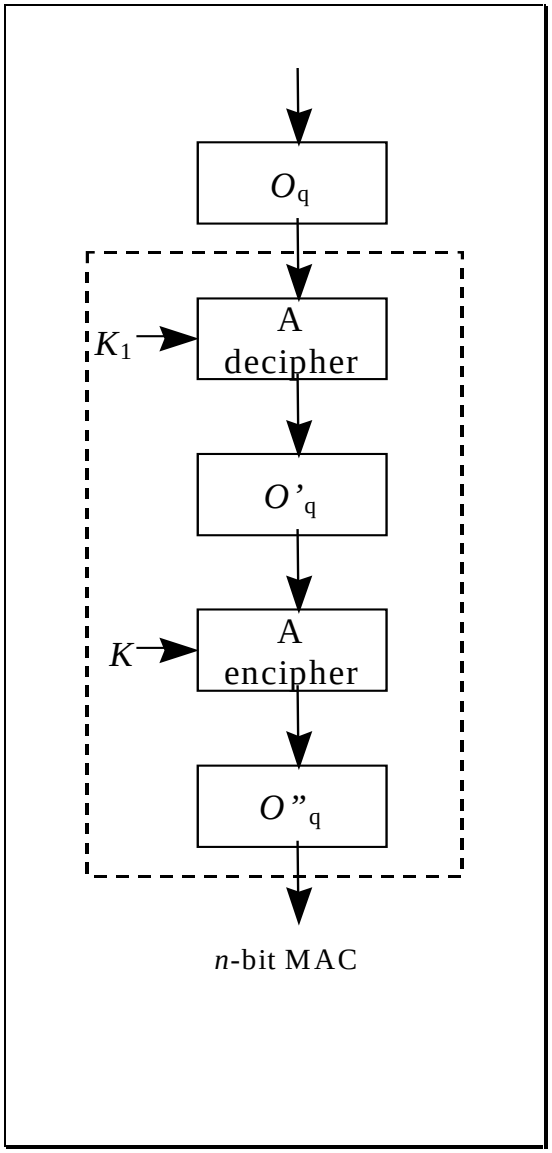


Figure 50: CBC-MAC Output Process.

8.4.6 CBC-MAC Examples

This section presents examples of the generation of a MAC employing the DES and FEAL block encipherment algorithms. The messages are 7-bit ASCII codes (no parity) for "Now_is_the_time_for_all_" and "Now_is_the_time_for_it" where "_" denotes a blank. The first message does not require any padding. The key (K) is 0123456789ABCDEF. The key (K1) for the output process is FEDCBA9876543210.

8.4.6.1 Examples using DES

Example 1: Now_is_the_time_for_all_

```
----------------------------------------
key(K)        : 01 23 45 67 89 AB CD EF
----------------------------------------
D1            : 4E 6F 77 20 69 73 20 74
D2            : 68 65 20 74 69 6D 65 20
D3            : 66 6F 72 20 61 6C 6C 20
----------------------------------------
I1 = D1       : 4E 6F 77 20 69 73 20 74
O1            : 3F A4 0E 8A 98 4D 48 15
I2 = O1 XOR D2: 57 C1 2E FE F1 20 2D 35
O2            : 0B 2E 73 F8 8D C5 85 6A
I3 = O2 XOR D3: 6D 41 01 D8 EC A9 E9 4A
O3            : 70 A3 06 40 CC 76 DD 8B
----------------------------------------
```

Output Process:

```
----------------------------------------
key(K1)       : FE DC BA 98 76 54 32 10
----------------------------------------
O’3           : B4 8D 36 EC 7A D5 69 4F
O"3           : A1 C7 2E 74 EA 3F A9 B6
----------------------------------------
```

The MAC is O"3 = `A1 C7 2E 74 EA 3F A9 B6`

Example 2: Now_is_the_time_for_it

```
----------------------------------------
key(K)        : 01 23 45 67 89 AB CD EF
----------------------------------------
D1            : 4E 6F 77 20 69 73 20 74
D2            : 68 65 20 74 69 6D 65 20
D3            : 66 6F 72 20 69 74 00 00
----------------------------------------
I1 = D1       : 4E 6F 77 20 69 73 20 74
O1            : 3F A4 0E 8A 98 4D 48 15
I2 = O1 XOR D2: 57 C1 2E FE F1 20 2D 35
O2            : 0B 2E 73 F8 8D C5 85 6A
I3 = O2 XOR D3: 6D 41 01 D8 E4 B1 85 6A
O3            : E4 5B 3A D2 B7 CC 08 56
----------------------------------------
```

Output Process:

```
----------------------------------------
key(K1)       : FE DC BA 98 76 54 32 10
----------------------------------------
O’3           : 32 8A C7 8B A1 CA 0B 3F
O"3           : 2E 2B 14 28 CC 78 25 4F
----------------------------------------
```

The MAC is O"3 = `2E 2B 14 28 CC 78 25 4F`

8.4.6.2 Examples using FEAL-32

Example 1: Now_is_the_time_for_all_

```
----------------------------------------
key(K)        : 01 23 45 67 89 AB CD EF
----------------------------------------
D1            : 4E 6F 77 20 69 73 20 74
D2            : 68 65 20 74 69 6D 65 20
D3            : 66 6F 72 20 61 6C 6C 20
----------------------------------------
I1 = D1       : 4E 6F 77 20 69 73 20 74
O1            : BF 68 7E 85 FC 63 A5 2A
I2 = O1 XOR D2: D7 0D 5E F1 95 0E C0 0A
O2            : 30 95 39 95 1A CF 62 1B
I3 = O2 XOR D3: 56 FA 4B B5 7B A3 0E 3B
O3            : 2A 7A C2 E7 67 0E B9 EC
----------------------------------------
```

Output Process:

```
----------------------------------------
key(K1)       : FE DC BA 98 76 54 32 10
----------------------------------------
O’3           : 5E D4 4C 5A D1 E5 61 EF
O"3           : 88 02 6E 69 54 5B 63 23
----------------------------------------
```

The MAC is O"3 = `88 02 6E 69 54 5B 63 23`

Example 2: Now_is_the_time_for_it

```
----------------------------------------
key(K)        : 01 23 45 67 89 AB CD EF
----------------------------------------
D1            : 4E 6F 77 20 69 73 20 74
D2            : 68 65 20 74 69 6D 65 20
D3            : 66 6F 72 20 69 74 00 00
----------------------------------------
I1 = D1       : 4E 6F 77 20 69 73 20 74
O1            : BF 68 7E 85 FC 63 A5 2A
I2 = O1 XOR D2: D7 0D 5E F1 95 0E C0 0A
O2            : 30 95 39 95 1A CF 62 1B
I3 = O2 XOR D3: 56 FA 4B B5 73 BB 62 1B
O3            : C9 78 9A 54 72 24 D8 E2
----------------------------------------
```

Output Process:

```
----------------------------------------
key(K1)       : FE DC BA 98 76 54 32 10
----------------------------------------
O’3           : AA 10 A1 5B 3D 95 12 F7
O"3           : B6 72 A6 02 1C EA D2 03
----------------------------------------
```

The MAC is O"3 = `B6 72 A6 02 1C EA D2 03`

8.5 DES-40

DES-40 is a variant of DES; however, it is no longer recommended for use. It uses an effective 40-bit key instead of the 56-bit key.

The key is presented as a 64-bit value with bits numbered k1 through k64 (where k1 is the most significant bit, and k64 is the least significant bit). k8, k16, k24, k32, k40, k48, k56, and k64 are ignored by DES and can be used to parity check the key.

The following bits shall be set to 0:

k1-4, k17-k20, k33-k36, k49-k52.

These are the top 4 bits of the 1st, 3rd, 5th, and 7th octets of the key.

8.6 Algorithm-Specific Use of Security Message Exchange Protocols

The security message exchange protocols described in Section 5.1 are not dependent on the use of any specific cryptographic algorithm. In the following sections, the use of these protocols with Diffie-Hellman for key exchange, with RSA for digital signature and key exchange, and with DSA for digital signature are specified.

8.6.1 RSA - Digital Signature and Key Exchange

RSA is a public-key algorithm that works for both encryption and digital signatures. The security of RSA depends on the difficulty of factoring large numbers. The public and private keys of RSA are generated as follows: Two random positive large prime integers, p and q are selected. Their product $n = pq$ is computed. n is called the public modulus. A random positive integer e less than n and relatively prime to product $(p-1)(q-1)$ is selected. This means that e and $(p-1)(q-1)$ have no common factor except 1. Then, a positive integer d such that $de-1$ is divisible by $(p-1)(q-1)$ is computed. In other words, $d = e^{-1} \bmod((p-1)(q-1))$. The values e and d are called the public and private exponent, respectively. The public key is the pair (e, n) and the private key is the pair (d, n). Once the public and private keys are computed, the prime factors, p and q are no longer needed and shall be either kept secret or destroyed.

An important property of RSA is that the steps of encryption and decryption can be reversed, i.e., $data = RSA_{(e,n)}(RSA_{(d,n)}(data)) = RSA_{(d,n)}(RSA_{(e,n)}(data))$. This property allows it to work for both encryption as well as for digital signatures.

In the following discussion, it is assumed that each authentication entity (*A* and *B*) possesses a public/private RSA key pair. Each authentication entity must either know or obtain its partner's public key. The three-way security message exchange protocol provides an option for the authentication entities to exchange certificates (which contain public key information). When supported, the authentication entities may use the certificate exchange option of the three-way security message exchange protocol to obtain each other's public key.

RSA can be used in both the two- and three-way security message exchange protocols for both digital signature as well as key exchange.

In the following discussions, upper-case italic symbols (e.g., *PS*) denote octet strings and lower-case italic symbols (e.g., *n*) denote integers.

8.6.1.1 RSA Encryption/Decryption Processes

The following sections describe the encryption/decryption process that shall be used in the two- and three-way security message exchange protocol when RSA is used for digital signature and/or key exchange. The encryption/decryption process described here is based on the methods of PKCS#1 [27].

8.6.1.1.1 RSA Encryption Process

Let the length of the modulus *n* in octets be *K*. The length *K* of the modulus shall be at least 12 octets to accommodate the block formats defined here. The message (*M*) to be encrypted shall have a length which is an integer multiple of 8 bits. To encrypt *M*, first divide it into data blocks of length *K*-11 octets, which is positive since the length *K* is at least 12 octets.

$$M = M_1, M_2, \ldots, M_m \qquad \text{where } m \geq 1$$

The last data block (i.e., M_m) may be of length less than *K*-11 octets. Encrypt each data block M_i using the four-step process described below to obtain EM_i. Then, concatenate the individually encrypted data blocks to obtain the encrypted message *EM*.

$$EM = EM_1, EM_2, \ldots, EM_m \qquad \text{where } m \geq 1$$

Let *D* represent any data block (M_i) of the message *M*. The encryption process of *D* consists of four steps which are described below.

1. **Encryption-block formatting:** Format the data block *D* to an encryption block (*EB*) octet string as follows.

   EB = 00, BT, PS, 00, D

   A 00 octet, a block type (*BT*) octet, a padding string (*PS*) octets, and a 00 octet are prepended to the data block *D* to form the encryption block (*EB*). The leading 00 octet ensures that the encryption block *EB* value will be less than the modulus *n* when it's converted to an integer. The block type *BT* octet shall be set to 01 for private-key operation and shall be set to 02 for public-key operation. The padding string *PS* shall consist of $K - 3 - \|D\|$ octets (where $\|D\|$ is the length of *D* in octets). The *PS* octet string shall be pseudorandomly generated and must have no octet with 00 value. The randomness of *PS* strengthens the security of RSA encryption. So, the total length of the encryption block (*EB*) is equal to *K* octets.

2. **Octet-string to integer conversion:** Convert the encryption block *EB* to an integer x. Let $EB_1, EB_2, \ldots, EB_K$ be the octets of *EB* from first to last. Then the integer x shall satisfy

   $$x = \sum_{i=1}^{K} 2^{8(K-i)} EB_i \qquad \text{where } EB_i \in [0,\ldots,255]$$

   With this representation, the first octet EB_1 is the most significant in the integer x and the last octet EB_K is the least significant.

3. **RSA computation:** Compute the RSA classical computation of the integer x as follows. Raise x to the power c modulo n to obtain y, the integer encrypted data block.

   $$y = x^c \bmod n \qquad 0 \leq y < n$$

   For a private-key operation, the integer c is an entity's private exponent d; for a public-key operation, the integer c is an entity's public exponent e.

4. **Integer to octet-string conversion:** Convert the integer encrypted data y to an octet string *ED* of length K octets. The encrypted data *ED* shall satisfy

   $$y = \sum_{i=1}^{K} 2^{8(K-i)} ED_i \qquad \text{where } ED_i \in [0,\ldots,255]$$

   where $ED_1, ED_2, \ldots, ED_K$ are the octets of *ED* from first to last. The first octet ED_1 is the most significant in the integer and the last octet ED_K is the least significant.

8.6.1.1.2 RSA Decryption Process

Let the length of the modulus *n* in octets be *K*. To decrypt the encrypted message *EM*, first divide it into *m* data blocks of length *K* octets. (Note that the length of *EM* is an integer multiple of *K* octets.)

$$EM = EM_1, EM_2, \ldots, EM_m \qquad \text{where } m \geq 1$$

Decrypt each data block EM_i using the four-step process described below to obtain M_i. Then, concatenate the individually decrypted data blocks to obtain the message *M*.

$$M = M_1, M_2, \ldots, M_m \qquad \text{where } m \geq 1$$

Let *ED* represent any encrypted data block (EM_i) of the message *EM*. The decryption process of *ED* consists of four steps that are described below.

1. **Octet-string to integer conversion:** Convert the encrypted data *ED* of length *K* octets to an integer y . The octet string *ED* shall satisfy

   $$y = \sum_{i=1}^{K} 2^{8(K-i)} ED_i \qquad \text{where } ED_i \in [0,\ldots,255]$$

   where $ED_1, ED_2, \ldots, ED_K$ are the octets of *ED* from first to last. The first octet ED_1 is the most significant in the integer and the last octet ED_K is the least significant.

2. **RSA computation:** Compute the RSA classical computation of the integer y as follows. Raise y to the power c modulo n to obtain x , the integer decrypted data block.

   $$x = y^c \bmod n \qquad 0 \leq x < n$$

   For a private-key operation, the integer c is an entity's private exponent d ; for a public-key operation, the integer c is an entity's public exponent e .

3. **Integer to octet-string conversion:** Convert the integer x to encryption block *EB* of length *K* octets. Let $EB_1, EB_2, \ldots, EB_K$ be the octets of *EB* from first to last. Then the integer x shall satisfy

   $$x = \sum_{i=1}^{K} 2^{8(K-i)} EB_i \qquad \text{where } EB_i \in [0,\ldots,255]$$

   With this representation, the first octet EB_1 is the most significant in the integer x and the last octet EB_K is the least significant.

4. **Encryption-block parsing:** Parse the encryption block (*EB*) octet string into a block type *BT*, a padding string *PS*, and the data block *D* as follows.

   EB = 00, BT, PS, 00, D

   The padding scheme allows the encryption block *EB* to be parsed unambiguously without knowing the length of the data block *D*. This is because the padding string *PS* contains no octets with value 00 and the padding string is separated from the data block *D* by an octet with value 00.

8.6.1.2 Digital Signature

The following sections describe the digital signature generation and validation with RSA using the methods of PKCS#1 [27].

Signature Generation:

For digital signature computation, the message (*M*) to be signed is first reduced using a hash algorithm (e.g., SHA-1) and then the hash value is encrypted with the RSA private key of the signer (i.e., the authentication entity that's generating the signature) using the RSA encryption process described above.

Refer to Sections 7.4.5.1 and 7.4.5.2 for specifications on constructing the digital signature buffer (or message) *M*.

The procedure to compute the digital signature (*S*) over the message *M* is as follows.

1. Run a hash algorithm (e.g., SHA-1) over *M* to produce a hash octet string *H*.
   $$H = Hash(M)$$
2. Encrypt *H* with the RSA private key of the signer (i.e., the authentication entity that's generating the signature) using the RSA encryption process described above to obtain a digital signature octet string *S*.
   $$S = RSA_{(d,n)}(H)$$

The signature octet string *S* is placed in the "Digital Signature Value" field in the appropriate digital signature octet group of the Security Services Information Element (SSIE).

Signature Verification:
For digital signature verification, the signature (*S*) octet string is first decrypted with the signer's RSA public key (using the RSA decryption process described above) and then compared with the hash of the message (*M*).

The procedure to verify the digital signature (*S*) over the message *M* is as follows.

1. Decrypt the digital signature *S* with the RSA public key of the signer (i.e., the authentication entity that generated the signature) using the RSA decryption process described above to obtain the octet string H'.
   $$H' = RSA_{(e,n)}(S)$$
2. Run the hash algorithm used to generate the signature over *M* to produce a hash octet string H''.
   $$H'' = Hash(M)$$
3. Compare the octet strings H' and H''. If they are equal, the signature verification process shall be successful, and it shall fail otherwise.

8.6.1.3 Key Exchange

Key exchange with RSA is achieved by encrypting the key (*C*) to be exchanged with the RSA public key of the recipient (i.e., the entity that should receive the key). The "Confidential Data" part (i.e., octet x.4 and higher) of the "Confidential Parameters Section" of the SSIE (see Section 7.3) contains the key (or keys) to be exchanged.

Sender's procedure:
Let *C* represent the octet string of the "Confidential Data" in the SSIE. The sender first encrypts *C* with the RSA public key of the receiver using the RSA encryption process described above to obtain an octet string *EC*.

$$EC = RSA_{(e,n)}(C)$$

Then, the sender replaces the entire octet string of the "Confidential Data" in the SSIE with *EC* and adjusts the length field for the Confidential Parameters Section if the length of EC is different from the length of *C*.

Receiver's procedure:
The receiver decrypts *EC* with its RSA private key using the RSA decryption process described above to obtain the octet string *C*.

$$C = RSA_{(d,n)}(EC)$$

8.6.2 DSA - Digital Signature

DSA is a public-key algorithm that can only be used for digital signatures. The security of DSA depends on the difficulty of computing discrete logarithms modulo a prime (i.e., in a prime finite field). A detailed description of the DSA algorithm can be found in [10].

DSA uses a number of public parameters in its operation. These parameters are *p* (a prime modulus), *q* (a prime divisor of *p*-1), and *g* (a generator). These parameters, along with the public key *y*, are contained in the DSA certificate for the user that generates the DSA digital signature (the private key *x* is kept secret by the user). In the following discussion of ATM authentication using DSA, it is assumed that each authentication entity (*A* and *B*) possesses a public/private DSA key pair, and that any entity which wishes to verify the signature has access to *p*, *q*, *g*, and *y*.

In order to generate a digital signature, the Digital Signature Standard [10] specifies the use of the Secure Hash Algorithm, which is defined in [9]. SHA-1 is used in DSS to generate a "fingerprint" of the message, which is then encrypted using DSA to bind the fingerprint to the signing entity. In order to generate the SHA-1 "fingerprint," the message must be padded such that its length is an integer multiple of 512 bits. This procedure, which is defined in [9], is summarized below:

SHA-1 padding procedure

Pad the message to produce a new message M, the length of which is a multiple of 512 bits. The padding is performed as follows:

1. Store the current length (in bits) of the message for later use.
2. Append a "1" bit to the original message data, followed by enough "0" bits to make the length of the new message 64 bits short of a 512 bit boundary.
3. Store the binary encoding of the message length (in bits) in the final 64 bits of the new message M. At this point, the length of M is a multiple of 512 bits.

In order to perform ATM authentication using SHA-1 and DSA, octet strings (e.g., padded message, DSA parameters, etc.) must be converted to integers. This conversion is defined in [10], and is summarized below:

Octet-String to Integer Conversion

An integer *x* is computed from a block of *K* octets $B_1, B_2, ..., B_K$ as follows:

$$x = \sum_{i=1}^{K} 2^{8(K-i)} B_i \qquad \text{where } B_i \in [0,\ldots,255]$$

where B_1 (the leftmost octet) is the most significant octet.

In order to transport DSA parameters in ATM information elements, integers (e.g., public parameters, signatures, etc.) must be converted to octet strings. This conversion is defined in [10] and is summarized below:

Integer to Octet-String Conversion

Given an integer *x*, determine a block of *K* octets B_1, B_2, ..., B_K such that the following relation applies:

$$x = \sum_{i=1}^{K} 2^{8(K-i)} B_i \qquad \text{where } B_i \in [0,\ldots,255]$$

where B_1 (the leftmost octet) is the most significant octet.

8.6.2.1 DSA Digital Signature Generation

The following steps are required to produce a DSA digital signature for use in the Security Message Exchange Protocols:

1. Construct the digital signature buffer according to the procedures defined in Sections 7.4.5.1and 7.4.5.2.
2. Pad the digital signature buffer to produce a message *M* using the padding procedure defined in [9] (and summarized earlier).
3. Calculate the SHA-1 hash *H=SHA(M)* as defined in [9] and convert the resulting octet string to a 160-bit (20 octet) integer as specified in [10] (and summarized earlier).
4. Calculate *r* and *s* as defined in [10].
5. Convert the 160-bit (20-octet) quantities *r* and *s* to octet strings using the procedure defined in [10] (and summarized earlier).
6. Insert the octet strings *r* and *s* into the "Digital Signature Value" in the appropriate digital signature octet group of the Security Services Information Element (SSIE).

8.6.2.2 DSA Digital Signature Verification

The following steps are required to validate a DSA digital signature when used in the Security Message Exchange Protocols:

1. Construct the digital signature buffer according to the procedures defined in Sections 7.4.5.1 and 7.4.5.2.
2. Pad the message to produce a new message *M'* using the padding procedure defined in [9] (and summarized earlier).
3. Calculate the SHA-1 hash *H'=SHA(M')* as defined in [9] and convert the resulting octet string to a 160-bit (20 octet) integer as specified in [10] (and summarized earlier).
4. Extract the received values of *r* and *s* from the "Digital Signature Value" field of the appropriate digital signature octet group of the SSIE. Convert the *r* and *s* octet strings to 160 bit (20 octet) integers *r'* and *s'* using the procedure defined in [10] (and summarized earlier).
5. Calculate *v* as defined in [10].
6. If *v=r'*, then the signature verification process shall be successful. Otherwise, it shall fail.

8.6.3 ESIGN - Digital Signature

ESIGN is a public-key algorithm that can only be used for digital signatures. The security of ESIGN depends on the difficulty of factoring large numbers. A detailed description of the ESIGN algorithm can be found in Section 8.3.

The public and private keys of ESIGN are generated as follows: Two random positive large prime integers, p and q ($p > q$) are selected. Their product $n = p^2 q$ is computed. n is called the public modulus. The private key for signature process is the pair (p, q) ($p > q$) and the public key for verification process is the pair (n, k) where k is an integer ($4 \le k$). A positive integer d is computed which is the least integer that is larger or equal to $|n|/3$ where $|n|$ is a bit length of n.

ESIGN Signature Process $SD = ESIGN_{(p, q)}(SB)$

1. **Octet-string to integer conversion:** Convert the signature block *SB* to an integer *m*. Let an integer *d* be 8*K* and SB_1, SB_2, ..., SB_K be the octets of *SB* from first to last. Then, an integer *m* to be signed shall satisfy

$$m = \sum_{i=1}^{K} 2^{8(K-i)} SB_i \quad \text{where} \quad SB_i \in [0,\ldots,255]$$

   With this representation, the first octet SB_1 has the most significance in the integer *m* and the last octet SB_K has the least significance.

2. **ESIGN computation:** Compute the ESIGN computation of the integer *m* to obtain *S* as follows: After a random positive integer *x* less than *pq* - 1 is selected,

$$w = \left\lceil \frac{m2^{2d} - (x^k \bmod n)}{pq} \right\rceil,$$

$$y = \frac{w}{kx^{k-1}} \bmod p \text{ , and}$$

$$S = x + ypq \text{ .}$$

   Clear definitions are described in Section 8.3.

3. **Integer to octet-string conversion:** Convert the integer signed data *S* to an octet string *SD* of length *3K* octets. The signed data *SD* shall satisfy

$$S = \sum_{i=1}^{3K} 2^{8(3K-i)} SD_i \quad \text{where} \quad SD_i \in [0,\ldots,255]$$

   where SD_1, SD_2, ..., SD_{3K} are the octets of *SD* from first to last. The first octet SD_1 has the most significance in the integer and the last octet SD_{3K} has the least significance.

ESIGN Verification Process $SB = ESIGN_{(n, k)}(SD)$

1. **Octet-string to integer conversion:** Convert the signed data *SD* of length *3K* octets to an integer *S*. The octet string *SD* shall satisfy

$$S = \sum_{i=1}^{3K} 2^{8(3K-i)} SD_i \quad \text{where} \quad SD_i \in [0,\ldots,255]$$

   where SD_1, SD_2, ..., SD_{3K} are the octets of *SD* from first to last. The first octet SD_1 has the most significance in the integer and the last octet SD_{3K} has the least significance.

2. **ESIGN computation:** Compute the ESIGN computation of the integer *S* to obtain *m* as follows;

$$m = \left\lfloor \frac{S^k \bmod n}{2^{2d}} \right\rfloor.$$

   Clear definitions are described in Section 8.3.

3. **Integer to octet-string conversion:** Convert the integer *m* to signature block *SB* of length *K* octets. Let SB_1, SB_2, ..., SB_K be the octets of *SB* from first to last. Then the integer *m* shall satisfy

$$m = \sum_{i=1}^{K} 2^{8(K-i)} SB_i \quad \text{where} \quad SB_i \in [0,\ldots,255]$$

With this representation, the first octet SB_1 has the most significance in the integer *m* and the last octet SB_K has the least significance.

8.6.3.1 ESIGN Signature Generation

For digital signature computation, the message (*M*) to be signed is first reduced using a hash algorithm (e.g., SHA-1) and then the hash value is signed with the ESIGN private key of the signer (i.e., the authentication entity that's generating the signature) using the ESIGN signature process in [33] [36].

Refer to Sections 7.4.5.1 and 7.4.5.2 for specifications on constructing the digital signature buffer (or message) *M*.

The procedure to compute the digital signature (*SD*) over the message *M* is as follows:

1. Run a hash algorithm (e.g., SHA-1) over *M* to produce a hash octet string *H*.
   $H = Hash(M)$
2. Format the hash data *H* to a signature block (*SB*) octet string as follows.
   $SB = 00, PS, FF, H$
   A *00* octet, a padding string (*PS*) octets, and a *FF* octet are prepended to the hash value *H* to form the signature block (*SB*). The leading *00* octet ensures that the signature block *SB* value will be less than 2^d when it's converted to an integer. The padding string *PS* shall consist of $K\text{-}2\text{-}\|H\|$ octets (where $\|H\|$ is the length of *H* in octet). The *PS* octet string shall have no octet with *FF* value. The total length of the signature block (*SB*) is equal to *K* octets.
3. Sign to *SB* with the ESIGN private key of the signer (i.e., the authentication entity that's generating the signature) using the ESIGN signature process described above to obtain a digital signature octet string *SD*. The total length of the signed data (*SD*) is equal to *3K* octets.
   $SD = ESIGN_{(p, q)}(SB)$

The signature octet string *SD* is placed in the "Digital Signature Value" field in the appropriate digital signature octet group of the Security Services Information Element (SSIE).

8.6.3.2 ESIGN Signature Verification

For digital signature verification, the signature (*SD*) octet string is verified with the signer's ESIGN public key and the hash of the message (*M*). The procedure to verify the digital signature (*SD*) over the message *M* is as follows:

1. Verify the digital signature *SD* with the ESIGN public key of signer (i.e., the authentication entity that generated the signature) using the ESIGN verification process described above to obtain the octet string *SB'*.
   $SB' = ESIGN_{(n, k)}(SD)$.
2. Parse the signature block (*SB'*) octet string into a padding string *PS*, and the data block *H'* as follows.
   $SB' = 00, PS, FF, H'$
   The padding scheme allows the signature block *SB'* to be parsed unambiguously without knowing the length of the hash value *H'*. This is because the padding string *PS* contains no octets with value *FF* and the padding string is separated from the data block *H'* by an octet with value *FF*. Then, the *H'* is picked out to verify.
3. Run the hash algorithm used to generate the signature over *M* to produce a hash octet string *H"*.
   $H'' = Hash(M)$

Compare the octet string *H'* and *H"*. If *H'* is equal to *H"*, the signature verification process shall be successful, and it shall fail otherwise.

8.6.4 Diffie-Hellman Key Exchange

Diffie-Hellman is a public-key algorithm that allows two parties (say *A* and *B*) to come up with a secret shared key that is known only to them. The two parties first agree on a pair of public parameters: p, a positive large prime integer and g, a positive integer. These two parameters are not secret. p is called the public modulus and g is called the public base. The base must satisfy $0 < g < p$. The party *A* generates a private random integer a such that $0 < a < p-1$ and computes $x = g^a \bmod p$, where $0 < x < p$. The values a and x are called the private and public key of *A*, respectively. Similarly, the party *B* generates a private random integer b such that $0 < b < p-1$ and computes $y = g^b \bmod p$, where $0 < y < p$. The values b and y are called the private and public key of *B*, respectively. Then, the two parties exchange their public keys, i.e., *A* sends x to *B* and *B* sends y to *A*. The public keys are not secret. Then, each party independently computes the Diffie-Hellman integer secret shared key z. That is *A* computes $z = y^a \bmod p$ and *B* computes $z = x^b \bmod p$, where $0 < z < p$.

Since Diffie-Hellman is a key exchange algorithm and does not protect against man-in-the-middle attack, it shall be used in combination with a digital signature algorithm (such DSA, RSA, etc.) to protect the exchange of public keys when used over an insecure channel. Additionally, the use of the Diffie-Hellman algorithm itself is limited to the three-way security message exchange protocol. The reason for this limitations is that the two-way security message exchange protocol cannot support Diffie-Hellman because encrypting $ConfPar_a$ in Flow-1 would require the knowledge of the secret shared key, which is not established yet.

8.6.4.1 Diffie-Hellman With Three-Way Security Message Exchange Protocol

The initiator first selects p (the public modulus) and g (the public base) and computes its public key x. The initiator converts the integers p, g, and x to octet strings *P*, *G*, and *X*, respectively.

Integer to octet-string or octet-string to integer conversion: Let r be an integer and *R* be its corresponding octet string of length K octets. The octet string *R* shall satisfy

$$r = \sum_{i=1}^{K} 2^{8(K-i)} R_i \qquad \text{where } R_i \in [0 \ldots 255]$$

where $R_1, R_2, \ldots, R_K$ are the octets of *R* from first to last. The first octet R_1 is the most significant in the integer and the last octet R_K is the least significant.

The initiator sends *P*, *G*, and *X* in $SecNeg_a$ of FLOW1-3WE to the responder. Upon receiving *P*, *G*, and *X*, the responder computes its public key y and the secret shared key z. The responder converts its public key y to octet string *Y* and sends it to the initiator in $SecNeg_b$ of FLOW2-3WE. Upon receiving *Y*, the initiator computes the secret shared key z. Both the initiator and responder convert the secret shared key z to octet string *Z*.

The low order 256 bits of Z shared by the initiator and responder is the Initial Key Exchange Key $\overline{Z}$ used to encrypt $ConfPar_a$ and $ConfPar_b$.

Let *C* represent the "Confidential Data" part (i.e., octet x.4 and higher) of the "Confidential Parameters Section" of the SSIE (see Section 7.3). To encrypt *C* with the secret shared key $\overline{Z}$, a *Zconcat* is first built from $\overline{Z}$ as follows: $Z_{concat} = Z_1, Z_2, \ldots$, where *Zconcat* is the concatenation of Z_1, Z_2, etc. such that its total length is greater than or equal to the length of *C*. Each Z_i (where $i \geq 1$) is computed as follows:

$$Z_i = SHA(\overline{Z}, KeyFill, A, B, i, R_A, \overline{Z}, ShaFill)$$

First, the shared key $\overline{Z}$ is appended *KeyFill* to the next 512-bit boundary, using the pad with length technique defined for SHA-1 (Secure Hash Algorithm) in [9]. Then, the filled shared key is concatenated with (immediately followed by) the source's distinguished name *A*, concatenated with (immediately followed by) the destination's distinguished name *B*, concatenated with (immediately followed by) a one-octet (8-bit) counter i, concatenated with (immediately followed by) a random number R_A generated by the source, and concatenated with (immediately followed by) the shared key $\overline{Z}$ again. A trailing pad (i.e., *ShaFill*) with length to the next 512-bit boundary for the entire message is added by SHA-1 itself. Then, the 20-octet SHA-1 message digest is calculated (as defined in [9]) and the result is Z_i.

Then, *Zmask* is formed by removing the rightmost $\|Zconcat\| - \|C\|$ octets of *Zconcat* (where $\|Zconcat\|$ is the length of *Zconcat* in octets and $\|C\|$ is the length of *C* in octets), so that *Zmask* has the same length as *C*. The encrypted *C* is obtained by *xor*ing *Zmask* with *C*. That is, $EC = Zmask \oplus C$. Then, the sender replaces the entire octet string of the "Confidential Data" in the SSIE with *EC*. To recover *C*, the encrypted *C* (i.e., *EC*) is *xor*ed with *Zmask*. That is, $C = Zmask \oplus EC$.

8.6.5 Session Key Exchange using MD5

The hash function to be used in SKE for a connection may be negotiated at the time the connection is established. Here the MD5 method of RFC-1321 [13] is defined as one option for use with SKE. The shared master key, $K_{m,AB}$, is not constrained by this scheme to any particular size.

The "*Mask*" for xoring with the session key is obtained using MD5 as follows:

$HalfMask1 = MD5(K_{m,AB}, KeyFill, A, KN_A, c1, K_{m,AB}, MD5Fill)$

$HalfMask2 = MD5(K_{m,AB}, KeyFill, A, KN_A, c2, K_{m,AB}, MD5Fill)$ if session key > 128 bits

$HalfMask2 = 0$ if session key < 128 bits

$Mask = (HalfMask2, HalfMask1)$

Where the constants c1 = 0000 0000 hex, and c2 = 5555 AAAA hex for the initiator, and where the constants c1 = 00FF FF00 hex, and c2 = 6666 CCCC hex for the responder

Note: for simplex connections (e.g., point-to-multipoint) the constants associated with the initiator are used.

The first half mask is computed as follows: The *KeyFill* is appended to the shared master key to the next 512-bit boundary, using the pad with length technique defined for MD5 in RFC-1321 [13]. Then, the filled master key is concatenated with (immediately followed by) *A*, concatenated with (immediately

followed by) KN_A, concatenated with (immediately followed by) the constant *c*1, and concatenated with (immediately followed by) the original variable length master key again. A trailing pad (i.e., *MD5Fill*) with length to the next 512-bit boundary for the entire message is added by MD5 itself. Then, the 16-octet MD5 message digest is calculated (as defined in RFC-1321 [13]), and the result is the *HalfMask*1.

The length of the session key being encrypted determines the computation of the second half mask. If it is greater than 128 bits, the second half mask is computed in a similar fashion to the first half mask, except that the constant c2 is used in place of c1. If the session key is 128 bits or less, the second half mask is simply set to zero.

The *Mask* is then obtained by concatenating the two *HalfMask*s. The *Mask* length is 32 octets, which is equal to the length of the "encrypted session key" field of the SKE OAM cell. To obtain the encrypted session key, the session key is first prepended with zeros (with *ZeroPad*) so that its total length is 256 bits (i.e., 32 octets). If the session key length is already 256 bits, no padding is required. Then, the padded session key is xored with the *Mask* to obtain the 32-octet encrypted session key.

$$Enc_{K_{m,AB}}\left(K_{s,AB}\right) = \left(ZeroPad, K_{s,AB}\right) \oplus Mask$$

To recover the session key, $K_{s,AB}$, from the encrypted session key, $Enc_{K_{m,AB}}(K_{s,AB})$, the encrypted session key is first xored with the *Mask* and then the prepended *ZeroPad* is removed.

8.6.6 Session Key Exchange using SHA-1 and RIPEMD-160

The hash function, H to be used in SKE for a connection may be negotiated at the time the connection is established. Here the SHA-1 [9] and the RIPEMD-160 [21] methods are defined as two options for use with SKE. The shared master key, $K_{m,AB}$, is not constrained by this scheme to any particular size.

The "*Mask*" for xoring with the session key is obtained using H as follows:

$HalfMask1 = trunc_{128}(H(K_{m,AB}, KeyFill, A, KN_A, c1, K_{m,AB}, H\_Fill))$

$HalfMask2 = trunc_{128}(H(K_{m,AB}, KeyFill, A, KN_A, c2, K_{m,AB}, H\_Fill))$ if session key > 128 bits

$HalfMask2 = 0$ if session key < 128 bits

$Mask = (HalfMask2, HalfMask1)$

Where the constants c1 = 0000 0000 hex, and c2 = 5555 AAAA hex for the initiator, and
where the constants c1 = 00FF FF00 hex, and c2 = 6666 CCCC hex for the responder.

The first half mask is computed as follows: The *KeyFill* is appended to the shared master key to the next 512-bit boundary, using the pad with length technique defined for SHA-1 in [9] or RIPEMD-160 in [21]. Then, the filled master key is concatenated with (immediately followed by) *A*, concatenated with (immediately followed by) KN_A, concatenated with (immediately followed by) the constant c1, and concatenated with (immediately followed by) the original variable length master key again. H itself adds a trailing pad (i.e., *H_Fill*) to the next 512-bit boundary for the entire message. Then, the 20-octet H message digest is calculated (as defined in [9] or [21]). The H digest is then truncated to 128 bits by throwing away the high order 32 bits, and the result is the *HalfMask*1.

The length of the session key being encrypted determines the computation of the second half mask. If it is greater than 128 bits, the second half mask is computed in a similar fashion to the first half mask, except

that the constant c2 is used in place of c1. If the session key is 128 bits or less, the second half mask is simply set to zero.

The *Mask* is then obtained by concatenating the two *HalfMask*s. The *Mask* length is 32 octets, which is equal to the length of the "encrypted session key" field of the SKE OAM cell. To obtain the encrypted session key, the session key is first prepended with zeros (with *ZeroPad*) so that its total length is 256 bits (i.e., 32 octets). If the session key length is already 256 bits, no padding is required. Then, the padded session key is xored with the *Mask* to obtain the 32-octet encrypted session key.

$$Enc_{K_{m,AB}}\left(K_{s,AB}\right) = \left(ZeroPad, K_{s,AB}\right) \oplus Mask$$

To recover the session key, $K_{s,AB}$, from the encrypted session key, $Enc_{K_{m,AB}}(K_{s,AB})$, the encrypted session key is first xored with the *Mask* and then the prepended *ZeroPad* is removed.

8.7 Asymmetric Authentication and Key Exchange Using Elliptic Curve Cryptosystems

This section describes the method of performing authentication and key exchange using an elliptic curve cryptosystem. This section is self-contained, that is, all references indicated in this section (Section 8.7) can be found in Section 8.7.6. Recent standardization results can be found in [ANS98], [ISO 15946-1], [ISO 15946-2], and [P1363].

Many public-key cryptographic systems are based on exponentiation operations in large finite mathematical groups. The cryptographic strength of these systems is derived from the believed computational intractability of computing logarithms in these groups. The most commonly seen groups are the multiplicative group of Z_p (the integers modulo a prime p) and F_{2^m} (characteristic 2 finite fields). The primary advantages of these groups have been their rich theory, easily understood structure, and straightforward implementation. However, they are not the only groups that have the requisite properties. In particular the mathematical structures known as elliptic curves have the requisite mathematical properties, have a rich theory, and are especially amenable to efficient implementation in hardware or software.

The algebraic system defined on the points of an elliptic curve provides an alternate means to implement the ElGamal and ElGamal-like public key encryption and signature protocols. These protocols are described in the literature in the algebraic system Z_p, integers modulo p, where p is a prime. For example, the Digital Signature Algorithm (DSA) defined in ANSI X9.30-1-1997 [ANS 97a] and in NIST's FIPS 186-1 [NIS 98], is an ElGamal-like signature scheme defined over Z_p. Precisely the same protocol for signing can be defined over the points on an elliptic curve.

Elliptic curves as algebraic/geometric entities have been studied extensively for the past 150 years, and from these studies has emerged a rich and deep theory. Elliptic curve systems as applied to ElGamal protocols were first proposed in 1985 independently by Neal Koblitz from the University of Washington, and Victor Miller, who was then at IBM, Yorktown Heights [Kob87, Mil86].

The security of the cryptosystems using elliptic curves hinges on the intractability of the discrete logarithm problem in the algebraic system. Since 1985, this problem has received attention from leading mathematicians around the world. Unlike the case of the discrete logarithm problem in finite fields, or the problem of factoring integers, there is no subexponential-time algorithm known for the elliptic curve discrete logarithm problem. The best algorithm known to date takes fully exponential time.

The primary advantage of elliptic curve systems is their high cryptographic strength relative to the key size. The attractiveness of the elliptic curve cryptosystems will increase relative to other public-key

cryptosystems, as computing power improvements force an increase in the key size. The significantly shorter key size results in significantly shorter certificates and system parameters. These advantages manifest themselves in many ways, including:

- Storage efficiencies,
- Bandwidth savings, and
- Computational efficiencies.

The computational efficiencies lead in turn to:

- Higher speeds,
- Lower power consumption, and
- Code size reductions.

Associated with any finite field F_q there are on the order of q different elliptic curves that can be formed and used for the cryptosystems. Thus, for a fixed finite field with q elements and with q large, there are many choices for the elliptic curve group. Since each elliptic curve operation requires a number of more basic operations in the underlying finite field F_q, a finite field may be selected with a very efficient software or hardware implementation, and there remain an enormous number of choices for the cryptosystem.

8.7.1 Definitions, Abbreviations, Symbols, and Notation

8.7.1.1 Definitions And Abbreviations

addition rule	An *addition rule* describes the addition of two elliptic curve points P_1 and P_2 to produce a third elliptic curve point P_3.
basis	A representation of the elements of the finite field F_{2^m}. Two special kinds of basis are *optimal normal basis* and *polynomial basis*.
bit string	A bit string is an ordered sequence of 0s and 1s.
characteristic 2 finite field	A finite field containing 2^m elements, where $m \geq 1$ is an integer.
cryptographic hash function	A (mathematical) function that maps values from a large (possibly very large) domain into a smaller range. It satisfies the following properties: 1. it is computationally infeasible to find any input which maps to any pre-specified output; 2. it is computationally infeasible to find any two distinct inputs that map to the same output.
EC-GDSA	A mechanism for producing a digital signature using elliptic curves.
EC	Elliptic Curve.
elliptic curve	An *elliptic curve* is a set of points specified by two parameters a and b, which are elements of a field F_q. The elliptic curve is said to be defined over F_q, and F_q is sometimes called the *underlying field*. If q is an odd prime p, $p > 3$, (so the field is F_p), then the Weierstrass equation defining the curve is of the form $y^2 = x^3 + ax + b$, where

	$((4a^3 + 27b^2) \bmod p) \neq 0$. If q is a power of 2 (so the field is F_{2^m}), then the Weierstrass equation defining the curve is of the form $y^2 + xy = x^3 + ax^2 + b$, where $b \neq 0$.
elliptic curve key pair	Given particular elliptic curve parameters, an *elliptic curve key pair* consists of an elliptic curve private key and the corresponding elliptic curve public key.
elliptic curve private key	Given particular elliptic curve parameters, an *elliptic curve private key* consists of a statistically unique and unpredictable integer d in the interval [2, n - 2].
elliptic curve public key	Given particular elliptic curve parameters and an elliptic curve private key d, the corresponding *elliptic curve public key* consists of the elliptic curve point $Q = dP$.
elliptic curve parameters	These parameters specify an underlying field F_q, the type of basis used to represent the elements of F_q, the equation of an elliptic curve over F_q, an elliptic curve point P of prime order, and the order n of P.
elliptic curve point	If E is an elliptic curve defined over a field F_q, then an *elliptic curve point P* is either (i) a pair of field elements (x_P, y_P) (where $x_P, y_P \in F_q$) such that the values $x = x_P$ and $y = y_P$ satisfy the equation defining E, or (ii) a special point 0 called the *point at infinity*.
nonsupersingular	If an elliptic curve is not supersingular, it is called *nonsupersingular*. Only nonsupersingular elliptic curves are considered in this specification.
octet	An *octet* is a bit string of length 8. A hexadecimal string of length 2 represents an octet. The first hexadecimal digit represents the four leftmost (high-order) bits of the octet, and the second hexadecimal digit represents the four rightmost (low-order) bits of the octet. For example, 9*D* represents the bit string 10011101. An octet also represents an integer in the interval [0,255]. For example, 9*D* represents the integer 157.
octet string	An octet string is an ordered sequence of octets.
order of a point	The *order of a point P* is the smallest positive integer n such that $nP = 0$ (the point at infinity).
order of a curve	The *order of an elliptic curve E* defined over the field F_q is the number of points on the elliptic curve E, including 0, and is denoted by $\#E(F_q)$.
owner	The entity whose identity is associated with a private/public key pair.
prime finite field	A finite field containing p elements, where p is an odd prime number.
scalar multiplication	If k is a positive integer, then kP denotes the point obtained by adding together k copies of the point P. The process of computing kP from P and k is called *scalar multiplication*.

The Secure Hash Algorithm, Revision 1 (SHA-1)	SHA-1 implements a hash function which maps messages of length less than 2^{64} bits to hash values of length exactly 160 bits.
supersingular	An elliptic curve E defined over F_p is *supersingular* if the order of E is $p + 1$. An elliptic curve defined over F_{2^m} is supersingular if its defining equation is of the form: $y^2 + cy = x^3 + ax + b$ where: $a,b,c \in F_{2^m}$ and $c \neq 0$. The use of such a curve is prohibited by this specification.
verifier	The entity that verifies the authenticity of a digital signature.
x-coordinate	The *x-coordinate* of an elliptic curve point, $P = (x_P, y_P)$, is x_P.
y-coordinate	The *y-coordinate* of an elliptic curve point, $P = (x_P, y_P)$, *is* y_P.

8.7.1.2 Symbols And Notation

$\lceil a \rceil$	Ceiling: the smallest integer $\geq a$. For example, $\lceil 5 \rceil = 5$ and $\lceil 5.3 \rceil = 6$.
$\lfloor a \rfloor$	Floor: the largest integer $\leq a$. For example, $\lfloor 5 \rfloor = 5$ and $\lfloor 5.3 \rfloor = 5$.
$[a,b]$	The interval of integers between and including a and b.
$X \oplus Y$	Bitwise exclusive-or of two bit strings X and Y of the same bit length.
$X\|\|Y$	Concatenation of two strings X and Y. X and Y are either both bit strings, or both octet strings.
$\|\|X\|\|$	Length in octets of the octet string X.
$\log_2 x$	The logarithmic function to the base 2.
a mod n	The unique remainder r, $0 \leq r \leq n - 1$, when integer a is divided by n. For example, 23 mod 7 = 2 since $23 = 7 \bullet 3 + 2$.
Z_p or F_p	The finite field containing p elements, where p is prime.
F_{2^m}	The finite field containing 2^m elements.
m	The *degree* of the finite field F_{2^m}.
F_q	The finite field containing q elements. For this specification, q will either be a prime number (p) or a power of 2 (2^m).
t	The length of a field element in bits; $t = \lceil \log_2 q \rceil$. In particular, if $q = 2^m$, then a field element in F_{2^m} can be represented as a bit string of bit length $t = m$.
l	The length of a field element in octets; $l = \lceil t / 8 \rceil$.
E	An elliptic curve.
P	A *base* point (x_P, y_P) on an elliptic curve.
0	A special point on an elliptic curve, called the point at infinity. This is the additive identity of the elliptic curve group
n	The order of the point P. For this specification, n is a prime number.

h	The maximum length, in bits, of an integer in the interval [0, n - 1]; $h = \lceil \log_2 n \rceil$.
f	The maximum length, in octets, of an integer in the interval [0, n - 1]; $f = \lceil h / 8 \rceil$.
E (F_q)	The set of all points on an elliptic curve E defined over F_q and including the point at infinity 0.
$\#E(F_q)$	If E is defined over F_q, then $\#E(F_q)$ denotes the number of points on the curve. $\#E(F_q)$ is called the order of the curve E.
M	Message to be signed.
M'	Message as received.
mod	Modulo.
mod n	Arithmetic modulo n.
p	An odd prime number.
Q	EC public key.

8.7.2 Mathematical Conventions

8.7.2.1 Finite Field Arithmetic

This section describes the representations that shall be used for the elements of the underlying finite field F_q.

8.7.2.1.1 The Finite Field F_p

Let p be an odd prime, $p > 3$. The finite field F_p is comprised of the set of integers {0, 1, 2, ..., p - 1}.

8.7.2.1.2 The Finite Field F_{2^m}

The finite field F_{2^m} is comprised of all bit-strings of bit length m.

8.7.2.1.3 Polynomial Basis

Let $f(x) = x^m + f_{m-1}x^{m-1} + ... + f_2x^2 + f_1x + f_0$, $f_i \in F_2$, be an irreducible polynomial of degree m over F_2, i.e., $f(x)$ cannot be factored into two polynomials over F_2, each of degree less than m. The *finite field* F_{2^m} is comprised of all polynomials over F_2 of degree less than m:

$$F_{2^m} = \{a_{m-1}x^{m-1} + ... + a_2x^2 + a_1x + a_0 : a_i \in \{0,1\}\},$$

i.e., $\{1, x, x^2, \ldots, x^{m-1}\}$ is the polynomial basis of F_{2^m}. The field element $(a_{m-1}x^{m-1} + ... + a_2x^2 + a_1x + a_0)$ is usually denoted by the binary string $(a_{m-1}...a_1a_0)$ of length m, so that

$$F_{2^m} = \{(a_{m-1}...a_1a_0) : a_i \in \{0,1\}\}.$$

Thus the elements of F_{2^m} can be represented by the set of all binary strings of length m.
Field elements are added and multiplied as follows:

- *Field addition*: $(a_{m-1}...a_1a_0) + (b_{m-1}...b_1b_0) = (c_{m-1}...c_1c_0)$ where $c_i = a_i + b_i$ in the field F_2. That is, field addition is performed componentwise.
- *Field multiplication*: $(a_{m-1}...a_1a_0)\ (b_{m-1}...b_1b_0) = (r_{m-1}...r_1r_0)$, where the polynomial $(r_{m-1}x^{m-1} + ... + r_1x + r_0)$ is the remainder when the polynomial $(a_{m-1}x^{m-1} + ... + a_2x^2 + a_1x + a_0)\ (b_{m-1}x^{m-1} + ... + b_2x^2 + b_1x + b_0)$ is divided by $f(x)$ over F_2.

This method of representing F_{2^m} is called a *polynomial basis representation*.

For performance reasons we choose the irreducible polynomial *f(x)* to have as few nonzero terms as possible (as *f(x)* is not divisible by *x* and has an odd number of terms, it has at least three terms). If, for a fixed *m*, there are two polynomials with the same number of terms, we choose the one for which *f(2)* is minimum (here *f(2)* is evaluated as a polynomial over the integers). For all field sizes proposed in this specification *f(x)* will be a trinomial, i.e., of the form $x^m + x^k + 1$ or a pentomial, i.e., of the form $x^m + x^k + x^j + x^i + 1$.

8.7.2.1.4 Field Sizes

For F_p, the prime p shall be in the range of 2^{150} to 2^{521}.

The following field sizes are typically used for F_{2^m}:

$$m = 163, 191, 233, 239, 283, 359, 409, 431, 571$$

8.7.2.1.5 Curve Parameters

Curve parameters for common field sizes and curve types recommended herein can be found in [ISO15946-1].

8.7.2.2 Data Representation

The data types in this section are octet strings, integers, field elements, and points.

Figure 51 provides a cross-reference for the sections defining conversions between data types that shall be used in the algorithms specified in this specification. The number on a line is the section number where the conversion technique is specified.

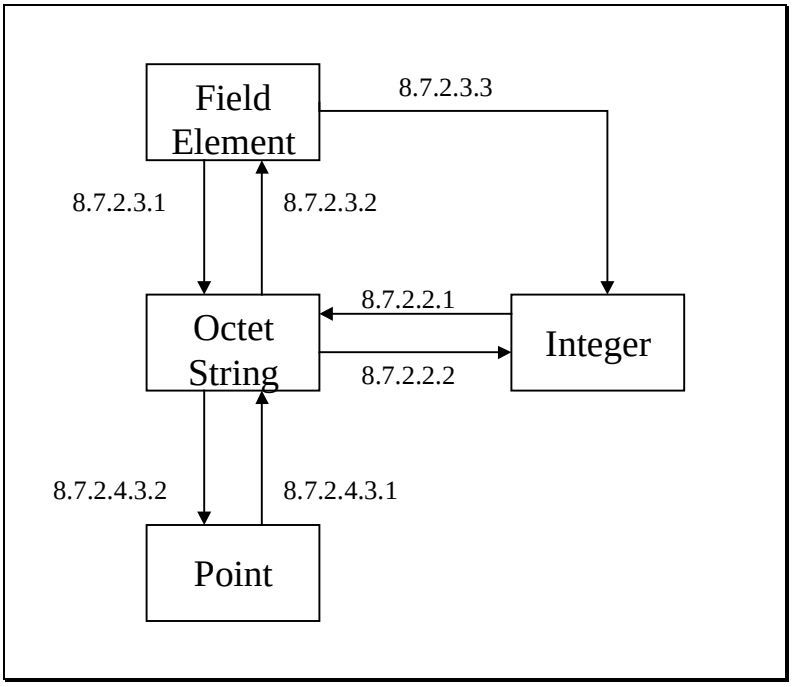


Figure 51: Data Types and Conversion Conventions.

8.7.2.2.1 Integer-to-Octet-String Conversion

Input: A nonnegative integer *x*, and the intended length *k* of the octet string satisfying:

$$2^{8k} > x.$$

Output: An octet string *M* of length *k* octets.

1. Let M_1, M_2, ..., M_k be the octets of *M* from leftmost to rightmost.
2. The octets of *M* shall satisfy:

$$x = \sum_{i=1}^{k} 2^{8(k-i)} M_i.$$

8.7.2.2.2 Octet-String-to-Integer Conversion

Input: An octet string *M* of length *k* octets.

Output: An integer *x*.

1. Let M_1, M_2, ..., M_k be the octets of *M* from leftmost to rightmost.
2. *M* shall be converted to an integer *x satisfying:*

$$x = \sum_{i=1}^{k} 2^{8(k-i)} M_i.$$

8.7.2.3 Finite Field Element Representations

8.7.2.3.1 Field-Element-to-Octet-String Conversion

Input: An element α in the field F_q.

Output: An octet string *S* of length $l = \lceil t / 8 \rceil$ octets, where $t = \lceil \log_2 q \rceil$.

1. If *q* is an odd prime, then α must be an integer in the interval: [0, *q* - 1];
   α shall be converted to an octet string of length *l* octets using the technique specified in Section 8.7.2.2.1.
2. If $q = 2^m$, then α must be a bit string of length *m* bits. Let $s_1,s_2,\ldots,s_m$ be the bits of α from leftmost to rightmost. Let $S_1,S_2,\ldots,S_l$ be the octets of *S* from leftmost to rightmost. The rightmost bit s_m shall become the rightmost bit of the last octet S_l, and so on through the leftmost bit s_1, which shall become the $(8l - m + 1)^{th}$ bit of the first octet S_1. The leftmost $(8l - m)$ bits of the first octet S_1 shall be zero.

8.7.2.3.2 Octet-String-to-Field-Element Conversion

Input: An octet string *S* of length *l* octets, and an indication of the field F_q used.

Output: An element α in F_q.

1. If *q* is an odd prime, then convert *S* to an integer α using the technique specified in Section 8.7.2.2.2. It is an error if α does not lie in the interval [0, *q* - 1].
2. If $q = 2^m$, then α shall be a bit string of length *m* bits. Let $s_1,s_2,\ldots,s_m$ be the bits of α from leftmost to rightmost. Let $S_1,S_2,\ldots,S_l$ be the octets of *S* from leftmost to rightmost. The rightmost bit of the last octet S_l shall become the rightmost bit s_m, and so on through the $(8l - m + 1)^{th}$ bit of the first octet S_1, which shall become the leftmost bit s_1. The leftmost $(8l - m)$ bits of the first octet S_1 are not used.

8.7.2.3.3 Field-Element-to-Integer Conversion

Input: An element α in the field F_q.

Output: An integer *x*.

1. If q is an odd prime then $x = \alpha$ (no conversion is required).
2. If $q = 2^m$, then α must be a bit string of length m bits. Let $s_1,s_2,\ldots,s_m$ be the bits of α from leftmost to rightmost. α shall be converted to an integer x satisfying:

$$x = \sum_{i=1}^{m} 2^{(m-i)} s_i$$

8.7.2.4 Elliptic Curve Parameters, Keys, and Point Representations

8.7.2.4.1 Elliptic Curve Parameters

Elliptic curve parameters may either be common to several key pairs (*common elliptic curve parameters*) or specific to one key pair (*specific elliptic curve parameters*). The elliptic curve parameters may be public; the security of the system does not rely on these parameters being secret. Two cases are distinguished:

1. When the underlying field is F_p (p an odd prime), and
2. When the underlying field is F_{2^m}.

8.7.2.4.1.1 Elliptic Curve Parameters Over F_p

Elliptic curve parameters over F_p shall consist of the following parameters:

a. A field size $q = p$ which defines the underlying finite field F_q, where p, $p > 3$, shall be a prime number;

b. Two field elements a and b in F_q which define the equation of the elliptic curve E: $y^2 = x^3 + ax + b$;

c. Two field elements x_P and y_P in F_q which define a point $P = (x_P,y_P)$ on E of prime order; and

d. The order n of the point P. It must be the case that $n > 2^{150}$.

8.7.2.4.1.2 Elliptic Curve Parameter Validation Over F_p

The following conditions shall be used to verify the elliptic curve parameters over F_q. A user of the system may alternately verify these conditions.

a. Verify that $q = p$ is an odd prime number.

b. Verify that $(4a^3 + 27b^2) \neq 0 \pmod{p}$.

c. Verify that $y_P^2 \equiv x_P^3 + ax_P + b \pmod{p}$.

d. Verify that n is prime and that $n > 2^{150}$.

e. Verify that $nP = 0$.

f. Verify that the MOV or equivalent condition holds (Section 8.7.8.1).

If any of the above verifications fail, then reject the elliptic curve parameters.

8.7.2.4.1.3 Elliptic Curve Parameters Over F_{2^m}

Elliptic curve parameters over F_{2^m} shall consist of the following parameters:

a. A field size $q = 2^m$ which defines the underlying finite field $F_{q;}$

b. Two field elements a and b in F_q which define the equation of the elliptic curve E;

c. Two field elements x_P and y_P in F_q which define a point $P = (x_P,y_P)$ on E of prime order; and

d. The order n of the point P. It must be the case that $n > 2^{150}$.

8.7.2.4.1.4 Elliptic Curve Parameter Validation Over F_{2^m}

The following conditions may be used to verify the elliptic curve parameters over F_{2^m}:

a. Verify that $q = 2^m$ for some m.

b. Verify that $b \neq 0$.

c. Verify that $y_P^2 + x_P y_P = x_P^3 + a x_P^2 + b$ in F_{2^m}

d. Verify that n is prime and that $n > 2^{150}$.

e. Verify that $nP =$ 0.

f. Verify that the MOV or equivalent condition holds (Section 8.7.8.1).

If any of the above verifications fail, then reject the elliptic curve parameters.

8.7.2.4.2 Key Generation

Given particular elliptic curve parameters, an elliptic curve key pair shall be generated by performing the following operations:

1. Select a statistically unique and unpredictable integer d in the interval [2, n - 2].
   It is acceptable to use a random or pseudorandom number. If a pseudorandom number is used, it shall be generated using the procedure of ANSI X9.30, Part 1 [ANS97a], Appendix B.
2. Compute the point $Q = (x_Q, y_Q) = dP$.
3. The key pair is (Q,d), where Q is the public key, and d is the private key.

The key and algorithm details are conveyed by the Security Services Information Element as described in Section 7.2.3.5.

8.7.2.4.3 Representing an Elliptic Curve Point

A finite point on E is specified by two elements x and y in F_q satisfying the defining equation for E. These are called the *affine coordinates* for the point. The point at infinity O has no affine coordinates. For purposes of internal computation, it is most convenient to represent O by a pair of coordinates (x,y) not on E. In the characteristic 2 case the simplest choice is O=(0,0). For $q=p$, one chooses O=(0,0) unless $b=0$ in which case O=(0,1).

An elliptic curve point P (which is not the point at infinity 0) is represented by two field elements, the x-coordinate of P and the y-coordinate of P: $P = (x_P, y_P)$.

8.7.2.4.3.1 Point-to-Octet-String conversion

The octet string representation of the point at infinity 0 shall be a single zero octet 00.

An elliptic curve point $P = (x_p , y_p)$ which is not the point at infinity shall be represented as an octet string in the following form:

Input: An elliptic curve point $P = (x_p , y_p)$, not the point at infinity.
Output: An octet string PO of length $2l$ octets. ($l = \lceil (\log_2 q)/8 \rceil$.)

1. Convert the field element x_p to an octet string X_1. (See Section 8.7.2.3.1.)
2. Convert the field element y_p to an octet string Y_1. (See Section 8.7.2.3.1.)
3. The result is the octet string $PO = X_1 \| Y_1$.

8.7.2.4.3.2 Octet-String-to-Point conversion

Input: An octet string *PO* of length 1 octet or 2*l* octets. ($l = \lceil (\log_2 q)/8 \rceil$.)
Output: An elliptic curve point $P = (x_p, y_p)$.

1. If the length of PO is 1 and has value 00, then output the point at infinity, otherwise:
2. Convert the first *l* octets X_1 to the field element x_p (See Section 8.7.2.3.2.)
3. Convert the last *l* octets Y_1 to the field element y_p. (See Section 8.7.2.3.2.)
4. The result is the elliptic curve point $P = (x_p, y_p)$.

8.7.3 The Elliptic Curve Digital Signature Algorithm (EC-GDSA)

8.7.3.1 Signature Generation

This section describes the EC-GDSA signature generation process. This signature is suggested for standardization in ISO/IEC JTC1.

The signature generation process consists of three steps: message digesting, elliptic curve computations, and modular computations.

The input to the signature process is:

- The message, *M*, of arbitrary length, which is represented by a bit string.
- Elliptic curve parameters *q*, *a*, *b*, $P = (x_P, y_P)$, and *n*.
- An elliptic curve private key *d*.

To sign a message *M*, *A* should do the following.

8.7.3.1.1 Message Digesting

Compute the hash value $e = H(M)$ using the hash function SHA-1 per ANSI X9.30-199X, Part 2 [ANS97b]. *e* is represented as an integer of length 160 bits.

8.7.3.1.2 Elliptic Curve Computations

1. Select a statistically unique and unpredictable integer *k* in the interval [2, *n* - 2].
2. Compute the elliptic curve point $(x_1, y_1) = kP$.
3. Convert the field element x_1 to an integer $\overline{x}_1$, as described in Section 8.7.2.3.3.
4. Set $r = \overline{x}_1 \mod n$.
5. If $r = 0$ then go to step 1.

8.7.3.1.3 Modular Computations

1. Compute $s = (kr - e)\, d^{-1} \mod n$ in the case of EC-GDSA.
2. If $s = 0$ then go to Step 1 of Section 8.7.3.1.2.

8.7.3.1.4 The Signature

The output from the signature generation process shall be the signature for *M*, which is represented as the two integers, *r* and *s*.

Note: If *k* is chosen correctly (see Section 8.7.3.1.2, item 1), the probability that either $r = 0$ or $s = 0$ is negligibly small.

8.7.3.2 Signature Verification

This section describes the EC-GDSA signature verification process.

The signature verification process consists of three steps: message digesting, elliptic curve computations, and signature checking.

The input to the signature verification process is:

- The received message, *M'*, represented as a bit string.
- The received signature for *M*, represented as the two integers, *r'* and *s'*.
- Elliptic curve parameters *q*, *a*, *b*, $P = (x_P, y_P)$, and *n*.
- An elliptic curve public key, *Q*.

To verify *A*'s signature on message *M*, *B* should do the following.

8.7.3.2.1 Message Digesting

Compute the hash value $e = H(M')$ using the hash function SHA-1 per ANSI X9.30-199X, Part 2. *e* is represented as an integer of length 160 bits.

8.7.3.2.2 Elliptic Curve Computations for EC-GDSA

1. If *r'* is not an integer in the interval [1, *n* -1], then reject the signature.
2. If *s'* is not an integer in the interval [1, *n* -1], then reject the signature.
3. Compute $w = (r')^{-1} \bmod n$.
4. Compute $u_1 = sw \bmod n$ and $u_2 = ew \bmod n$.
5. Compute the elliptic curve point $(x_1, y_1) = u_2P + u_1Q$.

8.7.3.2.3 Signature Checking

1. Convert the field element x_1 to an integer $\bar{x}_1$, as described in Section 8.7.2.3.3.
2. Compute $v = \bar{x}_1 \bmod n$.
3. If $r' = v$, then the signature is verified and the verifier can have a high level of confidence that the received message was sent by the party holding the secret key *d* corresponding to *Q*.

If *r'* does not equal *v*, then the message may have been modified, the message may have been incorrectly signed by the signatory, or the message may have been signed by an impostor. The message should be considered invalid.

8.7.4 EC-GDSA Asymmetric Authentication

An asymmetric authentication scheme based on elliptic curves can be derived from the signature scheme presented in Section 8.7.3 using the principle of "challenge-and-response."

8.7.4.1 Challenge

This section describes the challenge process.

B chooses at random a challenge integer *c*, where $0 < c < n$, and sends it to *A*.

8.7.4.2 Response Generation

This section describes the response generation process.

The response generation process consists of two steps: elliptic curve computations and modular computations.

The input to the response process is:

- The challenge *c*.
- Elliptic curve parameters.
- An elliptic curve private key *d*.

To generate a response to *B*'s challenge, *A* should do the following.

8.7.4.2.1 Elliptic Curve Computations

1. Choose a statistically unique and unpredictable integer k in the interval [2, n - 2].
2. Compute the curve point $R = (x_1,y_1) = kP$.
3. Convert the field element x_1 to the integer $\overline{x}_1$ as described in Section 8.7.2.3.3.
4. Set $r = \overline{x}_1 \mod n$.
5. If $r = 0$, go to step 1.

8.7.4.2.2 Modular Computations

1. Compute $s = (kr - c)d^{-1} \mod n$ in the case of EC-GDSA.
2. If $s = 0$ then go to Step 1 of 8.7.4.2.1.

8.7.4.2.3 The Response

The *response* (*r*,*s*) shall be sent to *B*.

8.7.4.3 Response Verification

This section describes the response verification process.

There are two steps to the response verification process: elliptic curve computations and response checking.

The input to the response verification process is:

- The challenge *c*.
- Elliptic curve parameters.
- An elliptic curve public key *Q*.
- The response (*r*,*s*).

To verify *A*'s response, *B* should do the following.

8.7.4.3.1 Elliptic Curve Computations for EC-GDSA

1. If *r'* is not an integer in the interval [1, n -1], then reject the response.
2. If *s'* is not an integer in the interval [1, n -1], then reject the response.
3. Compute $w = (r')^{-1} \mod n$.
4. Compute $u_1 = sw \mod n$ and $u_2 = cw \mod n$.

5. Compute the elliptic curve point $(x_1, y_1) = u_2P + u_1Q$.

8.7.4.3.2 Response Checking

1. Convert the field element x_1 to an integer $\overline{x}_1$, as described in Section 8.7.2.3.3.
2. Compute $v = \overline{x}_1 \mod n$.
3. If $r' = v$, then the response is verified and the verifier can have a high level of confidence that the response was sent by the party holding the secret key d corresponding to Q.

8.7.5 Elliptic Curve Key Agreement Scheme—Diffie-Hellman Analogue (ECKAS-DH)

This section describes the Elliptic Curve Key Agreement Scheme—Diffie-Hellman Analogue.

The input to the scheme is:

- Elliptic curve parameters.

However, it is not necessary that the users know the order n of the point P. The public and private keys of the users are not involved in this protocol.

8.7.5.1 Key Computations

To agree upon a common key, A and B do the following calculations:

1. A chooses a random integer a, greater than 1 but smaller than the field size, and determines the point aP. A sends aP to B.
2. B chooses a random integer b, greater than 1 but smaller than the field size, and determines the point bP. B sends bP to A.
3. A determines $a(bP)$, B determines $b(aP)$. Both points coincide and constitute the common key.

8.7.6 References

Elliptic curves cryptosystems were first proposed in 1985 independently by Neal Koblitz [Kob87] and Victor Miller [Mil86]. Since then, much research has been done towards improving the efficiency of these systems and evaluating their security. For a summary of this work, consult [Men93], [Bla99], and [Eng99].

A good reference on the theory of finite fields is the book of Lidl and Niederreiter [LN94].

The NIST Digital Signature Algorithm (DSA) is described in [ANS97a] and [NIS98]. The Secure Hash Algorithm is described in [ANS97b] and [NIS95]. Abstract Syntax Notation One, Basic Encoding Rules (BER) and Distinguished Encoding Rules (DER) are described in [ISO98a] and [ISO98b]. EC-GDSA is described in [ISO15946-2].

8.7.6.1 Normative References

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8.7.6.2 Informative References

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8.7.7 Security Considerations [informative]

This section is provided as initial guidance for implementers of this specification. This information should be expected to change over time. Implementers should review the current state of the art at the time of implementation.

This section summarizes the best attacks known on the elliptic curve discrete logarithm problem, which is the basis for the security of elliptic curve systems. Estimates of security levels for elliptic curve parameters of various sizes are provided.

Notation

E denotes an elliptic curve over the finite field F_q, $P \in E(F_q)$ is a point of order n, where n is a prime number and $n > 2^{150}$.

The Elliptic Curve Discrete Logarithm Problem

The elliptic curve discrete logarithm problem (ECDLP) is the following: given E, P and $Q \in E$, determine the integer l, $0 \le l \le n-1$, such that $Q = lP$, provided that such an integer exists.

The best algorithm known to date for ECDLP is the Pollard-ρ method [Pol78] which takes about $\sqrt{\pi n / 2}$ steps. By a *step* here, we shall mean an elliptic curve addition. The Pollard-ρ can be parallelized (see [OW94]) so that if m processors are used then the expected number of steps by each processor before a single discrete logarithm is obtained is $(\sqrt{\pi n / 2}) / m$.

The special classes of elliptic curves, called *supersingular curves*, have been prohibited in this specification by the requirement of the MOV condition (see Section 8.7.8.1). This is because there is a method for efficiently reducing the discrete logarithm problem in these curves to the discrete logarithm problem in a finite field.

Software Attacks

We assume that a MIPS (Million Instructions Per Second) machine can perform 4×10^4 elliptic curve additions per second. (This estimate is indeed conservative—an ASIC built for performing elliptic curve operations over the field $F_{2^{155}}$ has a 40 MHz clock-rate and can perform roughly 40,000 elliptic operations per second.) Then, the number of elliptic curve additions that can be performed by a 1 MIPS machine in one year is

$$(4 \times 10^4) \cdot (60 \times 60 \times 24 \times 365) \approx 2^{40}.$$

Table 16 shows, for various values of n, the computing power required to compute a single discrete logarithm. As an example, if 10,000 computers each rated at 1,000 MIPS are available, and $n \approx 2^{250}$, then an elliptic curve discrete logarithm can be computed in 3,800 years.

Odlyzko [Odl95] has estimated that if 0.1% of the world's computing power were available for one year to work on a collaborative effort to break some challenge cipher, then the computing power available would be 10^8 MIPS years in 2004 and 10^{10} to 10^{11} MIPS years in 2014.

Field size (in bits)	Size of *n* (in bits)	$\sqrt{\pi n / 2}$	MIPS years
155	150	2^{75}	3.8×10^{10}
158	153	2^{77}	1.1×10^{11}
209	204	2^{102}	5.0×10^{18}
210	205	2^{103}	7.1×10^{18}
239	234	2^{117}	1.6×10^{23}

Table 16: Computing Power to Compute Elliptic Curve Logarithms with the Pollard-ρ Method.

To put the numbers in Table 16 into some perspective, Table 17 (due to Odlyzko [Odl95]) shows the computing power required to factor integers with current versions of the general number field sieve.

Size of *n* (in bits)	MIPS years
512	3×10^4
768	2×10^8
1024	3×10^{11}
1280	1×10^{14}
1536	3×10^{16}
2048	3×10^{20}

Table 17: Computing Power Required to Factor Integers Using the General Number Field Sieve.

Hardware Attacks

A more promising attack (for well-funded attackers) on elliptic curve systems would be to build special-purpose hardware for a parallel search. Van Oorschot and Wiener [OW94] provide a detailed study of such a possibility. They estimated that if $n \approx 10^{36} \approx 2^{120}$, then a machine with m = 325,000 processors that could be built for about $10 million would compute a single discrete logarithm in about 35 days.

It must be emphasized that these estimates were made for specific elliptic curve parameters having $n \approx 10^{36} \approx 2^{120}$. This specification mandates that the parameter *n* should satisfy

$$n > 2^{150} \approx 10^{45}.$$

Discussion

It should be pointed out that for the software and hardware attacks described above, computation of a single elliptic curve discrete logarithm has the effect of revealing a *single* user's private key. The same effort must be repeated in order to determine another user's private key.

In [BDR96], Blaze et al. report on the minimum key lengths required for secure symmetric-key encryption schemes (such as DES and IDEA). Their report comes to the following conclusion:

> *To provide adequate protection against the most serious threats—well-funded commercial enterprises or government intelligence agencies—keys used to protect data today should be at least 75 bits long. To protect information adequately for the next 20 years in the face of expected advances in computing power, keys in newly deployed systems should be at least 90 bits long.*

Extrapolating these conclusions to the case of elliptic curves, we see that *n* should be at least 150 bits for short-term security, and at least 180 bits for medium-term security. This extrapolation is justified by the following considerations:

1. Exhaustive search through a *k*-bit symmetric-key cipher takes about the same time as the Pollard-ρ algorithm applied to an elliptic curve having a 2*k*-bit parameter *n*.
2. Both exhaustive search with a symmetric-key cipher and the Pollard-ρ algorithm can be parallelized with a linear speedup.
3. A basic operation with elliptic curves (addition of two points) is computationally more expensive than a basic operation in a symmetric-key cipher (encryption of one block).
4. In both symmetric-key ciphers and elliptic curve systems, a "break" has the same effect: it recovers a single private key.

More information regarding minimum key lengths can be found in [LV99].

8.7.8 Required Number-Theoretic Algorithms [normative]

8.7.8.1 The MOV and Frey-Rueck Condition

The reduction attack of Menezes, Okamoto, and Vanstone [MOV93] reduces the discrete logarithm problem in an elliptic curve (ECDLP) over F_q to the discrete logarithm in the finite field F_{q^B} for some $B \geq 1$. Other work has treated problems that are closely related to ECDLP. Frey and Rueck [FR94] used a variant of the Tate pairing for abelian varieties over local fields to obtain an attack, which works on projective irreducible nonsingular curves of genus *g* over finite fields.

The attack is only practical if *B* is small; this is not the case for most elliptic curves. The *MOV and Frey-Rueck condition* ensures that an elliptic curve is not vulnerable to this reduction attack.

Before performing the algorithm, it is necessary to select an MOV and Frey-Rueck threshold. This is a positive integer *B* such that taking discrete logarithms over F_{q^B} is at least as difficult as taking elliptic discrete logarithms over F_q. For this specification, a value $B \geq 20$ is required. This algorithm is used in elliptic curve parameter validation (Sections 8.7.2.4.1.2 and 8.7.2.4.1.4) and elliptic curve parameter generation (Section 8.7.8.3.2).

Input: An MOV and Frey-Rueck threshold *B*, a prime-power *q*, and a prime *n*.

Output: The message "True" if the MOV and Frey-Rueck condition is satisfied for an elliptic curve over F_q with a base point of order *n*; the message "False" otherwise.

1. Set $t = 1$.
2. For *i* from 1 to *B* do
   2.1 Set $t = t \cdot q \bmod n$.
   2.2 If $t = 1$ then output "False" and stop.
3. Output "True."

8.7.8.2 Primality

8.7.8.2.1 A Probabilistic Primality Test

The probabilistic primality test shall be performed as described below or using another method that can be demonstrated to be of equal or better quality (c.f. [P1363], [ANS98]).

If *n* is a large positive integer, the following probabilistic algorithm (the *Miller-Rabin test*) [Knu81] will determine whether *n* is prime or composite, with arbitrarily small probability of error. This algorithm is used in elliptic curve parameter validation (Sections 8.7.2.4.1.2 and 8.7.2.4.1.4), elliptic curve parameter generation (Section 8.7.8.3.2), and in checking for near primality (Section 8.7.8.2.2).

Input: A large odd integer *n*, a positive integer *T*.
Output: The message "prime" or "composite."

1. Compute *v* and odd *w* such that $n - 1 = 2^v w$.
2. For *j* from 1 to *T* do
   2.1 Choose random *a* in the interval [2, *n* - 1].
   2.2 Set $b = a^w \bmod n$.
   2.3 If *b* = 1 or *n* - 1 go to Step 2.6.
   2.4 For *i* from 1 to *v* - 1 do
      2.4.1 Set $b = b^2 \bmod n$.
      2.4.2 If *b* = *n* - 1 go to Step 2.6.
      2.4.3 If *b* = 1 output "composite" and stop.
      2.4.4 Next *i*.
   2.5. Output "composite" and stop.
   2.6. Next *j*.
3. Output "prime."

If the algorithm outputs "composite," then *n* is composite. If the algorithm outputs "prime," then *n* is *probably* prime. The probability of a false "prime" conclusion is less than 2^{-2T}. Thus the probability of error can be made negligible by taking large enough *T* (say, *T* = 50).

8.7.8.2.2 Checking for Near Primality

The near primality test shall be performed as described below or using another method that can be demonstrated to be of equal or better quality (c.f. [P1363], [ANS98]).

Given a trial division bound l_{max}, we say that the positive integer *k* is *smooth* if every prime divisor of *k* is at most l_{max}. Given a large positive integer r_{min}, we say that *u* is *nearly prime* if *u* = *kn* for some prime *n* $\geq r_{min}$ and some smooth integer *k*. The following algorithm checks for near primality. The algorithm is used in elliptic curve parameter generation (Section 8.7.8.3.2.).

Input: Positive integers *u*, l_{max}, and r_{min}.

Output: If *u* is nearly prime, a prime $n \geq r_{min}$ and a smooth integer *k* such that: *u* = *kn*.

If *u* is not nearly prime, the message "not nearly prime."

1. Set *n* = *u*, *k* = 1.
2. For *l* from 2 to l_{max} do
   2.1 If *l* is composite then go to Step 2.3.
   2.2 While (*l* divides *n*)
      2.2.1 Set *n* = *n* / *l* and *k* = *k*· *l*.
      2.2.2 If $n < r_{min}$ then output "not nearly prime" and stop.
   2.3 Next *l*.
3. If *n* is prime (see Section 8.7.8.2.1) then output *k* and *n* and stop.
4. Output "not nearly prime."

8.7.8.3 Elliptic Curve Algorithms

8.7.8.3.1 Finding a Point of Large Prime Order

A point of large prime order shall be found as described below or using another equivalent method (c.f. [P1363], [ANS98]).

If the order $\#E(F_q) = u$ of an elliptic curve E is nearly prime, the following algorithm efficiently produces a random point on E whose order is the large prime factor n of $u = kn$. The algorithm is used in elliptic curve parameter generation (Section 8.7.8.3.2.).

Input: A prime n, a positive integer k not divisible by n, and an elliptic curve E over the field F_q with $\#E(F_q) = u$.

Output: If $u = kn$, a point P on E of order n. If not, the message "wrong order."

1. Generate a random point G (not 0) on E (see Section 8.7.9.1.1).
2. Set $P = kG$.
3. If $P = 0$ then go to Step 1.
4. Set $Q = nP$.
5. If $Q \neq 0$ then output "wrong order" and stop.
6. Output P.

8.7.8.3.2 Selecting an Appropriate Curve and Point at Random

Given a field size q, a lower bound r_{min} for the point order, and trial division bound l_{max}, the following is the procedure that shall be used for randomly choosing a curve and point.

1. If $q = p$, then check the primality of p using the technique defined in Section 8.7.8.2.1.
2. Randomly select parameters $a, b \in F_q$ to define the elliptic curve equation.
   - In the case that q is a prime, verify that $4a^3 + 27b^2 \neq 0 \pmod{p}$.
     - The curve equation is $E: y^2 = x^3 + ax + b$.
     - In the case that $q = 2^m$, verify that $b \neq 0$. The curve equation is $E: y^2 + xy = x^3 + ax^2 + b$.
3. Compute the order of the curve $u = \#E(F_q)$. (See Note 5 below.)
4. Test u for near primality using the technique defined in Section 8.7.8.2.2. If the result is "not nearly prime," then go to Step 2. Otherwise, $u=kn$ where k is smooth and n is prime.
5. Check the MOV or equivalent condition (see Section 8.7.8.1) with inputs B, q, and n. If the result is "False," then go to Step 2.
6. Find a point P on E of order n using the technique defined in Section 8.7.8.3.1.
7. Output the curve E and the point P.

Notes:
1. r_{min} shall be selected so that $r_{min} > 2^{150}$. The security level can be increased by selecting a larger r_{min} (e.g., $r_{min} > 2^{160}$ or $r_{min} > 2^{200}$).
2. If q is prime then the order u of an elliptic curve E over F_q satisfies $q + 1 - 2\sqrt{q} \leq u \leq q + 1 + 2\sqrt{q}$. Hence r_{min} must be $\leq q+1-2\sqrt{q}$.
3. If $q = 2^m$ then the order u of an elliptic curve E over F_q satisfies $q + 1 - 2\sqrt{q} \leq u \leq q + 1 + 2\sqrt{q}$, and u is even. Hence r_{min} must be $\leq (q+1-2\sqrt{q})/2$.
4. l_{max} is typically a small integer (e.g., $l_{max} = 255$).
5. The order $\#E(F_q)$ can be computed by using Schoof's algorithm [Sco 85]. Although the basic algorithm is quite inefficient, several dramatic improvements and extensions of this method have been discovered in recent years. Currently it is feasible to compute orders of elliptic curves over F_p where p is as large as 10^{499}, and orders of elliptic curves over F_{2^m} where m is as large as 1300. Of more relevance is that the orders of elliptic curves over fields such as

$F_{2^{155}}$ can now be computed in less than 4 minutes on a workstation [LM 95]. Substantial improvements have made since [LM95].

8.7.9 Other Number-theoretic algorithms [informative]

8.7.9.1 Elliptic Curve Algorithms

8.7.9.1.1 Finding a Point on an Elliptic Curve

The following algorithms provide an efficient method for finding a statistically unbiased and unpredictable point (other than 0) on a given elliptic curve over a finite field.

Case I: Curves over F_p

Input: A prime p and the parameters a, b of an elliptic curve E over F_p.

Output: A randomly generated point (other than 0) on E.

1. Choose random integer x with $0 \le x < p$.
2. Set $\alpha \leftarrow x^3 + ax + b \bmod p$.
3. If $\alpha = 0$ then output $(x, 0)$ and stop.
4. If $\alpha^{(p-1)/2} \equiv -1 \pmod p$ then go to Step 1.
5. Find an integer y such that $y^2 \equiv \alpha \pmod p$.
6. Output (x, y).

Case* II*: Curves over F_{2^m}**.**

Input: A field F_{2^m} and the parameters a, b of an elliptic curve E over F_{2^m}.

Output: A randomly generated point (other than 0) on E.

1. Choose random x in F_{2^m}.
2. If $x = 0$ then output $(0, b^{2^{m-1}})$ and stop.
3. Set $\alpha = x^3 + ax^2 + b$.
4. If $\alpha = 0$ then output $(x, 0)$ and stop.
5. Set $\beta = x^{-2} \alpha$.
6. If $\mathrm{Tr}(\beta) = 1$ then go to Step 1 (Tr is the *trace* function).
7. Find an element z such that $z^2 + z = \beta$, see [P1363, A.4.7].
8. Set $y = xz$.
9. Output (x, y).

Appendix I Determination of Resynchronization Rate

(This Appendix does not form an integral part of this specification.)

Choice of Resynchronization rate is dependent on several factors including actual traffic rates and cell loss rates. The following information is presented as one possible method for choosing a resynchronization rate.

I.1 Expected Cell Loss Rates

Network cell loss statistics can be used to determine the appropriate resynchronization rate. Typical error rate requirements for ATM are specified by the Cell Loss Ratio (CLR), which is defined as: lost cells / transmitted cells. CLR requirements differ by type of traffic and Quality of Service (QoS). A typical worst case CLR requirement for an ATM network is 10^{-4} for low-priority Packet Video/Audio traffic when the Cell Loss Priority (CLP) bit in the cell header is set to one. This means that a single 622 Mbps connection carrying this type of traffic with a cell loss ratio of 10^{-4} will lose sync 142 times per second on average, assuming no cell loss insensitivity. This is a worst case example. More typical error ratios, e.g., 10^{-7} result in 0.14 lost cells per second on a full bandwidth 622 Mbps connection.

To conserve the bandwidth required for resynchronization, it is necessary to resynchronize based on the bandwidth of the connection and the negotiated QoS. Higher bandwidth connections are resynchronized more often than those of lower bandwidths are. Connections with lower CLR may resync at a lower rate than high CLR connections.

I.2 Determining CLR

The encryptor can use the expected CLR of the connection to adjust its frequency of transmitting resynchronization messages. The Quality of Service is specified by the user to the network in the QoS parameter of the SETUP message. The encryptor can intercept the SETUP message and use the QoS parameter to determine the acceptable CLR for the connection based on a user configurable mapping function. This provides a fair indication of the expected upper bound on the CLR to be encountered.

I.3 Resynchronization Rate

The resynchronization rate can be chosen to be ten times the cell loss rate (CLR). For example, a connection that loses 100 cells per second on average will have a resync rate of 1000 resyncs per second. Making the resync rate ten times the cell loss rate will ensure that on average only 5 percent of the traffic is lost due to loss of cryptographic synchronization. The resync rate for each connection can be based on the following formula:

> Resync rate (resyncs/second) = cell loss ratio (cells dropped/cells transmitted) x sustainable cell rate (cells transmitted/second) x 10.

Using the above formula, the maximum resync rate for a 622 Mbps connection will be 1417 times a second, for a CLR of 10^{-4}. This results in an added overhead of 0. 1%. There may be value in establishing a minimum resync rate.

Note: there is no value in resynchronizing in the middle of an AAL5 message, since any cell loss causes the entire message to be discarded by the receiver.

Appendix II Label-Based Access Control

(This Appendix does not form an integral part of this specification)

II.1 Scenarios

ATM access control can occur either within an ATM end-point or at any intermediate ATM node (i.e., an ATM switch or an in-line security device). In each case, network administrators establish (either through the network management protocol or through direct configuration of the ATM devices) that an ATM physical interface requires access control parameters. During connection establishment, an ATM component for such an interface is required to communicate the necessary access control parameters, and an ATM device receiving these access control parameters would perform access control using those parameters. This exchange of access control data could occur across (1) an end-point to private switch interface, (2) a private switch to private switch interface, (3) a private switch to public switch interface, or (4) a public switch to public switch interface. Also, the initiator of the access control parameters could be either the initiator of the connection, some intermediate ATM switch, or an ATM security device. A typical application for label-based access controls is shown in Figure 52.

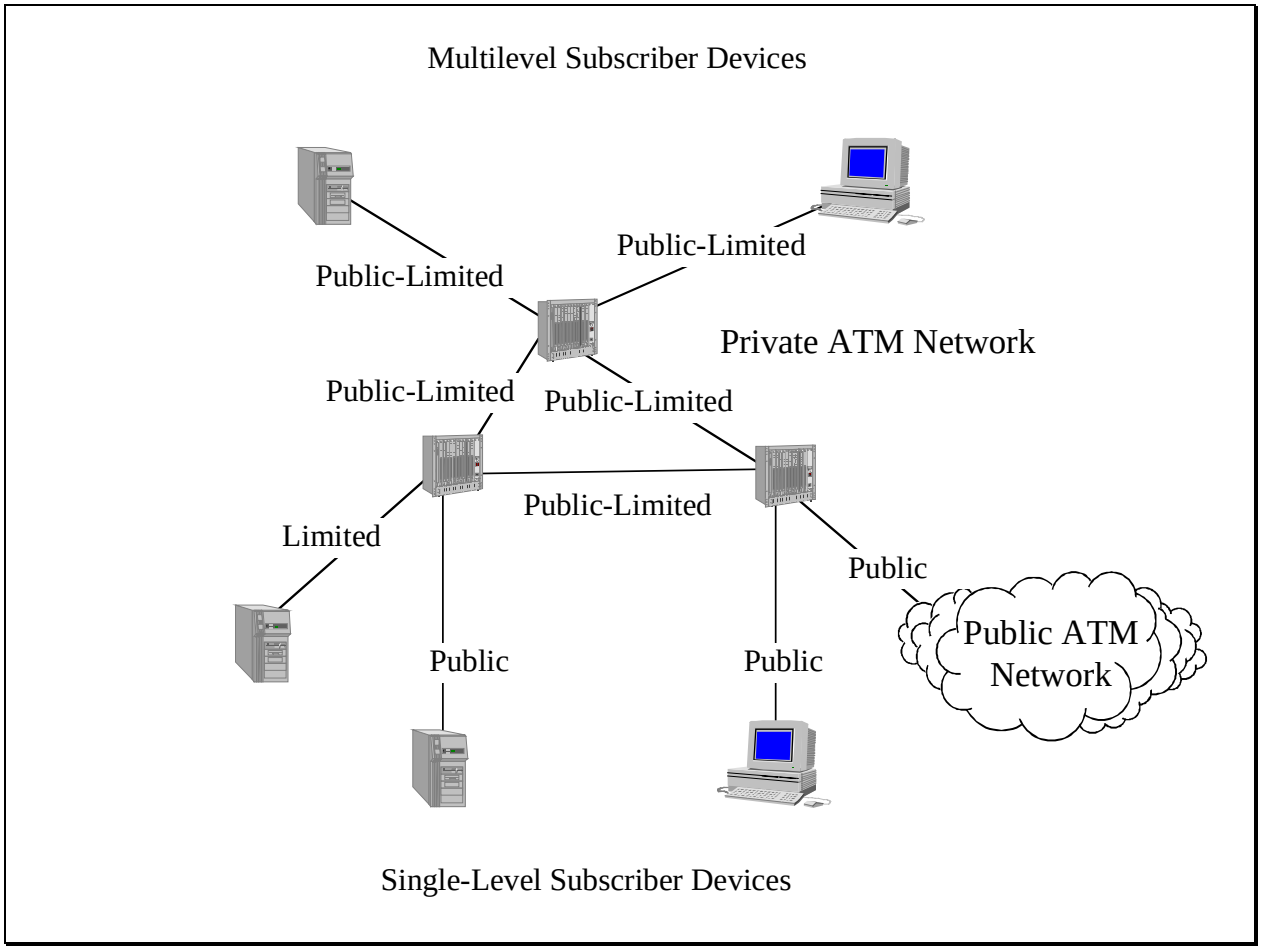

Figure 52: Typical Access Control Scenarios.

In this context, multilevel refers to a device that can interpret security labels and can maintain separation of data marked at different security levels. For this scenario, an enterprise marks its data as either "public," indicating that the data is releasable to the public, or "limited," indicating that the data must stay within the enterprise. In this scenario, the multilevel devices (switches and multilevel subscriber devices) within the private ATM network ensure that only publicly releasable information is sent to public subscriber devices or through the public ATM switches. Within the private ATM network, the multilevel devices (switches and multilevel subscriber devices) ensure that all connections are labeled.

This scenario requires labeling mechanisms within the private UNI and P-NNI. Figure 53 shows a scenario using labeling mechanisms within public ATM switches, requiring labeling mechanisms within the public UNI and B-ICI.

In this second scenario, the public network provider offers a multilevel access control service to subscriber networks, enabling selected private networks to communicate. Each subscriber interface is labeled with the set of companies permitted to send data across that interface. This mechanism restricts which private networks can communicate with a specific company's private networks. For example, neither Company A nor Company B could communicate directly with Company C's private networks. However, companies A and C do share a common private network (perhaps a consortium, common supplier, or common customer) through which they might communicate, depending on the policy of that private network. The multilevel devices (i.e., the public switches and the switches within the multilevel subscriber networks) ensure that each connection is labeled.

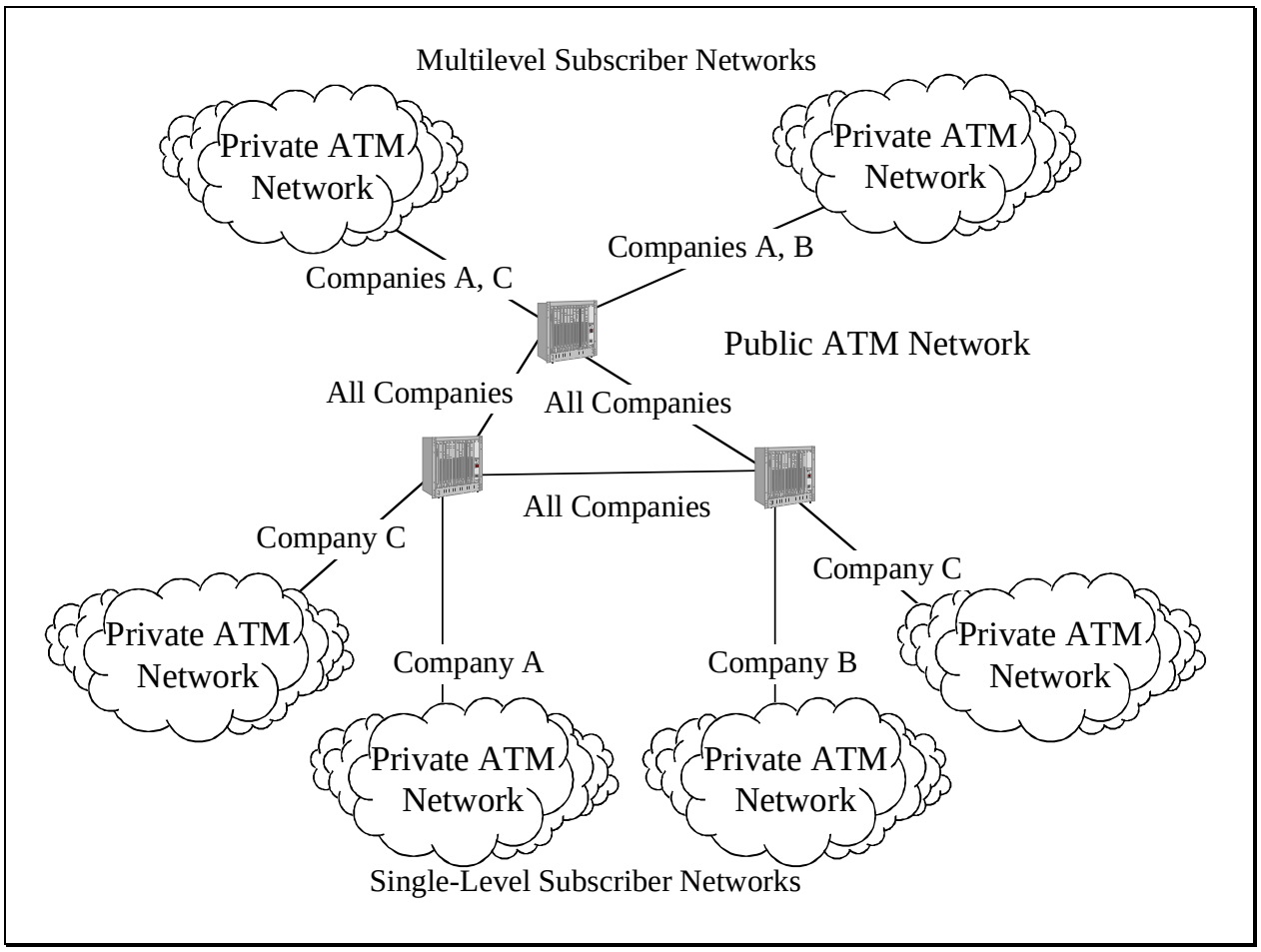

Figure 53: Access Control Scenario for Public Switches.

Access control enforcement is the same for both scenarios. On receipt of a connection request, the multilevel devices ensure that the connection request either (1) came from a single-level interface, in which case the connection is labeled at the level of the interface; or (2) came from a multilevel interface, in which case the connection must be in the set of security levels permitted for that interface. On transmission of a connection request, the multilevel devices ensure that the connection security level is transmitted during the connection setup protocol if the request is placed on an interface requiring labeling (e.g., a multilevel interface).

II.2 Label-Based Access Control Concepts

Typical label-based0 access control mechanisms are based on a concept of sensitivity levels. A sensitivity level represents the sensitivity of the data to disclosure. For example, a sensitivity level might indicate the extent to which a company's data must be protected, with different sensitivity levels (e.g., public data, proprietary, company confidential, company limited, and competition sensitive) indicating different degrees of control.

A typical sensitivity level comprises two components: (1) a hierarchical level and (2) a set of access categories. These levels are used with a partially ordered relation on the set of sensitivity levels. This

relation determines whether one sensitivity level is less than, equal to, greater than, or not comparable with another sensitivity level. The hierarchical level component of a sensitivity level is linearly ordered, with its own "less than" relation. The relation used for the access category sets is set containment. That is, one set of access categories is said to be "less than or equal to" another set of access categories if the first is a subset of the second. Thus, sensitivity level SL1=(HL1, SC1) is less than or equal to sensitivity level SL2=(HL2, SC2) provided HL1 is less than or equal to HL2 and SC1 is a subset of SC2, where HL1 and HL2 are the hierarchical level components and SC1 and SC2 are the access category set components of SL1 and SL2, respectively.

Sensitivity labels are the physical representation of a sensitivity level. There may be multiple representations of the same sensitivity level. For a given sensitivity level, there are typically multiple representations (or sensitivity labels), including the human readable label (e.g., company limited/finance) and the internal representation of that label within a computing system.

II.3 Label-Based Access Control Rules

Label-based access control mechanisms within a network component require that each network object (i.e., packet or connection) have an associated sensitivity level and typically assign maximum and minimum sensitivity levels to each external physical interface to enable enforcement of the following rules.

1. The system may transmit a network object across a physical interface provided the object's sensitivity level is less than or equal to the interface's maximum sensitivity level.
2. The system may accept a network object across a physical interface for delivery provided the object's sensitivity level is less than or equal to the interface's maximum sensitivity level *and* greater than or equal to the interface's minimum sensitivity level.

Note that the object sensitivity level may be determined either by a label attached to the object or implicitly by the sensitivity level of the physical interface in the case when the maximum and minimum sensitivity levels of the physical interface are equal.

In the context of performing label-based access control only on connection setup, the network object is the connection, and the label would be carried in the setup message.

Appendix III Security Services Information Element Examples

(This Appendix does not form an integral part of this specification.)

This Appendix provides examples of the message formats used for Signaling-based and In-band security message exchange.

III.1 Initiate In-Band Security Message Exchange Using a Simple Exchange in Signaling

III.1.1 Simple In-Band Exchange Indication

This example shows a case in which a simple two-way signaling based exchange declares that a security service will be required on this developing VC and that In-Band Security Message Exchange will be used between the two security agents to establish the service.

Flow-1: *A –> B*

The initiating security agent places this SSIE in the call SETUP message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								1
1	1	1	0	0	1	1	1	
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					2
			Flag	Reserved	Information Element Action Indicator			
0x0008								3 - 4
Length of Security Services Information Element (8)								
0	0	0	0	0	0	0	1	5
Security Association Section Type (SME)								
0x0005								6 - 7
Security Association Section Length (5)								
0	0	1	1	1	0	0	1	8
Version (1.1)			Transport Ind.		Flow Indicator		Discard	
0	0	1	0	0	0	0	0	9
Region (Remote)								
1	1	1	0	0	0	0	0	10
Role (Any)								
0	0	0	0	0	0	0	1	11
Relative ID (Security Association ID)								
0	0	0	1	0	0	0	0	12
Relative ID (SAS Number)				reserved				

Flow-2: *B –> A*

The responding security agent places this SSIE in the call CONNECT message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								1
1	1	1	0	0	1	1	1	
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					2
			Flag	Reserved	Information Element Action Indicator			
0x0008								3 - 4
Length of Security Services Information Element (8)								
0	0	0	0	0	0	0	1	5
Security Association Section Type (SME)								
0x0005								6 - 7
Security Association Section Length (5)								
0	0	1	1	1	0	1	1	8
Version (1.1)			Transport Ind.		Flow Indicator		Discard	
0	0	1	0	0	0	0	0	9
Region (Remote)								
1	1	1	0	0	0	0	0	10
Role (Any)								
0	0	0	0	0	0	0	1	11
Relative ID (Security Association ID)								
0	0	0	1	0	0	0	0	12
Relative ID (SAS Number)				reserved				

III.1.2 With Requested Service Declaration

This example shows a case in which a two-way Signaling-Based Security Message Exchange between two security agents includes an indication that the initiating security agent intends to authenticate and support data integrity and that the service negotiation will then take place using an In-Band SME. This provides the responding security agent the ability to deny the call if authentication and integrity are not supported.

Flow-1: *A –> B*

The initiating security agent places this SSIE in the call SETUP message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								1
1	1	1	0	0	1	1	1	
Information element identifier								
1	Coding		Information Element Instruction Field					

Ext	Standard		Flag	Reserved	Information Element Action Indicator			2
0x000C								
Length of Security Services Information Element (12)								3 - 4
0	0	0	0	0	0	0	1	
Security Association Section Type (SME)								5
0x0009								
Security Association Section Length (9)								6 - 7
0	0	1	1	1	0	0	1	
Version (1.1)			Transport Ind.		Flow Indicator		Discard	8
0	0	1	0	0	0	0	0	
Region (Remote)								9
1	1	1	0	0	0	0	0	
Role (Any)								10
0	0	0	0	0	0	0	1	
Relative ID (Security Association ID)								11
0	0	0	1	0	0	0	0	
Relative ID (SAS Number)				reserved				12
0	0	1	0	0	1	1	0	
Security Message Exchange Format Identifier (2-way)								13
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier								14
1	0	0	0	1	0	1	0	
Security Service Declaration Identifier								15
0	0	0	0	0	1	1	0	
Security Service Declaration (authentication and integrity)								16

Flow-2: *B –> A*

The responding security agent accepts the call, despite the fact that it cannot support data integrity. The responding security agent must also make a security service declaration in the CONNECT message, indicating that it can support establishing authentication in a subsequent in-band exchange. It is then up to the initiating security agent to decide if the VC setup and the subsequent in-band negotiation should proceed. If the initiating security agent cannot continue due to its local security policy, i.e., the VC must support cryptographic integrity, then the initiating security agent will instruct its signaling entity to clear the call with the appropriate cause code and diagnostic, (see Section 5.1.6, "Security Policy Violation").

The responding security agent places this SSIE in the call CONNECT message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								
1	1	1	0	0	1	1	1	1
Information element identifier								
1	Coding		Information Element Instruction Field					

Ext	Standard			Flag	Reserved	Information Element Action Indicator		2
0x000C								
Length of Security Services Information Element (12)								3 - 4
0	0	0	0	0	0	0	1	
Security Association Section Type (SME)								5
0x0008								
Security Association Section Length (8)								6 - 7
0	0	1	1	1	0	1	1	
Version (1.1)			Transport Ind.		Flow Indicator		Discard	8
0	0	1	0	0	0	0	0	
Region (Remote)								9
1	1	1	0	0	0	0	0	
Role (Any)								10
0	0	0	0	0	0	0	1	
Relative ID (Security Association ID)								11
0	0	0	1	0	0	0	0	
Relative ID (SAS Number)				reserved				12
0	0	1	0	0	1	1	0	
Security Message Exchange Format Identifier (2-way)								13
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier								14
1	0	0	0	1	0	1	0	
Security Service Declaration Identifier								15
0	0	0	0	0	1	0	0	
Security Service Declaration (authentication)								16

III.2 Two-Way Signaling-based Security Message Exchange

This example provides endpoint-to-endpoint authentication using the 2-way Security Message Exchange protocol in signaling. Because the distinguished name of the responding security agent (B) is known in 2-way SME, explicit security agent addressing is used in the SSIE. Since (B) is included in the SSIE SAS explicit scope field, it is not needed in the SME section of the SAS. Initiator (A) declares that it requires authentication and provides the optional fields needed to provide replay protection, T_a and R_a.

FLOW1-2WE: *A –> B*

A, B, SecOpt, {T_a*,* R_a*, {Enc*$_{Kb}$ *(ConfPar*$_a$*)}, Sig*$_{Ka}$ *(Hash (A, B,* T_a*,* R_a*, SecOpt, {ConfPar*$_a$*}))}*

The initiating security agent places this SSIE in the call SETUP message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								1
1	1	1	0	0	1	1	1	
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					2
			Flag	Reserved	Information Element Action Indicator			
0x007B								3 - 4
Length of Security Services Information Element (123)								
0	0	0	0	0	0	0	1	5
Security Association Section Type (SME)								
0x0078								6 - 7
Security Association Section Length (120)								
0	0	1	0	0	0	0	1	8
Version (1.1)			Transport Ind.		Flow Indicator		Discard	
1	0	0	0	0	0	0	0	9
Region (Explicit)								
0	0	0	0	0	0	0	0	10
Role								
0	0	0	0	0	0	0	1	11
Relative ID (Security Association ID)								
0	0	0	1	0	0	0	0	12
Relative ID (SAS Number)				reserved				
0	0	1	0	0	1	1	0	13
Security Message Exchange Format Identifier (Two Way)								
1	0	0	0	0	0	1	1	14
Responder Distinguished Name Identifier								
0	0	0	1	0	1	0	1	15
Responder Distinguished Name Length (21)								
0	0	0	0	0	1	0	0	16
Responder Distinguished Name Type (AESA NSAP ICD)								

0x43023405152319121100980962 45F2A8B2127400								
Responder Distinguished Name Value								17 - 36
0	0	1	0	0	1	1	0	
Security Message Exchange Format Identifier (Two Way)								37
1	0	0	0	0	0	1	0	
Initiator Distinguished Name Identifier (*A*)								38
0	0	0	1	0	1	0	1	
Initiator Distinguished Name Length (21)								39
0	0	0	0	0	1	0	0	
Initiator Distinguished Name Type (AESA NSAP ICD)								40
0x43023405152319121100980962 18430DE6372812								
Initiator Distinguished Name Value								41 - 60
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier (*SecOpt*)								61
1	0	0	1	0	0	1	1	
Authentication Service Options Identifier								62
1	0	0	0	0	0	0	1	
Requires Authentication								63
1	0	1	0	0	1	1	0	
Signature Algorithm Identifier								64
0	0	0	0	0	0	0	1	
Length of Signature Algorithm Contents (1)								65
0	0	0	0	0	0	1	0	
Signature Algorithm (DSA)								66
1	1	0	1	0	0	0	0	
Authentication Section Identifier								67
1	1	0	1	0	1	1	0	
Time-Variant Time Stamp Identifier								68
0x67456721								
Time Stamp Value								69 - 72
0x00000001								
Sequence Number								73- 76
1	1	0	1	0	1	0	0	
Initiator Random Number Identifier *(R_A)*								77
0xB564A3E1								
Initiator Random Number Value								78 - 81
1	1	0	1	1	0	1	0	
Security Message Exchange Digital Signature Identifier								82
0	0	1	0	1	1	0	0	
Security Message Exchange Digital Signature Length (44)								83
Digital Signature Value								84 - 127

FLOW2-2WE: *B –> A*

A, B, R_a, {EncK_a (ConfPar_b)}, SigK_b (Hash (A, B, R_a, {ConfPar_b}))}

Responder (B) indicates that it supports authentication by placing this SSIE in the call CONNECT message:

Bits								
8	7	6	5	4	3	2	1	Octet(s)
Security Services Information Element								1
1	1	1	0	0	1	1	1	
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					2
			Flag	Reserved	Information Element Action Indicator			
0x006E								3 - 4
Length of Security Services Information Element (110)								
0	0	0	0	0	0	0	1	5
Security Association Section Type (SME)								
0x006B								6 - 7
Security Association Section Length (107)								
0	0	1	0	0	0	1	1	8
Version (1.1)			Transport Ind.		Flow Indicator		Discard	
0	0	1	0	0	0	0	0	9
Region (remote)								
1	1	1	0	0	0	0	0	10
Role (any)								
0	0	0	0	0	0	0	1	11
Relative ID (Security Association ID)								
0	0	0	1	0	0	0	0	12
Relative ID (SAS Number)				reserved				
0	0	1	0	0	1	1	0	13
Security Message Exchange Format Identifier (Two Way)								
1	0	0	0	0	0	1	0	14
Initiator Distinguished Name Identifier (*A*)								
0	0	0	1	0	1	0	1	15
Initiator Distinguished Name Length (21)								
0	0	0	0	0	1	0	0	16
Initiator Distinguished Name Type (AESA NSAP ICD)								
0x43023405152319121100980962184 30DE6372812								17 – 36
Initiator Distinguished Name Value								
1	0	0	0	0	0	1	1	37
Responder Distinguished Name Identifier (*B*)								
0	0	0	1	0	1	0	1	

Responder Distinguished Name Length (21)								38
0	0	0	0	0	1	0	0	
Responder Distinguished Name Type (AESA NSAP ICD)								39
0x43023405152319121100980962 45F2A8B2127400								
Responder Distinguished Name Value								40 – 59
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier (*SecOpt*)								60
1	0	0	1	0	0	1	1	
Authentication Service Options Identifier								61
1	0	0	0	0	0	0	1	
Requires Authentication								62
1	1	0	1	0	0	0	0	
Authentication Section Identifier								63
1	1	0	1	0	1	0	0	
Initiator Random Number Identifier								64
0xB564A3E1								
Initiator Random Number Value								65-68
1	1	0	1	1	0	1	0	
Security Message Exchange Digital Signature Identifier								69
0	0	1	0	1	1	0	0	
Security Message Exchange Digital Signature Length (44)								70
Digital Signature Value								71 - 114

III.3 Three-Way In-Band Security Message Exchange

This example establishes endpoint-to-endpoint confidentiality, authentication, key exchange, and session key update using the 3-way Security Message Exchange protocol in-band.

Initiator (A) states that it requires confidentiality, authentication, key exchange, and session key update and that it also supports integrity. To do this, A declares the five security services it requires or supports and then specifies two choices for the confidentiality algorithm, a signature algorithm, a hash algorithm, a key exchange algorithm, and a session key update algorithm. The confidentiality algorithms are triple-DES/counter mode and FEAL/CBC, the signature algorithm is FEAL/CBC, the hash algorithm is MD5, the key exchange algorithm is FEAL/CBC, and session key update algorithm uses MD5.

FLOW1-3WE: *A –> B*

A, {B}, SecNeg$_a$, R$_a$, {Cert$_a$}

Bits								
8	7	6	5	4	3	2	1	Octet(s)
0	0	1	0	0	0	0	1	
In-Band Message Type (FLOW 1-3WE)								1
0x0068								
In-Band Message Length (104)								2 - 3

Security Services Information Element								
1	1	1	0	0	1	1	1	4
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					5
			Flag	Reserved	Information Element Action Indicator			
0x0064								
Length of Security Services Information Element (100)								6 - 7
0	0	0	0	0	0	0	1	
Security Association Section Type (SME)								8
0x0061								
Security Association Section Length (97)								9 - 10
0	0	1	1	1	0	0	1	
Version (1.1)			Transport Ind.		Flow Indicator		Discard	11
1	0	0	0	0	0	0	0	
Region (explicit)								12
0	0	0	0	0	0	0	0	
Role (any)								13
0	0	0	0	0	0	0	1	
Relative ID (Security Association ID)								14
0	0	0	1	0	0	0	0	
Relative ID (SAS Number)				reserved				15
1	0	0	0	0	1	0	0	
Security Agent Distinguished Name Identifier *{B}*								16
0	0	0	1	0	1	0	1	
Security Agent Distinguished Name Length (21)								17
0	0	0	0	0	1	0	0	
Security Agent Distinguished Name Type (AESA NSAP ICD)								18
0x43023405152319121100980962 45F2A8B2127400								
Security Agent Distinguished Name Value								19 - 38
0	0	1	0	0	1	1	1	
Security Message Exchange Format Identifier (Three Way)								39
1	0	0	0	0	0	1	0	
Initiator Distinguished Name Identifier (*A*)								40
0	0	0	1	0	1	0	1	
Initiator Distinguished Name Length (21)								41
0	0	0	0	0	1	0	0	
Initiator Distinguished Name Type (AESA NSAP ICD)								42
0x43023405152319121100980962 18430DE6372812								
Initiator Distinguished Name Value								43 - 62
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier (*$SecNeg_A$*)								63
1	0	0	1	0	0	0	0	

Data Confidentiality Service Options Identifier								64
1	0	0	0	0	0	0	1	
Requires Data Confidentiality at ATM Cell Level								65
1	0	0	1	0	0	1	1	
Authentication Service Options Identifier								66
1	0	0	1	0	0	0	1	
Requires Authentication								67
1	0	0	1	0	1	0	0	
Key Exchange Service Options Identifier								68
0	1	0	0	0	0	0	1	
Requires Key Exchange								69
1	0	0	1	0	1	0	1	
Session Key Update Service Options Identifier								70
1	0	0	0	0	0	0	1	
Requires Session Key Update								71
1	0	0	1	0	0	1	0	
Data Integrity Service Options Identifier								72
0	0	0	0	0	0	0	1	
Supports Data Integrity with Replay/Reordering Protection								73
1	0	1	0	0	0	0	0	
Data Confidentiality Algorithm Identifier								74
0	0	0	1	0	0	1	0	
Length of Data Confidentiality Algorithm Contents (18)								75
0	0	0	0	0	0	1	1	
Data Confidentiality Algorithm (Triple DES keying option 2)								76
0	0	0	0	0	0	1	0	
Data Confidentiality Algorithm Mode of Operation (Counter Mode)								77
1	0	1	0	0	0	0	0	
Data Confidentiality Algorithm Identifier								78
0	0	0	0	1	0	1	0	
Length of Data Confidentiality Algorithm Contents (10)								79
0	0	0	0	0	1	0	0	
Data Confidentiality Algorithm (FEAL)								80
0	0	0	0	0	0	0	1	
Data Confidentiality Algorithm Mode of Operation (CBC)								81
0x238609F0E71A9D17								
Data Confidentiality Algorithm Details - Initialization Vector (FEAL)								82 - 8189
1	0	1	0	0	1	1	0	
Signature Algorithm Identifier								90
0	0	0	0	0	0	0	1	
Length of Signature Algorithm Contents (1)								91
0	0	0	0	1	0	0	0	

Signature Algorithm (FEAL/CBC)								92
1	0	1	0	0	1	0	0	
Hash Algorithm Identifier								93
0	0	0	0	0	0	0	1	
Length of Hash Algorithm Contents (1)								94
0	0	0	0	0	0	0	1	
Hash Algorithm (MD5)								95
1	0	1	0	1	0	0	0	
Key Exchange Algorithm Identifier								96
0	0	0	0	0	0	0	1	
Length of Key Exchange Algorithm Contents (1)								97
0	0	0	0	1	0	0	0	
Key Exchange Algorithm (FEAL/CBC)								98
1	0	1	0	1	0	1	0	
Session Key Update Algorithm Identifier								99
0	0	0	0	0	0	0	1	
Length of Session Key Update Algorithm Contents (1)								100
0	0	0	0	0	0	0	1	
Session Key Update Algorithm (SKE with MD5)								101
1	1	0	1	0	0	0	0	
Authentication Section Identifier								102
1	1	0	1	0	1	0	0	
Initiator Random Number Identifier (R_a)								103
0x7A52D245								
Initiator Random Number Value								96104 - 99107

Responder (B) requires confidentiality, authentication, key exchange, and session key update and does not support integrity. The confidentiality algorithm is FEAL/CBC, the signature algorithm is FEAL/CBC, the hash algorithm is -MD5, the key exchange algorithm is FEAL/CBC, and the session key update algorithm is SKE with MD5.

FLOW2-3WE: *B –> A*

A, B, SecNeg$_b$, {{Enc$_{Ka}$ (ConfPar$_b$)}, R$_a$, R$_b$, {Cert$_b$}, Sig$_{Kb}$ (Hash (A, B, R$_a$, R$_b$, SecNeg$_a$, SecNeg$_b$, {ConfPar$_b$}))}

Bits								
8	7	6	5	4	3	2	1	Octet(s)
0	0	1	0	0	0	1	0	
In-Band Message Type (FLOW2-3WE)								1
0x008E								
In-Band Message Length (142)								2 - 3
Security Services Information Element								

1	1	1	0	0	1	1	1	4
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					5
			Flag	Reserved	Information Element Action Indicator			
0x008A								
Length of Security Services Information Element (138)								6 – 7
0	0	0	0	0	0	0	1	
Security Association Section Type (SME)								8
0x0087								
Security Association Section Length (135)								9 – 10
0	0	1	1	1	0	1	1	
Version (1.1)			Transport Ind.		Flow Indicator		Discard	11
0	0	0	0	0	0	0	0	
Region								12
1	1	1	0	0	0	0	0	
Role (any)								13
0	0	0	0	0	0	0	1	
Relative ID (Security Association ID)								14
0	0	0	1	0	0	0	0	
Relative ID (SAS Number)				reserved				15
0	0	1	0	0	1	1	1	
Security Message Exchange Format Identifier (Three Way)								16
1	0	0	0	0	0	1	0	
Initiator Distinguished Name Identifier (*A)*								17
0	0	0	1	0	1	0	1	
Initiator Distinguished Name Length (21)								18
0	0	0	0	0	1	0	0	
Initiator Distinguished Name Type (AESA NSAP ICD)								19
0x4302340515231912110098096218430DE6372812								
Initiator Distinguished Name Value								20 – 39
1	0	0	0	0	0	1	1	
Responder Distinguished Name Identifier (*B)*								40
0	0	0	1	0	1	0	1	
Responder Distinguished Name Length (21)								41
0	0	0	0	0	1	0	0	
Responder Distinguished Name Type (AESA NSAP ICD)								42
0x4302340515231912110098096245F2A8B2127400								
Responder Distinguished Name Value								43 – 62
1	0	0	0	1	0	0	0	
Security Service Specification Section Identifier (*SecNeg*$_b$)								63
1	0	0	1	0	0	0	0	
Data Confidentiality Service Options Identifier								64

1	0	0	0	0	0	0	1	
Requires Data Confidentiality at ATM Cell Level								65
1	0	0	1	0	0	1	1	
Authentication Service Options Identifier								66
1	0	0	1	0	0	0	1	
Requires Authentication								67
1	0	0	1	0	1	0	0	
Key Exchange Service Options Identifier								68
0	1	0	0	0	0	0	1	
Requires Key Exchange								69
1	0	0	1	0	1	0	1	
Session Key Update Service Options Identifier								70
1	0	0	0	0	0	0	1	
Requires Session Key Update								71
1	0	0	1	0	0	1	0	
Data Integrity Service Options Identifier								72
0	0	0	0	0	0	0	0	
Does not Support Data Integrity								73
1	0	1	0	0	0	0	0	
Data Confidentiality Algorithm Identifier								74
0	0	0	0	1	0	1	0	
Length of Data Confidentiality Algorithm Contents (10)								75
0	0	0	0	0	1	0	0	
Data Confidentiality Algorithm (FEAL)								76
0	0	0	0	0	0	0	1	
Data Confidentiality Algorithm Mode of Operation (CBC)								77
0x238609F0E71A9D17 Data Confidentiality Algorithm Details Initialization Vector (FEAL CBC)								78 –85
1	0	1	0	0	1	1	0	
Signature Algorithm Identifier								86
0	0	0	0	0	0	0	1	
Length of Signature Algorithm Contents (1)								87
0	0	0	0	1	0	0	0	
Signature Algorithm (FEAL/CBC)								88
1	0	1	0	0	1	0	0	
Hash Algorithm Identifier								89
0	0	0	0	0	0	0	1	
Length of Hash Algorithm Contents (1)								90
0	0	0	0	0	0	0	1	
Hash Algorithm (MD5)								91
1	0	1	0	1	0	0	0	

Key Exchange Algorithm Identifier								92
0	0	0	0	0	0	0	1	
Length of Key Exchange Algorithm Contents (1)								93
0	0	0	0	1	0	0	0	
Key Exchange Algorithm (FEAL/CBC)								94
1	0	1	0	1	0	1	0	
Session Key Update Algorithm Identifier								95
0	0	0	0	0	0	0	1	
Length of Session Key Update Algorithm Contents (1)								96
0	0	0	0	0	0	0	1	
Session Key Update Algorithm (SKE with MD5)								97
1	1	0	0	0	0	0	0	
Confidential Parameters Section Identifier *(ConfPar$_b$)*								98
0x0018								
Length of Confidential **Parameters** Section (24)								99 - 100
Confidential Data								101 - 124
1	1	0	1	0	0	0	0	
Authentication Section Identifier								125
1	1	0	1	0	1	0	0	
Initiator Random Number Identifier (R_a)								126
0x7A52D245								
Initiator Random Number Value								127 - 130
1	1	0	1	0	1	0	1	
Responder Random Number Identifier (R_b)								131
0x3A29657D								
Responder Random Number Value								132 - 135
1	1	0	1	1	0	1	0	
Security Message Exchange Digital Signature Identifier								136
0	0	0	0	1	0	0	0	
Security Message Exchange Digital Signature Length (8)								137
Digital Signature Value								138 - 145

FLOW3-3WE: *A –> B*

{A, B, {Enc$_{Kb}$ (ConfPar$_a$)}, R$_b$, Sig$_{Ka}$ (Hash (A, B, R$_b$, {ConfPar$_a$}))}

Bits								
8	7	6	5	4	3	2	1	Octet(s)

0	0	1	0	0	0	1	1	
In-Band Message Type (FLOW3-3WE)								1
0x0066								
In-Band Message Length (102)								2 - 3
Security Services Information Element								
1	1	1	0	0	1	1	1	4
Information element identifier								
1 Ext	Coding Standard		Information Element Instruction Field					
			Flag	Reserved	Information Element Action Indicator			5
0x0062								
Length of Security Services Information Element (98)								6 - 7
0	0	0	0	0	0	0	1	
Security Association Section Type (SME)								8
0x005F								
Security Association Section Length (95)								9 - 10
0	0	1	1	1	1	0	1	
Version (1.1)			Transport Ind.		Flow Indicator		Discard	11
0	0	0	0	0	0	0	0	
Region								12
1	1	1	0	0	0	0	0	
Role (any)								13
0	0	0	0	0	0	0	1	
Relative ID (Security Association ID)								14
0	0	0	1	0	0	0	0	
Relative ID (SAS Number)				reserved				15
0	0	1	0	0	1	1	1	
Security Message Exchange Format Identifier (Three Way)								16
1	0	0	0	0	0	1	0	
Initiator Distinguished Name Identifier (*A)*								17
0	0	0	1	0	1	0	1	
Initiator Distinguished Name Length (21)								18
0	0	0	0	0	1	0	0	
Initiator Distinguished Name Type (AESA NSAP ICD)								19
0x4302340515231912110098096218430DE6372812								
Initiator Distinguished Name Value								20 - 39
1	0	0	0	0	0	1	1	
Responder Distinguished Name Identifier (*B)*								40
0	0	0	1	0	1	0	1	
Responder Distinguished Name Length (21)								41
0	0	0	0	0	1	0	0	
Responder Distinguished Name Type (AESA NSAP ICD)								42
0x4302340515231912110098096245F2A8B2127400								
Responder Distinguished Name Value								43 - 62

1	1	0	0	0	0	0	0	
Confidential Parameters Section Identifier *(ConfPar$_a$)*								63
0x0018								
Length of Confidential **Parameters** Section (24)								64 - 65
Confidential Data								66 - 89
0	1	0	1	0	0	0	0	
Authentication Section Identifier								90
1	0	1	1	0	1	0	1	
Responder Random Number Identifier *(R_b)*								91
0x3A29657D								
Responder Random Number Value								92 - 95
1	0	1	1	1	0	1	0	
Security Message Exchange Digital Signature Identifier								96
0	0	0	0	1	0	0	0	
Security Message Exchange Digital Signature Length (8)								97
Digital Signature Value								98 - 105

FLOW3-3 CONFIRM-AP: *B –> A*
CONFIRM-AP

Bits								
8	7	6	5	4	3	2	1	Octet(s)
0	0	1	1	0	0	0	1	
In-Band Message Type (CONFIRM - AP)								1
0x0000								
In-Band Message Length (0)								2 - 3

Appendix IV Security Message Coding Principles and Identifier Values

(This Appendix does not form an integral part of this specification)

IV.1 Message Coding

The message formats specified in this specification have been designed to provide a flexible and expandable encoding for Security Message Exchange. In particular, they rely on the use of nested type-length-value (TLV) encodings. Each TLV entity is referred to as an octet group.

- The type of each octet group is identified by a one octet "identifier" field as listed in Table 18. Type values need only be unique among all possible type values that may occur at the same positions, however, in this version of the Security Specification, the type values have been assigned in a globally unique manner in order to make it easier for humans to determine the identity of each TLV information group.
- Most octet groups contain a one octet length field as shown in Table 18. However, because of their potential length, some contain a two octet length field. Also, some of the octet groups do not contain a length field, since the length is fixed or may be determined from the information contained within the individual octet groups nested within in the octet group. The value of the length field does not include the lengths of the type and length fields.
- The value field may contain a simple value or values, or one or more nested octet groups, that is, the value field of one octet group may contain one or more octet groups each with TLV coding. An overview of the nesting that may occur with the octet groups is depicted in Figure 54.

IV.2 Identifiers

Table 18provides a list of identifiers defined in this specification. They are used to identify octet groups in both in-band and signalling messages. The table shows:

- the 8 bit identifier value
- reference section in the specification where the format is defined
- the number of octets in the length field (or "–" if no length field is used)
- the use of the value field (see main body of specification for details)
- the name of the octet group which it identifies

Table 18: Security Message Identifiers

Codepoint	Reference	Size of Length field	Use of Value field	Name
0010 0001*	5.1.5.3.2.1	2	Complex (SSIE)	FLOW1-3WE
0010 0010*	5.1.5.3.2.1	2	Complex (SSIE)	FLOW2-3WE
0010 0011*	5.1.5.3.2.1	2	Complex (SSIE)	FLOW3-3WE

Codepoint	Reference	Size of Length field	Use of Value field	Name
0010 0100	5.1.3.2.10.1	–	–	(Not used - reserved)
0010 0101	5.1.3.2.10.1	–	Sections for: Security Service Confidentiality Authorization	Security Message Exchange Format (FLOW2-2WE optional)
0010 0110	5.1.3.2.10.1	–	Sections for: Security Service Confidentiality Authorization	Security Message Exchange Format (FLOW2-2WE required)
0010 0111	5.1.3.2.10.1	–	Sections for: Security Service Confidentiality Authorization	Security Message Exchange Format (3-way)
0010 1000	5.1.3.2.10.2	1	type + data	Label Based Access Control
0011 0001*	5.1.5.3.2.1	2	none	CONFIRM-AP
0011 0010*	5.1.5.3.2.1	2	Cause value	FAULT
1000 0010	7.1.1	1	name type + value	Initiator Distinguished Name
1000 0011	7.1.2	1	name type + value	Responder Distinguished Name
1000 0100	7.1.3	1	name type + value	Security Agent Distinguished Name
1000 1000	7.2	–	Complex: Sections for: Security Service Declarations Security Service Options, Security Service Algorithm	Security Service Specification Section
1000 1010	7.2.1	–	7 Boolean values	Security Service Declaration
1001 0000	7.2.2.1	–	1 of 3 values	Data Confidentiality Service Option
1001 0010	7.2.2.2	–	1 of 5 values	Data Integrity Service Options
1001 0011	7.2.2.3	–	1 of 3 values	Authentication Service Options
1001 0100	7.2.2.4	–	1 of 3 values	Key Exchange Service Options
1001 0101	7.2.2.5	–	1 of 3 values	Session Key Update Service Options
1001 0110	7.2.2.6	–	1 of 3 values	Access Control Service Options
1001 0111	7.2.2.7	–	1 of 3 values	Certificate Exchange Service Options
1010 0000	7.2.3.1	1	Algorithm, mode	Data Confidentiality Algorithm
1010 0010	7.2.3.2	1	Algorithm	Data Integrity Algorithm
1010 0100	7.2.3.3	1	Algorithm	Hash Algorithm
1010 0110	7.2.3.4	1	Algorithm	Signature Algorithm
1010 1000	7.2.3.5	1	Algorithm	Key Exchange Algorithm
1010 1010	7.2.3.6	1	Algorithm	Session Key Update Algorithm

Codepoint	Reference	Size of Length field	Use of Value field	Name
1010 1100	7.2.3.7	1	Complex: Algorithms for: Signature Hash	Authentication Algorithm Group
1010 1110	7.2.3.8	1	Complex: Algorithms for: MAC Signature Key Exchange Key Update Hash	Integrity Algorithm Group
1011 0000	7.2.3.9	1	Complex: Algorithms for: Encryption Signature Key Exchange Key Update Hash	Confidentiality Algorithm Group
1011 0010	7.2.3.7/ 7.2.3.8/ 7.2.3.9	1	Algorithm details	Signature Algorithm Details
1011 0100	7.2.3.7/ 7.2.3.8	1	Algorithm details	Hash Algorithm Details
1011 0110	7.2.3.8	1	Algorithm details	MAC Algorithm details
1011 1000	7.2.3.8 7.2.3.9	1	Algorithm details	Key Exchange Algorithm Details
1011 1010	7.2.3.9	1	Algorithm details	Key Update Algorithm Details
1011 1110	7.2.3.9	1	Algorithm details	Encryption Algorithm Details
1100 0000	7.3	2	Encrypted data	Confidential Parameters Section
1100 0100	7.3.1	–	Complex: (Next 3): Master Key 1st data Conf Session key 1st data Integ Session key	Confidential Parameters
1100 1000	7.3.2	1	value	Master Key
1100 1010	7.3.3	1	value	First Data Confidentiality Session Key
1100 1100	7.3.4	1	value	First Data Integrity Session Key
1101 0000	7.4	–	Complex: (next 5): Initiator Random Number Responder Random Number Time-variant stamp Credentials SME or SAS Digital signature	Authentication Section

Codepoint	Reference	Size of Length field	Use of Value field	Name
1101 0100	7.4.1	–	4 octet value	Initiator Random Number
1101 0101	7.4.2	–	4 octet value	Responder Random Number
1101 0110	7.4.3	–	4 octet time stamp 4-octet sequence #	Time-variant Time Stamp
1101 1000	7.4.4	2	type + value	Credentials
1101 1010	7.4.5	1	values (algorithm specific)	Security Message Exchange Digital Signature
1101 1100	7.4.6	2	values (algorithm specific)	SAS Digital Signature

* Although these message types are for in-band only, the codepoints are assigned so as not to overlap with the codepoints used in signaling.

"Complex" indicates the value field contains other fields which are individually identified with one of these identifiers.

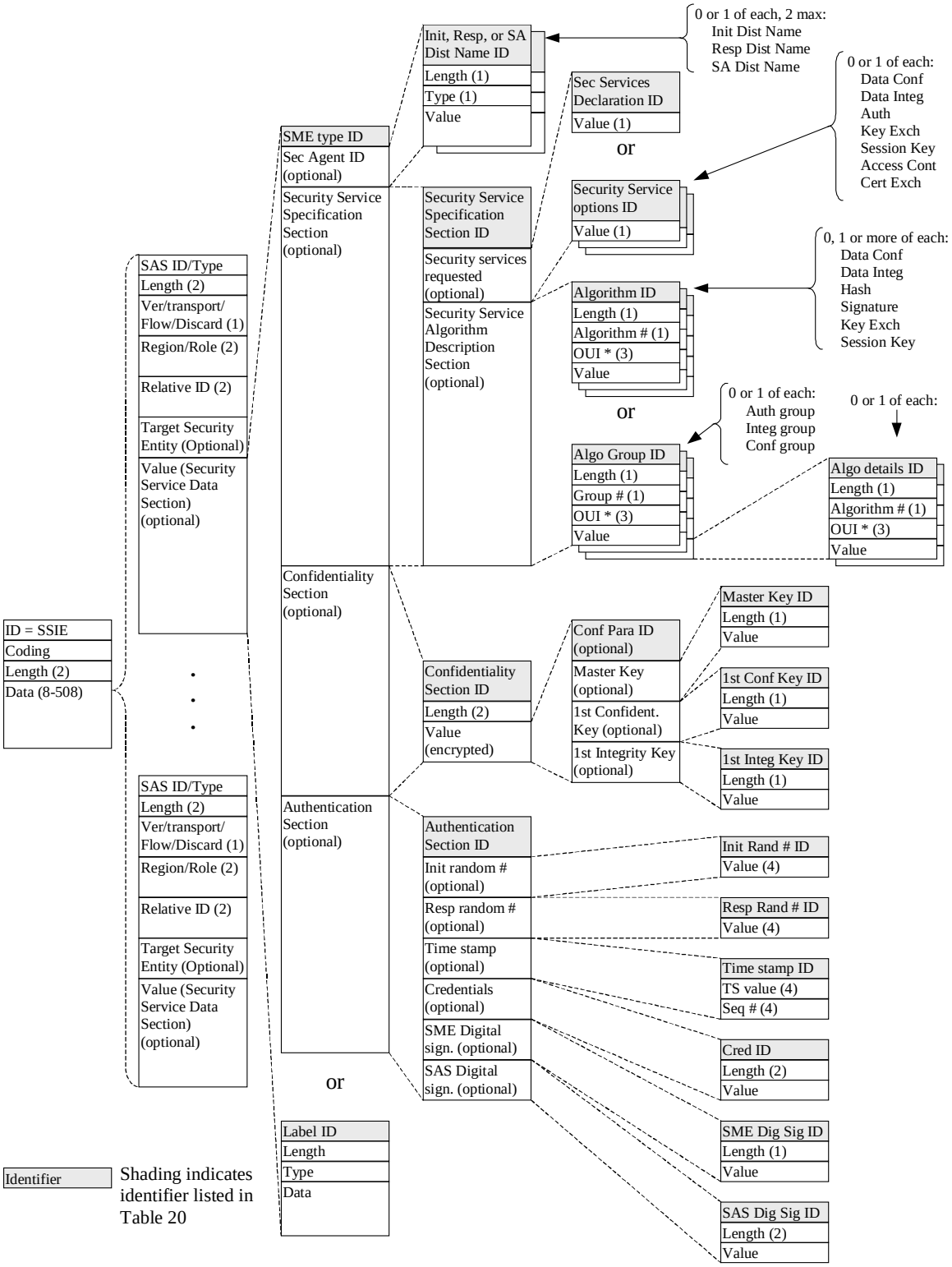

Figure 54: Overview of Nesting of Security Message Exchange Octet Groups.