

WAP WTLS
WAP-199-WTLS
Version 18-Feb-2000

Wireless Application Protocol
Wireless Transport Layer Security Specification

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Contents

1	SCOPE	5
2	DOCUMENT STATUS	6
2.1	COPYRIGHT NOTICE	6
2.2	ERRATA	6
2.3	COMMENTS	6
3	REFERENCES	7
3.1	NORMATIVE REFERENCES	7
3.2	INFORMATIVE REFERENCES	8
3.3	ACKNOWLEDGEMENTS	8
4	DEFINITIONS AND ABBREVIATIONS	9
4.1	DEFINITIONS	9
4.2	ABBREVIATIONS	11
4.3	DOCUMENT CONVENTIONS	12
5	WTLS ARCHITECTURAL OVERVIEW	13
5.1	REFERENCE MODEL	13
6	WTLS ELEMENTS FOR LAYER-TO-LAYER COMMUNICATION	14
6.1	NOTATIONS USED	14
6.1.1	<i>Definition of Service Primitives and Parameters</i>	14
6.1.2	<i>Time Sequence Charts</i>	14
6.1.3	<i>Primitive Types</i>	15
6.1.4	<i>Service Parameter Tables</i>	15
6.2	WTLS TRANSPORT SERVICE	16
6.2.1	<i>Service Primitives</i>	16
6.3	WTLS CONNECTION MANAGEMENT	16
6.3.1	<i>Overview</i>	16
6.3.2	<i>Service Primitives</i>	17
6.3.3	<i>Constraints on Using the Service Primitives</i>	20
7	WTLS STATE TABLES	22
7.1	CLIENT STATE TABLES	22
7.2	SERVER STATE TABLES	25
8	PRESENTATION LANGUAGE	29
8.1	BASIC BLOCK SIZE	29
8.1.1	<i>Bit Order</i>	29
8.2	MISCELLANEOUS	29
8.3	VECTORS	29
8.4	NUMBERS	30
8.5	ENUMERATEDS	30
8.6	CONSTRUCTED TYPES	31
8.6.1	<i>Variants</i>	31
8.7	CRYPTOGRAPHIC ATTRIBUTES	32
8.8	CONSTANTS	33
8.9	STRING CONSTANTS	33
9	RECORD PROTOCOL SPECIFICATION	34

9.1	CONNECTION STATE	34
9.2	RECORD LAYER.....	37
9.2.1	Fragmentation.....	37
9.2.2	Record Compression and Decompression.....	39
9.2.3	Record Payload Protection	40
10	HANDSHAKE PROTOCOL SPECIFICATION.....	43
10.1	CHANGE CIPHER SPEC PROTOCOL	43
10.2	ALERT PROTOCOL	44
10.2.1	Closure Alerts.....	45
10.2.2	Error Alerts	46
10.3	HANDSHAKE PROTOCOL OVERVIEW	48
10.4	HANDSHAKE RELIABILITY OVER DATAGRAMS	51
10.5	HANDSHAKE PROTOCOL	51
10.5.1	Hello Messages.....	52
10.5.2	Server Certificate	60
10.5.3	Server Key Exchange Message.....	64
10.5.4	Certificate Request	66
10.5.5	Server Hello Done	66
10.5.6	Client Certificate	67
10.5.7	Client Key Exchange Message	67
10.5.8	Certificate Verify.....	69
10.5.9	Finished.....	69
11	CRYPTOGRAPHIC COMPUTATIONS	71
11.1	COMPUTING THE MASTER SECRET	71
11.1.1	RSA Encryption Scheme	71
11.1.2	Diffie-Hellman.....	71
11.1.3	EC Diffie-Hellman.....	71
11.1.4	Session resume	72
11.2	KEY CALCULATION.....	72
11.3	HMAC AND THE PSEUDORANDOM FUNCTION.....	74
11.3.1	MAC Calculation.....	74
11.3.2	Pseudo-random Function.....	75
APPENDIX A ALGORITHM DEFINITIONS		76
APPENDIX B IMPLEMENTATION NOTES		90
B.1	NEGOTIATING NULL CIPHER SPEC	90
B.2	ANONYMOUS HANDSHAKES	90
B.3	KEY REFRESH.....	91
B.4	DENIAL-OF-SERVICE ATTACKS	91
APPENDIX C IMPLEMENTATION CLASSES.....		92
APPENDIX D REQUIREMENTS FOR THE WTLS PROTOCOL		93
APPENDIX E STATIC CONFORMANCE REQUIREMENT		94
E.1	WTLS SERVER OPTIONS.....	94
E.2	WTLS CLIENT OPTIONS	97

The following changes have been made to version 05-Nov-1999

1. Clarifying the sequence number value for no_connection alert (10.2.2)
2. Reduce risk of attack based on sequence numbers of forged messages (B.4)
3. Clarifying handling of hello request (10.5.1.1, B.4)
4. Additional ECC Key exchange suites for use with uncompressed points (11.1.3, A)
5. Clarify encoding and validation of alert checksums when there is no received record (10.2)
6. Using certificate URL (10.2, 10.5.2, 10.5.6)
7. Certificate name convention (3.1, 10.5.2)

1 Scope

The Wireless Application Protocol (WAP) is a result of continuous work to define an industry-wide specification for developing applications that operate over wireless communication networks. The scope for the WAP Forum is to define a set of specifications to be used by service applications. The wireless market is growing very quickly, and reaching new customers and services. To enable operators and manufacturers to meet the challenges in advanced services, differentiation and fast/flexible service creation WAP Forum defines a set of protocols in transport, security, transaction, session and application layers. For additional information on the WAP architecture, please refer to “*Wireless Application Protocol Architecture Specification*” [WAPARCH].

The Security layer protocol in the WAP architecture is called the Wireless Transport Layer Security, WTLS. The WTLS layer operates above the transport protocol layer. The WTLS layer is modular and it depends on the required security level of the given application whether it is used or not. WTLS provides the upper-level layer of WAP with a secure transport service interface that preserves the transport service interface below it. In addition, WTLS provides an interface for managing (eg, creating and terminating) secure connections.

The primary goal of the WTLS layer is to provide privacy, data integrity and authentication between two communicating applications. WTLS provides functionality similar to TLS 1.0 and incorporates new features such as datagram support, optimised handshake and dynamic key refreshing. The WTLS protocol is optimised for low-bandwidth bearer networks with relatively long latency.

2 Document Status

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- PDF format at <http://www.wapforum.org/>.

2.1 Copyright Notice

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2.2 Errata

Known problems associated with this document are published at <http://www.wapforum.org/>.

2.3 Comments

Comments regarding this document can be submitted to WAP Forum in the manner published at <http://www.wapforum.org/>.

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3.3 Acknowledgements

WTLS is derived from [TLS]. TLS is based on the SSL 3.0 specification.

4 Definitions and Abbreviations

4.1 Definitions

For the purposes of this specification the following definitions apply.

Abbreviated Handshake

A creation of a new *connection state* based on an existing *secure session*. See also *Session Resume*.

Connection State

The operating environment of the *record protocol*. The connection state includes all parameters that are needed for the cryptographic operations (encryption/decryption and MAC calculation/verification). Each *secure connection* has a connection state

Datagram Transport

A transport service that does not guarantee that the sent transport SDUs are not lost, duplicated or delivered out of order.

Handshake

The procedure of agreeing on the protocol options to be used between a client and a server. It includes the negotiation of security parameters (eg, algorithms and key lengths), key exchange and authentication. Handshaking occurs in the beginning of each secure connection.

Handshake Protocol

The protocol that carries out the *handshake*.

Full Handshake

A creation of a new *secure session* between two peers. The full handshake includes the parameter negotiation and the exchange of public-key information between the client and server.

Optimised Handshake

A creation of a new *secure session* between two peers. Unlike in the *full handshake*, the server looks up the client certificate from its own source without requesting it over the air from the client.

Record

A protocol data unit (PDU) in the *record protocol* layer.

Record Protocol

The record protocol takes messages to be transmitted, optionally compresses the data, applies a MAC, encrypts and transmits the result. Received data is decrypted, verified, decompressed and then delivered to higher level clients. There are four record protocol clients described in this document: the handshake protocol, the alert protocol, the change cipher spec protocol and the application data protocol.

Secure Connection

The WTLS connection that has a *connection state*. Each secure connection is identified by the transport addresses of the communicating peers.

Secure Session

The secure session that is negotiated on a handshake. The items that are negotiated (eg, session identifier, algorithms and master secret) are used for creating *secure connections*. Each secure session is identified by a session ID allocated by the server.

Session Resume

A new *secure connection* can be established based on a previously negotiated *secure session*. So if there is an existing secure session it is not necessary to perform the full handshake and cryptographic calculations again. For example, a secure connection may be terminated and resumed later. Many secure connections can be established using the same secure session through the resumption feature of the WTLS *handshake protocol*.

Shared Secret Authentication

An authentication method based on a shared secret. This method works without public-key algorithms but requires that the premaster secret is implanted or entered manually into both client and server. The shared secret is sensitive information and, therefore, a secure channel is needed for the distribution.

4.2 Abbreviations

For the purposes of this specification the following abbreviations apply.

API	Application Programming Interface
CA	Certification Authority
CBC	Cipher Block Chaining
DH	Diffie-Hellman
EC	Elliptic Curve
ECC	Elliptic Curve Cryptography
ECDH	Elliptic Curve Diffie-Hellman
ECDSA	Elliptic Curve Digital Signature Algorithm
IV	Initialisation Vector
MAC	Message Authentication Code
ME	Management Entity
OSI	Open System Interconnection
PDU	Protocol Data Unit
PRF	Pseudo-Random Function
SAP	Service Access Point
SDU	Service Data Unit
SHA-1	Secure Hash Algorithm
SMS	Short Message Service
SSL	Secure Sockets Layer
TLS	Transport Layer Security
WAP	Wireless Application Protocol
WDP	Wireless Datagram Protocol
WSP	Wireless Session Protocol
WTLS	Wireless Transport Layer Security
WTP	Wireless Transaction Protocol

4.3 Document Conventions

This specification uses the same keywords as specified in RFC 2119 [RFC2119] for defining the significance of each particular requirement. These words are:

MUST

This word, or the terms "REQUIRED" or "SHALL", mean that the definition is an absolute requirement of the specification.

MUST NOT

This phrase, or the phrase "SHALL NOT", mean that the definition is an absolute prohibition of the specification.

SHOULD

This word, or the adjective "RECOMMENDED", means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.

SHOULD NOT

This phrase, or the phrase "NOT RECOMMENDED" mean that there may exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

MAY

This word, or the adjective "OPTIONAL", means that an item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because the vendor feels that it enhances the product while another vendor may omit the same item. An implementation which does not include a particular option **MUST** be prepared to interoperate with another implementation which does include the option, though perhaps with reduced functionality. In the same vein an implementation which does include a particular option **MUST** be prepared to interoperate with another implementation which does not include the option (except, of course, for the feature the option provides.)

5 WTLS Architectural Overview

5.1 Reference model

A model of layering the protocols in WAP is illustrated in Figure 1. The layering of WAP protocols and their functions is similar to that of the ISO OSI Reference Model [ISO7498] for upper layers. Layer Management Entities handle protocol initialisation, configuration, and error conditions (such as loss of connectivity due to the mobile terminal roaming out of coverage) that are not handled by the protocol itself.

WTLS is designed to function on connection-oriented and/or datagram transport protocols. Security is assumed to be an optional layer above the transport layer. The security layer preserves the transport service interfaces. The session or application management entities are assumed to provide additional support required to manage (eg, initiate and terminate) secure connections.

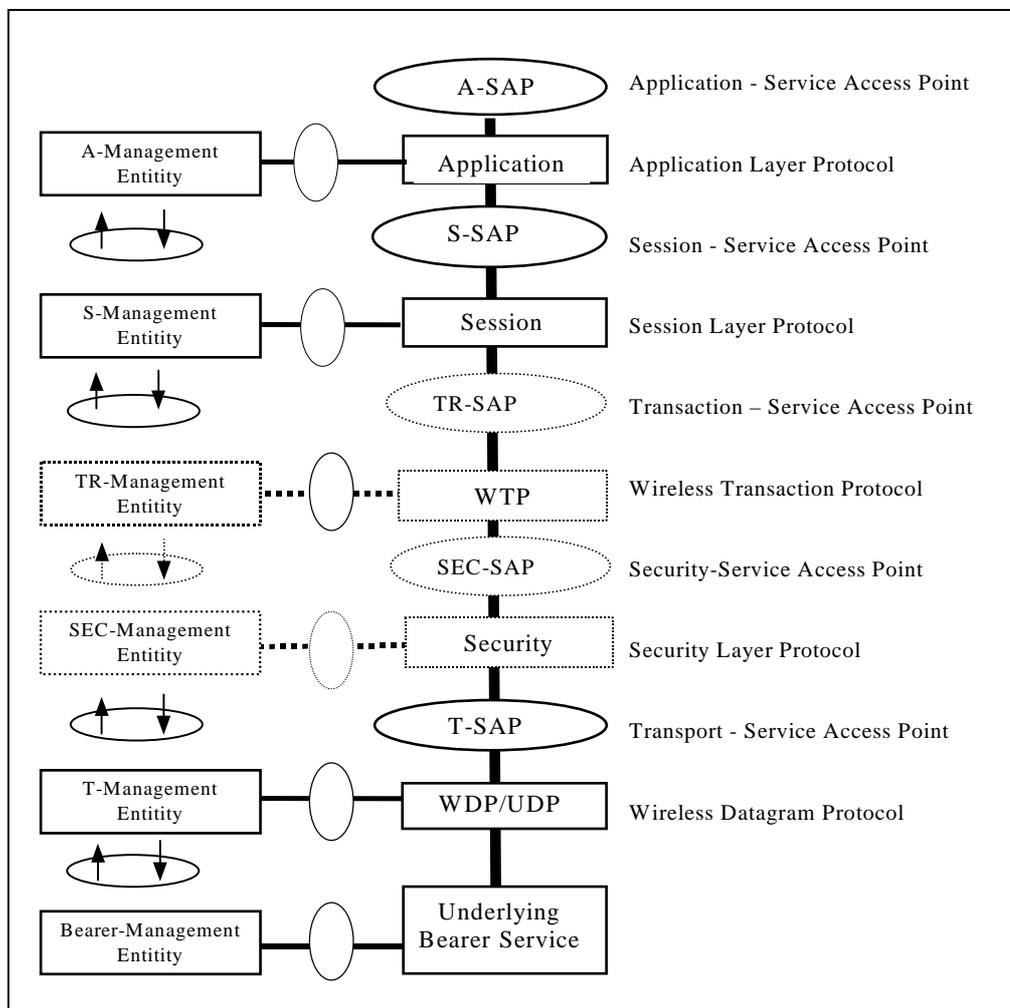


Figure 1: Wireless Application Protocol Reference Model

6 WTLS Elements for Layer-to-Layer Communication

6.1 Notations Used

6.1.1 Definition of Service Primitives and Parameters

Communication between layers is accomplished by means of service primitives. Service primitives represent, in an abstract way, the logical exchange of information and control between the security layer and adjacent layers.

Service primitives consist of commands and their respective responses associated with the services requested of another layer. The general syntax of a primitive is:

X-Service.type (Parameters)

where X designates the layer providing the service. For this specification X is “SEC” for the Security layer.

Service primitives are not the same as an application programming interface (API) and are not meant to imply any specific method of implementing an API. Service primitives are an abstract means of illustrating the services provided by the protocol layer to the layer above. The mapping of these concepts to a real API and the semantics associated with a real API are an implementation issue and are beyond the scope of this specification.

6.1.2 Time Sequence Charts

The behaviour of service primitives is illustrated using time sequence charts, which are described in [ISO10731].

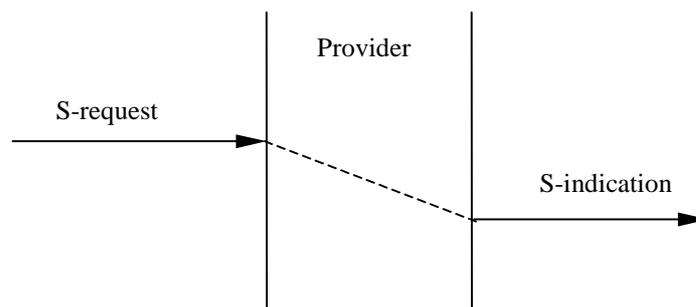


Figure 2: A Non-confirmed Service

Figure 2 illustrates a simple non-confirmed service, which is invoked using a request primitive and results in an indication primitive in the peer. The dashed line represents propagation through the provider over a period of time indicated by the vertical difference between the two arrows representing the primitives.

6.1.3 Primitive Types

The primitives types defined in this specification are:

Type	Abbreviation	Description
request	req	Used when a higher layer is requesting a service from the next lower layer
indication	ind	A layer providing a service uses this primitive type to notify the next higher layer of activities related to the request primitive type of the peer (such as the invocation of the request primitive) or to the provider of the service (such as a protocol generated event)
response	res	A layer uses the response primitive type to acknowledge receipt of the indication primitive type from the next lower layer
confirm	cnf	The layer providing the requested service uses the confirm primitive type to report that the activity has been completed successfully

6.1.4 Service Parameter Tables

The service primitives are defined using tables indicating which parameters are possible and how they are used with the different primitive types. For example, a simple confirmed primitive might be defined using the following:

Parameter	Primitive	S-primitive			
		<i>req</i>	<i>ind</i>	<i>res</i>	<i>cnf</i>
Parameter 1		M	M(=)		
Parameter 2				O	C(=)

If some primitive type is not possible, the column for it will be omitted. The entries used in the primitive type columns are defined in the following table:

M	Presence of the parameter is mandatory – it MUST be present
C	Presence of the parameter is conditional depending on values of other parameters
O	Presence of the parameter is a user option – it MAY be omitted
P	Presence of the parameter is a service provider option – an implementation MAY not provide it
	The parameter is absent
*	Presence of the parameter is determined by the lower layer protocol
(=)	The value of the parameter is identical to the value of the corresponding parameter of the preceding service primitive

In the example table above, *Parameter 1* is always present in *S-primitive.request* and corresponding *S-primitive.indication*. *Parameter 2* **MAY** be specified in *S-primitive.response* and in that case it **MUST** be present and have the equivalent value also in the corresponding *S-primitive.confirm*; otherwise, it **MUST NOT** be present.

6.2 WTLS Transport Service

6.2.1 Service Primitives

6.2.1.1 SEC-Unitdata

This primitive is used to exchange user data between the peers. SEC-Unitdata can only be invoked when there is an existing secure connection between the transport addresses of the peers.

Parameter	Primitive	SEC-Unitdata	
		<i>req</i>	<i>ind</i>
Source Address		M	M(=)
Source Port		M	M(=)
Destination Address		M	O(=)
Destination Port		M	O(=)
User Data		M	M(=)

Source Address identifies the originator.

Source Port identifies the port from which the message is sent.

Destination Address identifies the peer to which the user data is sent.

Destination Port identifies the port to which the message is sent.

User Data is the data to be transmitted.

6.3 WTLS Connection Management

6.3.1 Overview

WTLS Connection management allows a client to connect with a server and to agree on protocol options to be used. The secure connection establishment consists of several steps and either client or server can interrupt the negotiation at will (eg, if the parameters proposed by the peer are not acceptable). The negotiation may include the security parameters (eg, cryptographic algorithms and key lengths), key exchange and authentication. Either the server or client service user can also terminate the connection at any time.

The primitive sequence for establishing a secure session (full handshake) is shown in Figure 3.

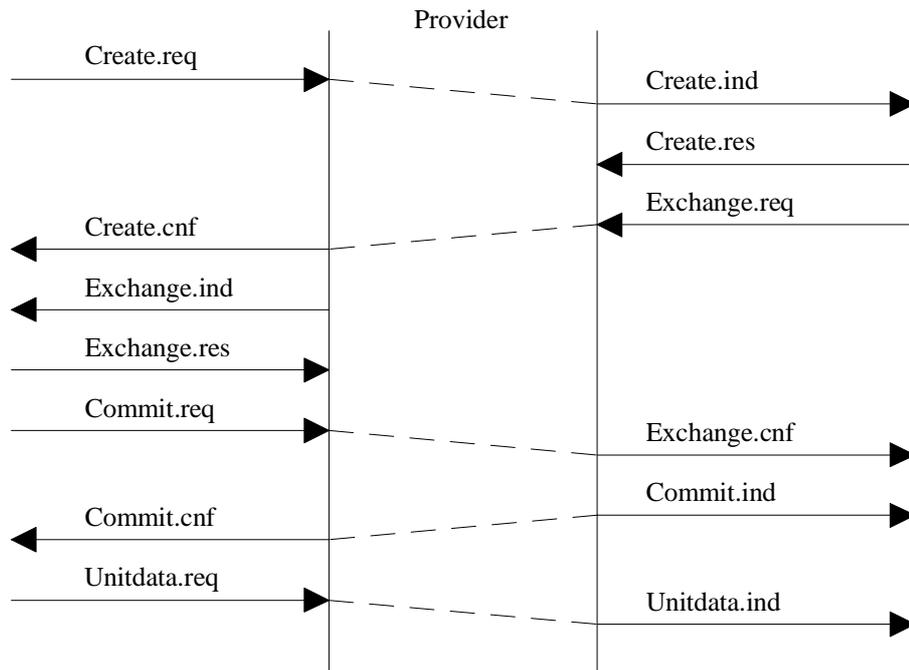


Figure 3: Full Handshake

The primitive sequence for establishing a secure session in an optimised or abbreviated way is shown in Figure 4.

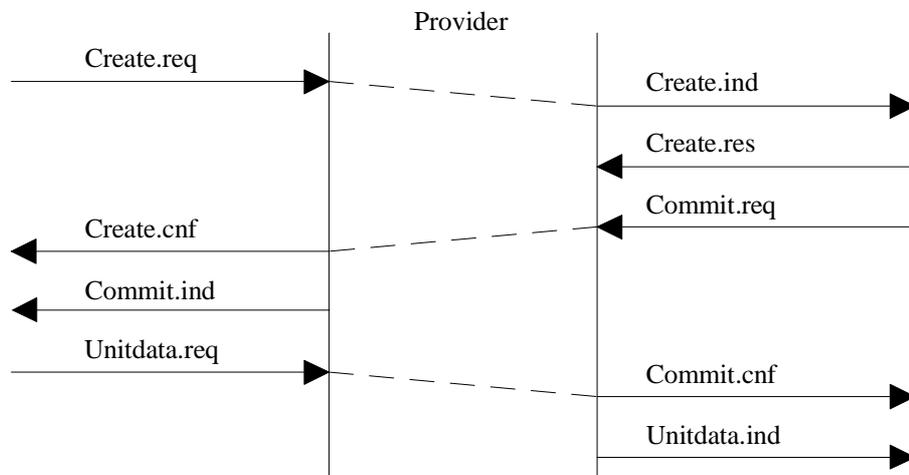


Figure 4: Abbreviated or Optimised Handshake

6.3.2 Service Primitives

6.3.2.1 SEC-Create

This primitive is used to initiate a secure connection establishment.

Parameter	Primitive	SEC-Create			
		<i>req</i>	<i>ind</i>	<i>res</i>	<i>cnf</i>
Source Address		M	M(=)		
Source Port		M	M(=)	-	-
Destination Address		M	O(=)	-	-
Destination Port		M	O(=)		
Client Identities		O	C(=)	-	-
Proposed Key Exchange Suites		M	M(=)	-	-
Proposed Cipher Suites		M	M(=)	-	-
Proposed Compression Methods		M	M(=)	-	-
Sequence Number Mode		O	C(=)	M	M(=)
Key Refresh		O	C(=)	M	M(=)
Session Id		O	C(=)	M	M(=)
Selected Key Exchange Suite		-	-	M	M(=)
Selected Cipher Suite		-	-	M	M(=)
Selected Compression Method		-	-	M	M(=)
Server Certificate		-	-	O	C(=)

Source Address identifies the originator.

Source Port identifies the port from which the message is sent.

Destination Address identifies the peer to which the user data is sent.

Destination Port identifies the port to which the message is sent.

Client Identities identify the originator in a transport independent way. This parameter may be used by the server to look up the corresponding client certificate. Client can send several identities corresponding to different keys or certificates.

Proposed Key Exchange Suites include the key exchange suites proposed by the client.

Proposed Cipher Suites include the cipher suites proposed by the client.

Proposed Compression Methods include the compression methods proposed by the client.

Sequence Number Mode defines how sequence numbers are used in this secure connection.

Key Refresh defines how often the encryption and protection keys are refreshed within a secure connection.

Session Id identifies the secure session. It is unique per server.

Selected Key Exchange Suite identifies the key exchange suite selected by the server.

Selected Cipher Suite identifies the cipher suite selected by the server.

Selected Compression Method identifies the compression method chosen by the server.

Server Certificate is the public-key certificate of the server.

6.3.2.2 SEC-Exchange

This primitive is used in a secure connection creation if the server wishes to perform public-key authentication or key exchange with the client.

Parameter	Primitive	SEC-Exchange			
		<i>req</i>	<i>ind</i>	<i>res</i>	<i>cnf</i>
Client Certificate		-	-	M	M(=)

Client Certificate is the public-key certificate of the client.

6.3.2.3 SEC-Commit

This primitive is initiated when the handshake is completed and either peer requests to switch into the newly negotiated connection state.

Parameter	Primitive	SEC-Commit			
		<i>req</i>	<i>ind</i>	<i>res</i>	<i>cnf</i>
-		-	-	-	-

6.3.2.4 SEC-Terminate

This primitive is used to terminate the connection.

Parameter	Primitive	SEC-Terminate	
		<i>req</i>	<i>Ind</i>
Alert Description		M	M(=)
Alert Level		M	M(=)

Alert Description identifies the reason that caused the termination.

Alert Level defines whether the session (fatal) or just a connection (critical) is terminated.

6.3.2.5 SEC-Exception

This primitive is used to inform the other end about warning level alerts.

Parameter	Primitive	SEC-Exception	
		<i>req</i>	<i>ind</i>
Alert Description		M	M(=)

Alert Description identifies what caused the warning.

6.3.2.6 SEC-Create-Request

This primitives is used by the server to request the client to initiate a new handshake.

Parameter	Primitive	SEC-Create-Request	
		<i>req</i>	<i>ind</i>
Source Address		O	C(=)
Source Port		O	C(=)
Destination Address		O	C(=)

Destination Port	O	C(=)
------------------	---	------

Source Address identifies the originator.

Source Port identifies the port from which the message is sent.

Destination Address identifies the client to which the data is sent. This parameter is needed when the primitive is used in a NULL session state.

Destination Port identifies the port to which the data is sent.

6.3.3 Constraints on Using the Service Primitives

The following tables define the permitted primitive sequences on the service interface. The client and server have separate tables, since the service is asymmetric.

Only the permitted primitives are listed on the rows; the layer prefix is omitted for brevity. The table entries are interpreted as follows:

Table 1: Table Entry Legend

Entry:	Description
	The indication or confirm primitive cannot occur.
N/A	Invoking this primitive is an error. The appropriate action is a local implementation matter.
STATE_NAME	Primitive is permitted and moves the service interface view to the named state.

Table 2: Permitted Client Security Layer Primitives

CLIENT SEC- Primitive	Session States							
	NULL	CREATING	CREATED	EXCHANGE	COMMIT1	COMMIT2	OPENING	OPEN
Create.req	CREATING	N/A	N/A	N/A	N/A	N/A	N/A	CREATING
Commit.req	N/A	N/A	N/A	N/A	COMMIT2	N/A	N/A	N/A
Terminate.req	N/A	NULL	NULL	NULL	NULL	NULL	NULL	NULL
Exception.req	N/A	CREATING	CREATED	EXCHANGE	COMMIT1	COMMIT2	OPENING	OPEN
Unitdata.req	N/A	N/A	N/A	N/A	N/A	N/A	OPENING	OPEN
Exchange.res	N/A	N/A	N/A	COMMIT1	N/A	N/A	N/A	N/A
Exchange.ind			EXCHANGE					
Commit.ind			OPENING					
Terminate.ind		NULL				NULL	NULL	NULL
Exception.ind		CREATING				COMMIT2	OPEN	OPEN
Create-Request.ind	NULL						OPEN	OPEN
Unitdata.ind							OPEN	OPEN
Create.cnf		CREATED						
Commit.cnf						OPEN		

Table 3: Permitted Server Security Layer Primitives

SERVER	Session States						
SEC-Primitive	NULL	CREATING	CREATED	EXCHANGE	COMMIT	OPENING	OPEN
Exchange.req	N/A	N/A	EXCHANGE	N/A	N/A	N/A	N/A
Commit.req	N/A	N/A	COMMIT	N/A	N/A	N/A	N/A
Create-Request.req	NULL	N/A	N/A	N/A	N/A	N/A	OPEN
Terminate.req	N/A	NULL	NULL	NULL	NULL	NULL	NULL
Exception.req	N/A	CREATING	CREATED	EXCHANGE	COMMIT	OPENING	OPEN
Unitdata.req	N/A	N/A	N/A	N/A	N/A	N/A	OPEN
Create.res	N/A	CREATED	N/A	N/A	N/A	N/A	N/A
Commit.ind						OPEN	
Create.ind	CREATING			CREATING	CREATING		CREATING
Terminate.ind				NULL	NULL		NULL
Exception.ind	NULL			EXCHANGE	COMMIT		OPEN
Unitdata.ind							OPEN
Exchange.cnf				OPENING			
Commit.cnf					OPEN		

7 WTLS State Tables

The following state tables define the actions of WTLS on a datagram transport service provider.

WTLS PDUs are identified in *italics*.

By default, all WTLS PDUs will be processed under the state that is currently in use.

If any PDUs other than the ones listed under Conditions are received, the receiver may generate an alert depending on the severity of the case. See Section 10.2 for more detailed information.

Although the state tables provided are helpful to understand the WTLS protocol, they are not the formal and complete definition. Those tables tend to be concise and readable so that certain level of details are not reflected. It is therefore essential that the textual description of this specification is the unique and complete definition of the WTLS protocol.

7.1 Client State Tables

The following tables show the protocol states and event processing on the client.

Client Secure Session NULL			
Event	Conditions	ACTION	Next State
SEC-Create.req		T-Unitdata.req (<i>ClientHello</i>) The sequence number is present during a handshake	CREATING
T-Unitdata.ind	<i>HelloRequest</i>	SEC-Create-Request.ind The client may initiate a handshake with SEC-Create.req, initiate an <i>alert (no_renegotiation)</i> or ignore the request.	NULL

Client Secure Session CREATING			
Event	Conditions	ACTION	Next State
SEC-Terminate.req		T-Unitdata.req (<i>Alert (fatal or critical)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	CREATING
T-Unitdata.ind	<i>ServerHello</i> <i>Certificate*</i> <i>ServerKeyExchange*</i> <i>CertificateRequest*</i> <i>ServerHelloDone</i>	SEC-Create.cnf SEC-Exchange.ind	EXCHANGE
	<i>ServerHello</i> <i>Certificate*</i> <i>ChangeCipherSpec</i> <i>Finished</i>	SEC-Create.cnf SEC-Commit.ind The read current state is set to the pending state by <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the new state and the read sequence number set to zero.	CREATED
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	CREATING
Retransmission timer expires		T-Unitdata.req (<i>ClientHello</i>) The last buffer resent without incrementing the sequence number The retransmission timer is cleared The retransmission counter is incremented	CREATING
Retransmission counter exceeds the maximum value		SEC-Terminate.ind	NULL

*) Whether these messages are present or not depends on the chosen key exchange method.

Client Secure Session EXCHANGE			
Event	Conditions	ACTION	Next State
SEC-Exchange.res		Create a buffer with: <i>Certificate*</i> <i>ClientKeyExchange*</i> <i>CertificateVerify*</i>	COMMIT1
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	EXCHANGE

*) Whether these messages are present or not depends on the chosen key exchange method.

Client Secure Session COMMIT1			
Event	Conditions	ACTION	Next State
SEC-Commit.req		Append to the buffer: <i>ChangeCipherSpec</i> <i>Finished</i> The write current state is set to the pending state by <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the new negotiated state and the write sequence number is set to zero. Send the buffer out with T-Unitdata.req	COMMIT2
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	COMMIT1

Client Secure Session COMMIT2			
Event	Conditions	ACTION	Next State
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	COMMIT2
T-Unitdata.ind	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	COMMIT2
	<i>ChangeCipherSpec</i> <i>Finished</i>	The read current state is set to the pending state after <i>ChangeCipherSpec</i> is received so that <i>Finished</i> is processed under the new negotiated state and the read sequence number is set to zero. SEC-Commit.cnf	OPEN
Retransmission timer expires	No response from the server is received	T-Unitdata.req The last buffer is resent without incrementing the sequence number The retransmission timer is cleared The retransmission counter is incremented	COMMIT2
Retransmission counter exceeds the maximum value		SEC-Terminate.ind	NULL

Client Secure Session CREATED			
Event	Conditions	ACTION	Next State
	Implementation may send <i>ChangeCipherSpec</i> and <i>Finished</i> immediately without user data	Create a buffer with: <i>ChangeCipherSpec</i> <i>Finished</i> The write current state is set to the pending state by <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the new negotiated state and the write sequence number is set to zero. Send it out with T-Unitdata.req	OPENING
	Implementation may delay sending <i>ChangeCipherSpec</i> and <i>Finished</i> and prepend it to user data (if any)	Create a buffer with: <i>ChangeCipherSpec</i> <i>Finished</i> The write current state is set to the pending state by <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the new negotiated state and the write sequence number is set to zero. Set up a <i>Finished</i> prepending timer	OPENING
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	CREATED

Client Secure Session OPENING			
Event	Conditions	ACTION	Next State
SEC-Unitdata.req		Prepend buffer to user data and call T-Unitdata.req	OPENING
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	OPENING
	Finished prepending timer is set	Prepend buffer to user data and call T-Unitdata.req Remove the Finished prepending timer.	OPENING
Finished prepending timer expires		Send buffer out it T-Unitdata.req	OPENING
T-Unitdata.ind	User data is received	SEC-Unitdata.ind	OPEN
	<i>Alert (duplicate_ finished_received)</i>		OPEN
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	OPEN
	<i>HelloRequest</i>	SEC-Create-Request.ind The client may initiate a handshake with SEC-Create.req, initiate an <i>alert (no_renegotiation)</i> or ignore the request.	OPEN

Client Secure Session OPEN			
Event	Conditions	ACTION	Next State
SEC-Create.req		T-Unitdata.req (<i>ClientHello</i>)	CREATING
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	OPEN
SEC-Unitdata.req		T-Unitdata.req	OPEN
T-Unitdata.ind	User data received	SEC-Unitdata.ind	OPEN
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	OPEN
	<i>HelloRequest</i>	SEC-Create-Request.ind The client may initiate a handshake with SEC-Create.req, initiate an <i>alert (no_renegotiation)</i> or ignore the request.	OPEN

7.2 Server State Tables

The following tables show the protocol states and event processing on the server.

Server Secure Session NULL			
Event	Conditions	ACTION	Next State
SEC-Create-Request.req		T-Unitdata.req (<i>HelloRequest</i>) The rate at which HelloRequests are sent should be limited.	NULL
T-Unitdata.ind	<i>ClientHello</i>	SEC-Create.ind	CREATING
	<i>Alert (no_renegotiation)</i>	SEC-Exception.ind	NULL

Server Secure Session CREATING			
Event	Conditions	ACTION	Next State
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	CREATING
SEC-Create.res		Create a buffer with: <i>ServerHello</i> <i>Certificate*</i>	CREATED

*) Whether this message is present or not depends on the chosen key exchange method.

Server Secure Session CREATED			
Event	Conditions	ACTION	Next State
SEC-Exchange.req	Full handshake	Append to the buffer: <i>ServerKeyExchange*</i> <i>CertificateRequest*</i> <i>ServerHelloDone</i> Send it out with T-Unitdata.req	EXCHANGE
SEC-Commit.req	Optimized or abbreviated handshake	Append to the buffer: <i>ChangeCipherSpec</i> <i>Finished</i> The write current state is set to the pending state by <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the new negotiated state and the write sequence number is set to zero. Send the buffer out with T-Unitdata.req	COMMIT
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	CREATED

*) Whether these messages are present or not depends on the chosen key exchange method.

Server Secure Session EXCHANGE			
Event	Conditions	ACTION	Next State
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	EXCHANGE
T-Unitdata.ind	<i>ClientHello</i> A record identical to the previous one is received	Resend last buffer with T-Unitdata.req	EXCHANGE
	<i>ClientHello</i> A record not identical to the previous one is received	SEC-Create.ind	CREATING
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	EXCHANGE
	<i>Certificate*</i> <i>ClientKeyExchange*</i> <i>CertificateVerify*</i> <i>ChangeCipherSpec</i> <i>Finished</i>	SEC-Exchange.cnf SEC-Commit.ind The read current state is set to the pending state after <i>ChangeCipherSpec</i> is received so that <i>Finished</i> is processed under the new negotiated state and the read sequence number is set to zero. Create a new buffer with: <i>ChangeCipherSpec</i> <i>Finished</i> The write current state is set to the pending state by sending the <i>ChangeCipherSpec</i> so that <i>Finished</i> is processed under the newly negotiated state and the write sequence number is set to zero. Send it out with T-Unitdata.req	OPENING

*) Whether these messages are present or not depends on the chosen key exchange method.

Server Secure Session COMMIT			
Event	Conditions	ACTION	Next State
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	COMMIT
T-Unitdata.ind	<i>ClientHello</i> A record identical to the previous one is received	Resend last buffer with T-Unitdata.req	COMMIT
	<i>ClientHello</i> A record not identical to the previous one is received	SEC-Create.ind	CREATING
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	COMMIT
	<i>ChangeCipherSpec</i> <i>Finished</i>	The read current state is set to the pending state after <i>ChangeCipherSpec</i> is received so that <i>Finished</i> is processed under the new negotiated state and the read sequence number is set to zero. SEC-Commit.cnf	OPEN
	<i>ChangeCipherSpec</i> <i>Finished</i> and user data	The read current state is set to the pending state after <i>ChangeCipherSpec</i> is received so that <i>Finished</i> is processed under the new negotiated state and the read sequence number is set to zero. SEC-Commit.cnf SEC-Unitdata.ind	OPEN

Server Secure Session OPENING			
Event	Conditions	ACTION	Next State
SEC-Create-Request.req		T-Unitdata.req (<i>HelloRequest</i>)	OPENING
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	OPENING
SEC-Unitdata.req		T-Unitdata.req	OPENING
T-Unitdata.ind	<i>ClientHello</i>	SEC-Create.ind	CREATING
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	OPENING
	User data received	SEC-Unitdata.ind	OPEN
	<i>Certificate*</i> <i>ClientKeyExchange*</i> <i>CertificateVerify*</i> <i>ChangeCipherSpec</i> <i>Finished</i> A group of records identical to the previous one is received	Resend last buffer with T-Unitdata.req	OPENING

Server Secure Session OPEN			
Event	Conditions	ACTION	Next State
SEC-Create-Request.req		T-Unitdata.req (<i>HelloRequest</i>)	OPEN
SEC-Terminate.req		T-Unitdata.req (<i>Alert (critical or fatal)</i>)	NULL
SEC-Exception.req		T-Unitdata.req (<i>Alert (warning)</i>)	OPEN
SEC-Unitdata.req		T-Unitdata.req	OPEN
T-Unitdata.ind	<i>ClientHello</i>	SEC-Create.ind	CREATING
	<i>Alert (critical or fatal)</i>	SEC-Terminate.ind	NULL
	<i>Alert (warning)</i>	SEC-Exception.ind	OPEN
	User data received	SEC-Unitdata.ind	OPEN
	<i>ChangeCipherSpec</i> <i>Finished</i> A record identical to the previous <i>Finished</i> is received	The read state is unchanged by the <i>ChangeCipherSpec</i> since it is a duplicate. T-Unitdata.req (<i>Alert (duplicate_finished_received)</i>)	OPEN
<i>ChangeCipherSpec</i> <i>Finished</i> and user data A record identical to the previous <i>Finished</i> is received	The read state is unchanged by the <i>ChangeCipherSpec</i> since it is a duplicate. SEC-Unitdata.ind T-Unitdata.req (<i>Alert (duplicate_finished_received)</i>)	OPEN	

8 Presentation Language

This document deals with the formatting of data in an external representation similar to TLS. The following very basic and somewhat casually defined presentation language syntax will be used. The syntax draws from several sources in its structure. Although it resembles the programming language “C” in its syntax and XDR [XDR] in both its syntax and intent, it would be risky to draw too many parallels. The purpose of this presentation language is to document WTLS only, not to have general application beyond that particular point.

8.1 Basic Block Size

The representation of all data items is explicitly specified. The basic block size is one byte (ie 8 bits). Multiple byte data items are concatenations of bytes, from left to right, from top to bottom. From the byte stream a multi-byte item (a numeric in the example) is formed (using C notation) by:

```
value = (byte[0] << 8*(n-1)) | (byte[1] << 8*(n-2)) | ... | byte[n-1];
```

This byte ordering for multi-byte values is the commonplace network byte order or big endian format.

8.1.1 Bit Order

The bits in a byte are ordered from left to the right. The leftmost bit is bit 0 while the rightmost bit is bit 7. Bit 0 is the Most Significant Bit while bit 7 is the Least Significant Bit.

8.2 Miscellaneous

Comments begin with “/*” and end with “*/”.

Optional components are denoted by enclosing them in “[[]]” double brackets.

Single byte entities containing uninterpreted data are of type opaque.

8.3 Vectors

A vector (single dimensioned array) is a stream of homogeneous data elements. The size of the vector may be specified at documentation time or left unspecified until runtime. In either case the length declares the number of bytes, not the number of elements, in the vector. The syntax for specifying a new type T’ that is a fixed length vector of type T is

```
T T’ [n];
```

Here T’ occupies n bytes in the data stream, where n is a multiple of the size of T. Then length of the vector is not included in the encoded stream.

In the following example, Datum is defined to be three consecutive bytes that the protocol does not interpret, while Data is three consecutive Datum, consuming a total of nine bytes.

```
opaque Datum[3]; /* three uninterpreted bytes */
Datum Data[9]; /* 3 consecutive 3 byte vectors */
```

Variable length vectors are defined by specifying a subrange of legal lengths, inclusively, using the notation <floor..ceiling>. When encoded, the actual length precedes the vector's contents in the byte stream. The length will be in the form of a number consuming as many bytes as required to hold the vector's specified maximum (ceiling) length. A variable length vector with an actual length field of zero is referred to as an empty vector.

```
T T' <floor..ceiling>;
```

In the following example, mandatory is a vector that must contain between 300 and 400 bytes of type opaque. It can never be empty. The actual length field consumes two bytes, a uint16, sufficient to represent the value 400 (see Section 8.4). On the other hand, longer can represent up to 800 bytes of data, or 400 uint16 elements, and it may be empty. Its encoding will include a two byte actual length field prepended to the vector. The length of an encoded vector must be an even multiple of the length of a single element (for example, a 17 byte vector of uint16 would be illegal).

```
opaque mandatory<300..400>;    /* length field is 2 bytes, cannot be empty */
uint16 longer<0..800>;        /* zero to 400 16-bit unsigned integers */
```

The notation

```
A = B[first..last];
```

indicates that vector A is assigned to be the elements from first to last of B.

8.4 Numbers

The basic numeric data type is unsigned byte (uint8). All larger numeric data types are formed from fixed length series of bytes concatenated as described in Section 8.1 and are also unsigned. The following numeric types are predefined:

```
uint8 uint16[2];
uint8 uint24[3];
uint8 uint32[4];
uint8 uint64[8];
```

All values, here and elsewhere in the specification, are stored in "network" or "big-endian" order; the uint32 represented by the hex bytes 01 02 03 04 is equivalent to the decimal value 16909060.

8.5 Enumerateds

An additional sparse data type is available called enum. A field of type enum can only assume the values declared in the definition. Each definition is a different type. Only enumerateds of the same type may be assigned or compared. Every element of an enumerated MUST be assigned a value, as demonstrated in the following example. Since the elements of the enumerated are not ordered, they can be assigned any unique value, in any order.

```
enum { e1(v1), e2(v2), ... , en(vn), [[(n)]] } Te;
```

Enumerateds occupy as much space in the byte stream as would its maximal defined ordinal value. The following definition would cause one byte to be used to carry fields of type Color.

```
enum { red(3), blue(5), white(7) } Color;
```

One may optionally specify a value without its associated tag to force the width definition without defining a superfluous element. In the following example, Taste will consume two bytes in the data stream but can only assume the values 1, 2 or 4.

```
enum { sweet(1), sour(2), bitter(4), (32000) } Taste;
```

The names of the elements of an enumeration are scoped within the defined type. In the first example, a fully qualified reference to the second element of the enumeration would be Color.blue. Such qualification is not required if the target of the assignment is well specified.

```
Color color = Color.blue; /* overspecified, legal */
Color color = blue;      /* correct, type implicit */
```

For enumerations that are never converted to external representation, the numerical information may be omitted.

```
enum { low, medium, high } Amount;
```

8.6 Constructed Types

Structure types may be constructed from primitive types for convenience. Each specification declares a new, unique type. The syntax for definition is much like that of C.

```
struct {
    T1 f1;
    T2 f2;
    ...
    Tn fn;
} [[T]];
```

The fields within a structure may be qualified using the type's name using a syntax much like that available for enumerations. For example, T.f2 refers to the second field of the previous declaration. Structure definitions may be embedded.

8.6.1 Variants

Defined structures may have variants based on some knowledge that is available within the environment. The selector **MUST** be an enumerated type that defines the possible variants the structure defines. There **MUST** be a case arm for every element of the enumeration declared in the select, or a default arm for those elements missing. The body of the variant structure may be given a label for reference. The mechanism by which the variant is selected at runtime is not prescribed by the presentation language.

```

struct {
    T1 f1;
    T2 f2;
    ...
    Tn fn;
    Td fd;
    select (E) {
        case e1: Te1;
        case e2: Te2;
        ...
        case en: Ten;
        default: TeDefault;
    } [[fv]];
} [[Tv]];

```

For example:

```

enum { apple, orange } VariantTag;
struct {
    uint16 number;
    opaque string<0..10>;    /* variable length */
} V1;
struct {
    uint32 number;
    opaque string[10];      /* fixed length */
} V2;
struct {
    select (VariantTag) {    /* value of selector is implicit */
        case apple: V1;     /* VariantBody, tag = apple */
        case orange: V2;   /* VariantBody, tag = orange */
    } variant_body;
} VariantRecord;

```

Variant structures may be qualified (narrowed) by specifying a value for the selector prior to the type. For example, a `orange VariantRecord`

is a narrowed type of `VariantRecord` containing a `variant_body` of type `V2`.

8.7 Cryptographic Attributes

The four cryptographic operations digital signing, stream cipher encryption, block cipher encryption, and public key encryption are designated digitally-signed, stream-ciphered, block-ciphered, and public-key-encrypted, respectively. A field's cryptographic processing is specified by prepending an appropriate key word designation before the field's type specification. Cryptographic keys are implied by the current session state (see Section 9.1).

In digital signing, one-way hash functions are used as input for a signing algorithm. A digitally-signed element is encoded as an opaque vector $\langle 0..2^{16}-1 \rangle$, where the length is specified by the signing algorithm and key.

In stream cipher encryption, the plaintext is exclusive-Ored with an identical amount of output generated from a cryptographically-secure keyed pseudorandom number generator.

In block cipher encryption, every block of plaintext encrypts to a block of ciphertext. All block cipher encryption is done in CBC (Cipher Block Chaining) mode, and all items which are block-ciphered will be an exact multiple of the cipher block length.

In public-key encryption, a public key algorithm is used to encrypt data in such a way that it can be decrypted only with the matching private key. A public-key-encrypted element is encoded as an opaque vector $\langle 0..2^{16}-1 \rangle$, where the length is specified by the signing algorithm and key.

In the following example:

```
block-ciphered struct {
    uint8 field1;
    uint8 field2;
    digitally-signed opaque hash[20];
} UserType;
```

The contents of hash are used input for the signing algorithm, then the entire structure is encrypted with a block cipher. The length of this structure, in bytes would be exact multiple of the cipher block length.

8.8 Constants

Typed constants can be defined for purpose of specification by declaring a symbol of the desired type and assigning values to it. Under-specified types (opaque, variable length vectors, and structures that contain opaque) cannot be assigned values. No fields of a multi-element structure or vector may be elided

For example,

```
struct {
    uint8 f1;
    uint8 f2;
} Example1;
```

```
Example1 ex1 = {1, 4}; /* assigns f1 = 1, f2 = 4 */
```

8.9 String Constants

A string constant must be interpreted as a vector of bytes (uint8) with a fixed length. Strings are enclosed with quotation marks. Unlike in C, no terminating nulls are implied. ASCII coding must be used.

For example,

```
block = H(parameter, "key expansion");
/* string length is 13 bytes (no terminating null) */
```

9 Record Protocol Specification

The WTLS Record Protocol is a layered protocol. The Record Protocol takes messages to be transmitted, optionally compresses the data, applies a MAC, encrypts, and transmits the result. Received data is decrypted, verified, and decompressed, then delivered to higher level clients.

Four record protocol clients are described in this document: the change cipher spec protocol, the handshake protocol, the alert protocol, and the application data protocol. If a WTLS implementation receives a record type it does not understand, it should ignore it.

Several records can be concatenated into one transport SDU. For example, several handshake messages can be transmitted in one transport SDU. This is particularly useful with packet-oriented transports such as GSM short messages.

9.1 Connection State

A WTLS connection state is the operating environment of the WTLS Record Protocol. It specifies a compression algorithm, encryption algorithm and MAC algorithm. In addition, the parameters for these algorithms are known: the MAC secret and the bulk encryption keys and IVs for the secure connection in both the read and the write directions.

Logically, there are always two connection states outstanding: the current state and the pending state. All records are processed under the current state. The security parameters for the pending state are set by the WTLS Handshake Protocol. The Handshake Protocol must make the pending state current. The pending state is then reinitialised to an empty state. The initial current state always specifies that no encryption, compression, or MAC will be used.

The security parameters for a WTLS connection state are set by providing the following values. Note that the following values are agreed on in a handshake procedure between a client and server when a secure session is negotiated (for more information see Chapter 10):

These parameters are defined in the presentation language as:

```
enum { server(1), client(2) } ConnectionEnd;

uint8 BulkCipherAlgorithm;

enum { stream(1), block(2), (255) } CipherType;

enum { true, false } IsExportable;

uint8 MACAlgorithm;

enum { off(0), implicit(1), explicit(2), (255) } SequenceNumberMode;

uint8 CompressionMethod;
```

```

struct {
    ConnectionEnd      entity;
    BulkCipherAlgorithm bulk_cipher_algorithm;
    CipherType        cipher_type;
    uint8              key_size; /* bytes */

    uint8              iv_size; /* bytes */
    uint8              key_material_length; /* bytes */
    IsExportable       is_exportable;
    MACAlgorithm       mac_algorithm;
    uint8              mac_key_size; /* bytes */
    uint8              mac_size; /* bytes */
    opaque             master_secret[20];
    opaque             client_random[16];
    opaque             server_random[16];
    SequenceNumberMode sequence_number_mode;
    uint8              key_refresh;
    CompressionMethod  compression_algorithm;
} SecurityParameters;

```

Item	Description
Connection End	Whether this entity is considered a client or a server in this secure session.
Bulk Cipher Algorithm	An algorithm to be used for bulk encryption. This specification includes the key size of this algorithm, how much of that key is secret, whether it is a block or stream cipher, the block size of the cipher (if appropriate), and whether it is considered as an “export cipher”. Bulk cipher algorithms are listed in Appendix A.
MAC Algorithm	An algorithm to be used for message authentication. This specification includes the size of the key used for MAC calculation and the size of the hash which is returned by the MAC algorithm. MAC algorithms are listed in Appendix A.
Compression Algorithm	The algorithm to compress data prior to encryption. This specification must include all information the algorithm requires to do compression.
Master Secret	A 20 byte secret shared between the two peers in the secure connection.
Client Random	A 16 byte value provided by the client.
Server Random	A 16 byte value provided by the server.

Item	Description
Sequence Number Mode	<p>Which scheme is used to communicate sequence numbers in this secure connection:</p> <p>Implicit sequence numbering</p> <p>Sequence numbers will be used as an input to MAC calculations. This requires that a reliable transport protocol is used.</p> <p>Explicit sequence numbering</p> <p>The sequence number will be sent in plaintext with record layer messages and it is used as an input to MAC calculations. This option MUST be used when operating on a datagram transport protocol. Note that in this case sequence numbers do not have to be in unbroken sequence, but they have to be sent in monotonic way (the sequence number of each sent record is greater than the previous one).</p> <p>Off</p> <p>No sequence numbers will be used. This option is not recommended and choosing it makes the system vulnerable for playback attacks. In this case, protection against such attacks must be provided by upper protocol layers.</p>
Key Refresh	<p>Defines how often some connection state parameters (encryption key, MAC secret, and IV) are updated New keys are calculated at every</p> $n = 2^{\text{key_refresh}}$ <p>messages, ie, when the sequence number is 0, n, 2n, 3n etc.</p> <p>For example, if three is chosen as a value for key_refresh, a new set of keys is generated for every eight (2^3) messages, ie, messages with sequence numbers 0, 8, 16 etc. If zero is chosen, a new key set is generated for each message (2^0).</p>

Once the security parameters have been set and the keys have been generated, the connection states can be instantiated by making them the current states. These current states must be updated for each record processed. Each connection state includes the following elements:

Item	Description
Compression State	The current state of the compression algorithm. Note that a stateful compression cannot be used when operating on top of a datagram protocol. If a stateful compression is used, there are separate states for both directions.
Client write MAC secret	The secret used for MAC calculation/verification for records sent by the client. The secret must be updated according to the key refresh parameter.
Client write encryption key	The key used for encryption/decryption of records sent by the client. The key must be updated according to the key refresh parameter.
Client write IV	The base IV used to calculate a record level IV for block ciphers running in CBC mode for records sent by the client.
Client write sequence number	The sequence number used for records sent by the client. Sequence numbers are of type uint16 and may not exceed $2^{16}-1$. When a new connection state is established the sequence number of the first record is zero.
Server write MAC secret	The secret used for MAC calculation/verification for records sent by the server. The secret must be updated according to the key refresh parameter.
Server write encryption key	The key used for encryption/decryption of records sent by the server. The key must be updated according to the key refresh parameter.
Server write IV	The base IV used to calculate a record level IV for block ciphers running in CBC mode for records sent by the server.
Server write sequence number	The sequence number used for records sent by the server. Sequence numbers are of type uint16 and may not exceed $2^{16}-1$. When a new connection state is established the sequence number first record is zero.

9.2 Record Layer

The WTLS Record Layer receives uninterpreted data from higher layers in non-empty blocks of size maximum of $2^{16}-1$.

9.2.1 Fragmentation

Unlike in TLS, the record layer does not fragment information blocks. It is assumed that the transport layer takes care of the necessary fragmentation and reassembly.

```
enum {
    change_cipher_spec(1), alert(2), handshake(3),
    application_data(4), (15)
} ContentType;
```

```
enum { without(0), with(1) } SequenceNumberIndication;
```

```
enum { without(0), with(1) } FragmentLengthIndication;
```

```

struct {
    opaque record_type[1];
    select (SequenceNumberIndication) {
        case without: struct {};
        case with: uint16 sequence_number;
    }
    select (FragmentLengthIndication) {
        case without: struct {};
        case with: uint16 length;
    } opaque fragment[WTLSPplaintext.length];
} WTLSPplaintext;

```

Description of WTLSPplaintext fields:

Item	Description		
record_type	Defines the higher level protocol used to process the enclosed fragment. Contains also information about the existence of optional fields in the record and an indication about ciphering state. Each of the bits in this field remain constant once set and must not be altered in the translations between WTLSPplaintext, WTLSCompressed and WTLSCiphertext.		
	Bits	Length	Description
	0	1 bit	<p>Record length field indicator defines whether the record contains a length field:</p> <p>0 = no record length field 1 = record length field included</p> <p>In some circumstances, it is possible to avoid sending the record length in the record layer. This reduces the amount of overhead two bytes per record. The requirements for leaving the field out are:</p> <ol style="list-style-type: none"> 1. The receiver must be able to determine the size of the transport SDU. 2. This is the last (or the only) record in this transport SDU. <p>If both requirements are met, each peer can decide per message whether they use the record length field or not. If possible the record length field should be left out.</p>
	1	1 bit	<p>Sequence number field indicator defines whether the next byte in this record contains a sequence number field:</p> <p>0 = no sequence number field 1 = sequence number included</p> <p>The sequence number field MUST be used with datagram transports (see Section 9.2.3.1 for explicit sequence numbering).</p>
	2	1 bit	<p>Cipher spec indicator defines whether this record is transmitted under a cipher spec different from null</p> <p>0 = null cipher spec used 1 = current, different from null, cipher spec is used</p> <p>Null cipher spec means that no compression, MAC protection or encryption is used. Its usage is restricted to handshake messages starting a new session and certain alerts sent in cleartext (see Section 10.2.2).</p>

Item	Description		
	3	1 bit	Reserved for future use
	4 – 7	4 bits	Content type
sequence_number	An optional sequence number of the record. Note that this field MUST be used with datagram transports (see Section 9.2.3.1 for explicit sequence numbering).		
length	The optional length (in bytes) of the following WTLSP plaintext.fragment. This field MUST be used if several records are concatenated into one transport SDU.		
fragment	The application data. This data is transparent and treated as an independent block to be dealt with by the higher level protocol specified by the type field.		

Note: Data of different WTLS Record layer content types may be interleaved. Application data is generally of lower precedence for transmission than other content types.

9.2.2 Record Compression and Decompression

All records are compressed using the compression algorithm defined in the current connection state. There is always an active compression algorithm; however, initially it is defined as NULL. Note that a stateful compression algorithm can not be used if WTLS is ran on top of a datagram transport.

The compression algorithm translates a WTLSP plaintext structure into a WTLSP compressed structure. This means that the WTLSP plaintext.fragment is compressed and copied. Other fields (such as the fragment length) are updated if needed.

```
struct {
    opaque record_type[1];
    select (SequenceNumberIndication) {
        case without: struct {};
        case with: uint16 sequence_number;
    }
    select (FragmentLengthIndication) {
        case without: struct {};
        case with: uint16 length;
    }
    opaque fragment[WTLSPCompressed.length];
} WTLSPCompressed;
```

Description of WTLSPCompressed fields:

Item	Description
record_type	As in Section 9.2.1.
sequence_number	As in Section 9.2.1.
length	The optional length (in bytes) of the following WTLSPCompressed.fragment (See Section 9.2.1).
fragment	The compressed form of WTLSP plaintext.fragment.

9.2.3 Record Payload Protection

The encryption and MAC functions translate a WTLSCompressed structure into a WTLSCiphertext. The decryption functions reverse the process.

```
struct {
    opaque record_type[1];
    select (SequenceNumberIndication) {
        case without: struct {};
        case with: uint16 sequence_number;
    }
    select (FragmentLengthIndication) {
        case without: struct {};
        case with: uint16 length;
    }
    select (SecurityParameters.cipher_type) {
        case stream: GenericStreamCipher;
        case block: GenericBlockCipher;
    } fragment;
} WTLSCiphertext;
```

Item	Description
record_type	As in Section 9.2.1.
sequence_number	As in Section 9.2.1.
length	The optional length (in bytes) of the following WTLSCiphertext.fragment (See Section 9.2.1).
fragment	The encrypted form of WTLSCompressed.fragment.

9.2.3.1 Explicit Sequence Numbering

When explicit sequence numbering is used, record verification and decryption require special measures. Explicit sequence numbering **MUST** be used with a datagram transport protocols meaning that records can be lost, duplicated, or received out of order.

The receiver **MUST** discard duplicated records, which can be realized by keeping books about received records. This can be implemented by using a sliding window. For example, a window with size of 32 can be used. Using this window, the receiver can keep books on received messages with sequence numbers in the range

$$n - 32 + 1 \dots n$$

where n is the current sequence number, which is the largest sequence number for the last records of no more than 32 (i.e., window size) received. Records with sequence numbers less or equal to $n - 32$ must be discarded. A record is received if it is not otherwise discarded or ignored. A record with a sequence number greater than $n - 32$ must be examined. If it is received and the sequence number in the record is greater than n , n must be replaced with that sequence number and the window is effectively advanced. Like the sequence number, n monotonically increments, and always starts with 0, as described below.

When a handshake starts with plain text message exchanges, sequence numbers start from zero and are incremented by one in each handshake message. When a handshake starts on a secure connection, the current sequence numbers for the secure connection is used for handshake messages and are incremented by one for each handshake message. They are set to zero after ChangeCipherSpec message for either cases. In retransmissions, sequence numbers remain the same as in the original messages. When the sequence number exceeds $2^{16}-1$ the secure connection MUST be closed.

In handshake messages, sequence numbers MUST be used (even on connection oriented transports). After negotiation, sequence numbers are either used or not. Note that with datagram transport protocols, sequence numbers MUST always be used.

9.2.3.2 Null or Standard Stream Cipher

Stream ciphers (including BulkCipherAlgorithm NULL) convert WTLSCompressed.fragment structures to and from stream WTLSCiphertext.fragment structures.

```
stream-ciphered struct {
    opaque content[WTLSCompressed.length];
    opaque MAC[SecurityParameters.mac_size];
} GenericStreamCipher;
```

The MAC is generated as:

```
HMAC_hash ( MAC_secret, seq_number + WTLSCompressed.record_type +
            WTLSCompressed.length + WTLSCompressed.fragment )
```

where “+” denotes concatenation. If WTLSCompressed.length is not available, the actual length of the compressed fragment should be used instead.

Note that no stream ciphers except BulkCipherAlgorithm NULL are defined in the current WTLS specification.

9.2.3.3 CBC Block Cipher

For block ciphers (such as RC5 and DES), the encryption and MAC functions convert WTLSCompressed.fragment structures to and from block WTLSCiphertext.fragment structures.

```
block-ciphered struct {
    opaque content[WTLSCompressed.length];
    opaque MAC[SecurityParameters.mac_size];
    uint8 padding[padding_length];
    uint8 padding_length;
} GenericBlockCipher;
```

The MAC is generated as described in Section 9.2.3.2.

Item	Description
Padding	Padding that is added to force the length of the plaintext to be a multiple of the block cipher's block length. Each uint8 in the padding data vector MUST be filled with the padding length value.
padding_length	The padding length should be such that the total size of the GenericBlockCipher structure is a

Item	Description
	multiple of the cipher's block length. Legal values range from zero to 255, inclusive.

The encrypted data length (WTLSCiphertext.length) is one more than the sum of WTLSCompressed.length, SecurityParameters.mac_size, and padding_length.

Example: If the block length is 8 bytes, the content length (WTLSCompressed.length) is 59 bytes, and 10 bytes of the MAC are used, the length before padding is 70 bytes. Since $70 \bmod 8$ is 6, 2 bytes of padding are required.

Generation of the encryption key and the initialization vector (IV) is explained in the Section 11.2.

10 Handshake Protocol Specification

The WTLS Handshake Protocol is composed of three sub-protocols which are used to allow peers to agree upon security parameters for the record layer, authenticate themselves, instantiate negotiated security parameters, and report error conditions to each other.

The Handshake Protocol is responsible for negotiating a secure session, which consists of the following items:

Item	Description
Session Identifier	An arbitrary byte sequence chosen by the server to identify an active or resumable secure session.
Protocol Version	WTLS protocol version number.
Peer Certificate	Certificate of the peer. This element of the state may be null.
Compression Method	The algorithm used to compress data prior to encryption.
Cipher Spec	Specifies the bulk data encryption algorithm (such as null, RC5, DES, etc.) and a MAC algorithm (such as SHA-1). It also defines cryptographic attributes such as the <code>mac_size</code> .
Master Secret	20-byte secret shared between the client and server.
Sequence Number Mode	Which sequence numbering scheme (off, implicit, or explicit) is used in this secure connection.
Key Refresh	Defines how often some connection state values (encryption key, MAC secret, and IV) calculations are performed.
Is Resumable	A flag indicating whether the secure session can be used to initiate new secure connections.

These items are then used to create security parameters for use by the Record Layer when protecting application data. Many secure connections can be instantiated using the same secure session through the resumption feature of the WTLS Handshake Protocol.

10.1 Change Cipher Spec Protocol

The change cipher spec protocol exists to signal transitions in ciphering strategies. The protocol consists of a single message, which is encrypted and compressed under the current (not the pending) connection state. The message consists of a single byte of value 1.

```
struct {
    enum { change_cipher_spec(1), (255) } type;
} ChangeCipherSpec;
```

The change cipher spec is sent either by the client or server to notify the other party that subsequent records will be protected under the newly negotiated CipherSpec and keys. In practise, sending this message means that the sender has set the current write state to the pending state. When a ChangeCipherSpec is received the receiver should set the current read state to the pending state. The change cipher spec message is sent during the handshake after the security parameters have been agreed upon, but before the verifying finished message is sent. Implementations **MUST** check that the change cipher spec message is sent or received before sending or receiving the verifying finished message, so that the finished and subsequent messages are protected under the newly negotiated Cipher Spec and keys.

10.2 Alert Protocol

One of the content types supported by the WTLS Record layer is the alert type. Alert messages convey the severity of the message and a description of the alert.

Alert messages with a level of fatal result in the immediate termination of the secure connection. In this case, other connections using the secure session **MAY** continue, but the session identifier **MUST** be invalidated, preventing the failed secure session from being used to establish new secure connections. However, session invalidation is not required in response to a fatal alert under certain scenarios (see Section 10.2.2).

Alert messages with a level of critical result in the immediate termination of the secure connection. Other connections using the secure session **MAY** continue and the session identifier **MAY** be preserved to be used for establishing new secure connections.

An alert message is either sent as specified by the current connection state (ie, compressed and encrypted), or under null cipher spec (ie, without compression or encryption).

A 4-byte checksum is used in alerts. The checksum is calculated from the last record (ie, WTLSCiphertext structure) received from the other party, in the following way:

1. Pad the record with zero bytes so that its length is equal to 0 modulo 4
2. Devide the result into 4-byte blocks
3. XOR these blocks together

If an alert needs to be sent without having received any records from the other party, a checksum with four zero bytes **MUST** be used.

The receiver of an alert **MUST** verify that the checksum matches with the message earlier sent by him. If the receiver of the alert can determine that the sender has not received any messages from which to calculate the checksum, an alert with a checksum of four zero bytes may be accepted.

```
enum { warning(1), critical(2), fatal(3), (255) } AlertLevel;
```

```

enum {
    connection_close_notify(0),
    session_close_notify(1)
    no_connection(5),
    unexpected_message(10),
    time_required(11),
    bad_record_mac(20),
    decryption_failed(21),
    record_overflow(22),
    decompression_failure(30),
    handshake_failure(40),
    bad_certificate(42),
    unsupported_certificate(43),
    certificate_revoked(44),
    certificate_expired(45),
    certificate_unknown(46),
    illegal_parameter(47),
    unknown_ca(48),
    access_denied(49),
    decode_error(50),
    decrypt_error(51),
    unknown_key_id(52),
    disabled_key_id(53),
    key_exchange_disabled(54),
    session_not_ready(55),
    unknown_parameter_index(56),
    duplicate_finished_received(57),
    export_restriction(60),
    protocol_version(70),
    insufficient_security(71),
    internal_error(80),
    user_canceled(90),
    no_renegotiation(100), (255)
} AlertDescription;

```

```

struct {
    AlertLevel level;
    AlertDescription description;
    opaque checksum[4]
} Alert;

```

10.2.1 Closure Alerts

The client and the server must share knowledge that the secure connection is ending. Either party may initiate the exchange of closing messages.

Alert	Description
connection_close_notify	This message notifies the recipient that the sender will not send any more messages using this connection state.
session_close_notify	This message notifies the recipient that the sender will not send any more messages using this connection state or the secure session.

Either party may initiate a close by sending a *connection_close_notify* or *session_close_notify* alert. Any data received after a closure alert is ignored. It is required that the other party responds with a *connection_close_notify* or *session_close_notify* alert of its own, respectively, and close down the secure connection immediately, discarding any pending writes. In the case of a *session_close_notify*, the receiver MUST also invalidate the session identifier. It is not required for the initiator of the close to wait for the responding *connection_close_notify* or *session_close_notify* alert before closing the read side of the secure connection. The alert level MUST be set to *critical* for *connection_close_notify* and *fatal* for *session_close_notify*.

10.2.2 Error Alerts

Error handling in the WTLS Handshake protocol is very simple. When an error is detected, the detecting party sends a message to the other party. Upon transmission or receipt of a fatal alert message, both parties immediately close the secure connection. Servers and clients are required to forget any session identifiers, keys, and secrets associated with a failed secure connection. Upon transmission or receipt of a critical alert message, both parties immediately close the secure connection but MAY preserve the session-identifiers and use that for establishing new secure connections. The following error alerts are defined:

Alert	Description
no_connection	A message was received while there is no secure connection with the sender. This message is fatal or critical. The message is sent in cleartext. This alert SHOULD be accepted regardless of the sequence number in the record which carries this alert. The sender SHOULD use the value $2^{16} - 1$.
unexpected_message	An inappropriate message was received. This alert SHOULD be fatal or critical.
time_required	This alert is a warning sent by the server, to inform the client that more time is required for a certain handshake operation, than would be expected for the client retransmission timer. When receiving this alert, the client should clear its retransmission timer.
bad_record_mac	This alert is returned if a record is received with an incorrect MAC. This message is generally a warning. The message is sent in cleartext.
decryption_failed	A WTLSCiphertext decrypted in an invalid way: either it wasn't a multiple of the block length or its padding values, when checked, weren't correct. This message is generally a warning. The message is sent in cleartext.
record_overflow	A WTLSCiphertext record was received which had a length more than allowed bytes, or a record decrypted to a WTLSCompressed record with more than allowed bytes. This message is generally a warning. The message is sent in cleartext.
decompression_failure	The decompression function received improper input (eg, data that would expand to excessive length). This message is generally a warning. The message is sent in cleartext.
handshake_failure	Reception of a handshake_failure alert message indicates that the sender was unable to negotiate an acceptable set of security parameters given the options available. This is a fatal error.
bad_certificate	A certificate was corrupt, contained signatures that did not verify correctly, etc.
unsupported_certificate	A certificate was of an unsupported type.
certificate_revoked	A certificate was revoked by its signer. Note that certificate revocation is likely to be checked by servers only.
certificate_expired	A certificate has expired or is not currently valid.
certificate_unknown	Some other (unspecified) issue arose in processing the certificate, rendering it

Alert	Description
	unacceptable.
illegal_parameter	A field in the handshake was out of range or inconsistent with other fields. This is always fatal.
unknown_ca	A valid certificate chain or partial chain was received, but the certificate was not accepted because the CA certificate could not be located or couldn't be matched with a known, trusted CA. This message is always fatal.
access_denied	A valid certificate was received, but when access control was applied, the sender decided not to proceed with negotiation. This message is always fatal.
decode_error	A message could not be decoded because some field was out of the specified range or the length of the message was incorrect. This message is fatal or critical.
decrypt_error	A handshake cryptographic operation failed, including being unable to correctly verify a signature, decrypt a key exchange, or validate a finished message. This message SHOULD be sent as fatal.
unknown_key_id	None of the client key_id's listed in ClientHello.client_key_ids is known or recognized to the server, or the client did not supply any items, if the server has the policy that requires recognition of client_key_id's. This is generally a fatal alert.
disabled_key_id	All the client_key_id's listed in ClientHello.client_key_ids are disabled administratively. This is generally a critical alert.
key_exchange_disabled	To protect the outcome of the anonymous key exchange from being overridden by the undesirable subsequent anonymous key exchanges, key exchange is administratively disabled.
session_not_ready	The secure session is not ready to resume new secure connections due to administrative reasons such as that the session is temporarily not available due to maintenance in the server. This is generally a critical alert.
unknown_parameter_index	The client has suggested a key exchange suite that could be supported by the server, but the server does not know the key exchange parameter index supplied. When receiving this alert, the client may initiate a new handshake and suggest another parameter index, supply the parameters explicitly or let the server supply the parameters.
duplicate_finished_received	In an abbreviated or optimised handshake, the client has sent a second (resent) finished message. This message is generally a warning.
export_restriction	A negotiation not in compliance with export restrictions was detected. This message is always fatal.
protocol_version	The protocol version the client (or server) has attempted to negotiate is recognised, but not supported by the server (or client). (For example, old protocol versions might be avoided for security reasons). This message is always fatal.
insufficient_security	Returned instead of handshake_failure when a negotiation has failed specifically because the server requires ciphers more secure than those supported by the client. This message is always fatal.
internal_error	An internal error unrelated to the peer or the correctness of the protocol makes it impossible to continue (such as a memory allocation failure). This message is fatal or critical.
user_canceled	This handshake is being cancelled for some reason unrelated to a protocol failure. If the

Alert	Description
	user cancels an operation after the handshake is complete, just closing the secure connection by sending a <i>connection_close_notify</i> is more appropriate. This alert should be followed by a <i>connection_close_notify</i> . This message is generally a warning.
no_renegotiation	Sent by the client in response to a hello request or by the server in response to a client hello after initial handshaking. Either of these would normally lead to renegotiation; when that is not appropriate, the recipient SHOULD respond with this alert; at that point, the original requester can decide whether to proceed with the secure connection.

For all errors where an alert level is not explicitly specified, the sending party may determine at its discretion whether this is a fatal or critical error or a warning; if an alert with a level of warning or critical is received, the receiving party may decide at its discretion whether to treat this as a fatal error or not. However, all messages which are transmitted with a level of fatal MUST be treated as fatal messages.

Implementations MAY maintain a count of received alerts with a level of warning or critical, and treat them as fatal when a certain configurable limit is exceeded.

A fatal alert only terminates the session to be created and leaves the existing session intact if the handshaking is conducted on an existing secure session. However, there may be some cases that closing the existing session is desirable. A *session_close_notify* MUST be sent to the peer if one of the parties decide to terminate the existing session immediately after a fatal alert is sent or received during a handshake that intends to create a new session. Under any other circumstances, a fatal alert is treated normally as described at the beginning of this section.

An existing valid session SHOULD not be invalidated if a clear text fatal alert is received, although it MUST be invalidated if the fatal alert is not in clear text. A clear text alert is neither encrypted nor authenticated (e.g., MAC).

10.3 Handshake Protocol Overview

The cryptographic parameters of the secure session are produced by the WTLS Handshake Protocol, which operates on top of the WTLS Record Layer. When a WTLS client and server first start communicating, they agree on a protocol version, select cryptographic algorithms, optionally authenticate each other, and use public-key encryption techniques to generate a shared secret.

The WTLS Handshake Protocol involves the following steps:

- Exchange hello messages to agree on algorithms, exchange random values.
- Exchange the necessary cryptographic parameters to allow the client and server to agree on a pre-master secret.
- Exchange certificates and cryptographic information to allow the client and server to authenticate themselves.
- Generate a master secret from the pre-master secret and exchanged random values.
- Provide security parameters to the record layer.
- Allow the client and server to verify that their peer has calculated the same security parameters and that the handshake occurred without tampering by an attacker.

These goals are achieved by the handshake protocol, which can be summarised as follows: The client sends a client hello message to which the server must respond with a server hello message, or else a fatal error will occur and the secure connection will fail. The client hello and server hello are used to establish security enhancement capabilities between client and server. The client hello and server hello establish the following attributes: Protocol Version, Key Exchange Suite, Cipher Suite, Compression Method, Key Refresh, and Sequence Number Mode. Additionally, two random values are generated and exchanged: ClientHello.random and ServerHello.random.

Following the hello messages, the server will send its certificate, if it is to be authenticated. Additionally, a server key exchange message may be sent, if it is required (eg, the server does not have a certificate, or if its certificate is for signing only). The server may request a certificate from the client (or get the certificate from some certificate distribution service), if that is appropriate to the key exchange suite selected. Now the server will send the server hello done message, indicating that the hello-message phase of the handshake is complete. (The previous handshake messages are combined in one lower layer message.) The server will then wait for a client response. If the server has sent a certificate request message, the client must send the certificate message. The client key exchange message is now sent if the client certificate does not contain enough data for key exchange or if it is not sent at all. The content of that message will depend on the public key algorithm selected between the client hello and the server hello. If the client is to be authenticated using a certificate with a signing capability (eg, RSA), a digitally-signed certificate verify message is sent to explicitly verify the certificate.

At this point, a change cipher spec message is sent by the client, and the client copies the pending Cipher Spec into the current write Cipher Spec. The client then immediately sends the finished message under the new algorithms, keys, and secrets. From now on, the Cipher Spec indicator is set to 1 in the messages. When the server receives the change cipher spec message it also copies the pending Cipher Spec into the current read Cipher Spec. In response, the server will also send its own ChangeCipherSpec message, set its current write Cipher Spec to the pending Cipher Spec, and send its own finished message under the new Cipher Spec. At this point, the handshake is complete and the client and server may begin to exchange application layer data. (See flow chart below.)

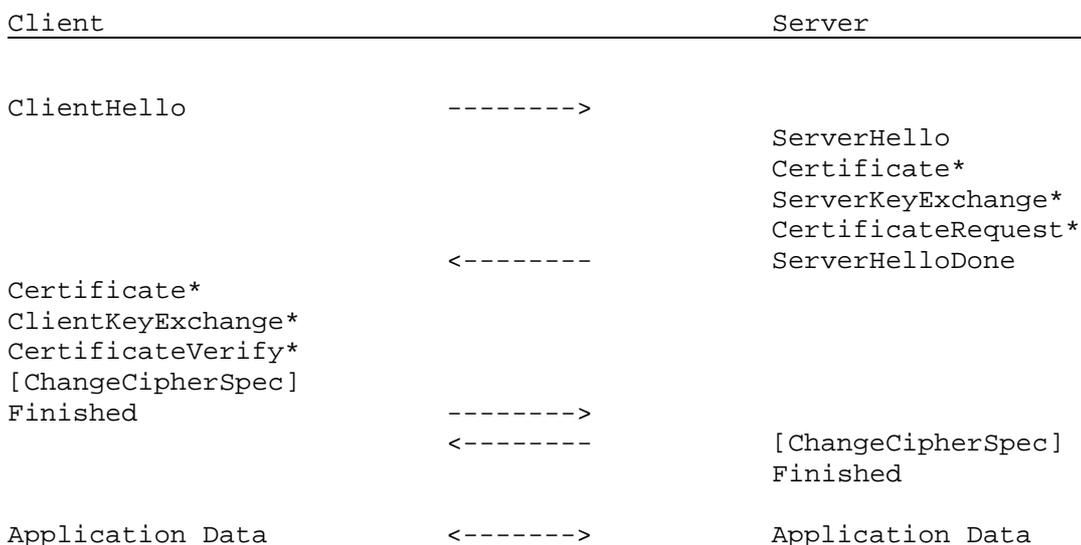


Figure 5. Message flow for a full handshake

* Indicates optional or situation-dependent messages that are not always sent.

When the client and server decide to resume a previous secure session instead of negotiating new security parameters the message flow is as follows:

The client sends a ClientHello using the Session ID of the secure session to be resumed. The server then checks its secure session cache for a match. If a match is found, and the server is willing to re-establish the secure connection under the specified secure session, it will send a ServerHello with the same Session ID value. At this point, the server must send a ChangeCipherSpec message and proceed directly to the Finished message to which the client should respond with its own ChangeCipherSpec and Finished message. Once the re-establishment is complete, the client and server may begin to exchange application layer data. (See flow chart below.) In addition, a new key refresh rate MAY be negotiated during the abbreviated handshake for a secure connection. If a Session ID match is not found, the server generates a new session ID and the TLS client and server perform a full handshake.

Note that many simultaneous secure connections can be instantiated under one secure session. Each secure connection established from the same secure session shares some parameters with the others (eg, master secret).

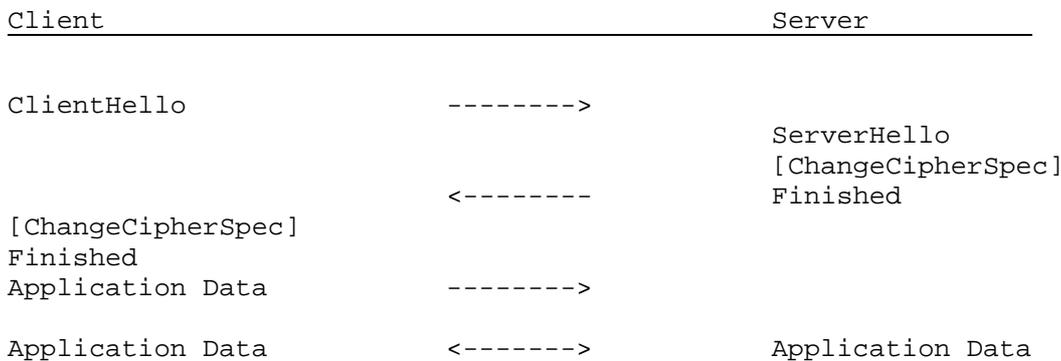
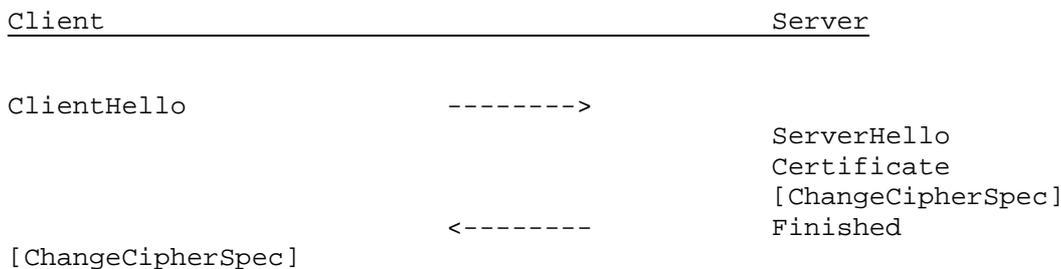


Figure 6. Message flow for an abbreviated handshake

The shared-secret handshake means that the new secure session is based on a shared secret already implanted in both ends (eg, physically). In this case, the shared secret is used as the pre-master secret and the SHARED_SECRET key exchange suite is requested by the client in ClientHello. The message flow is similar to the abbreviated handshake in Figure 6, except that the ClientHello.session_id is empty and that a non-empty identifier **MUST** be supplied in the corresponding element for SHARED_SECRET key exchange suite of the ClientHello.client_key_ids. Like the secure sessions created by any other types of handshakes, a secure session created by the shared-secret handshake **MAY** also be resumable.

Another variation is that the server, after receiving the ClientHello, can retrieve client's certificate using a certificate distribution service or from its own sources. In a EC Diffie-Hellman type key exchange method, assuming the EC Diffie-Hellman parameters are provided in the certificates, the server can calculate the pre-master secret and master secret at this point. In this case, the server sends its certificate, a Change Cipher Spec, and a Finished message. The client responds with a ChangeCipherSpec and Finished message and application data can now be exchanged.



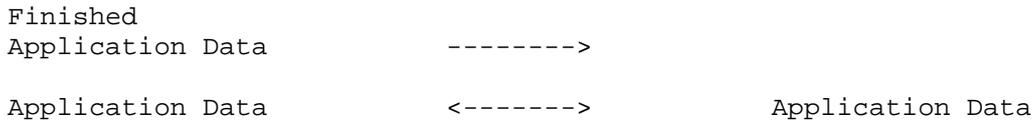


Figure 7. Message flow for an optimised full handshake

10.4 Handshake Reliability over Datagrams

In the datagram environment, handshake messages may be lost, out of order, or duplicated. To make the handshake reliable over datagrams, WTLS requires that the handshake messages going in the same direction must be concatenated in a single transport Service Data Unit (SDU) for transmission, that the client retransmits the handshake messages if necessary, and that the server **MUST** appropriately respond the retransmitted messages from the client.

The handshake may consist of multiple messages to be delivered in one direction before any responses are required from the other end. Those messages must be concatenated into a single transport SDU for transmission or retransmission to guarantee that all the messages in the same SDU arrive in order. For instance, ServerHello, ChangeCipherSpec, and Finished messages can be sent in a single transport SDU for the abbreviated handshake. The maximum size of SDU for the underlying transport service layer must be sufficient to contain all those messages.

Since each record can only contain one handshake message under any circumstances, the concatenation of handshake messages must be implemented through the concatenation of the corresponding records.

For the full handshake, the client must retransmit ClientHello and Finished messages if the expected response messages are not received from the server for a predefined time-out period. Note that the whole transport SDU which contains the Finished message must be retransmitted. After the number of retransmissions exceeds the maximum predefined retransmission counter, the client terminates the handshake. Those predefined time-out and counter values may be obtained from the WTP stack through the management entity if the WTP stack is present above the WTLS stack.

For the optimized and abbreviated handshakes, like the full handshake, the client retransmits ClientHello, if necessary. In addition, the client must also prepend ChangeCipherSpec and Finished messages with the Application Data message until an Application Data message from the server is received and decrypted successfully or a *duplicated_finished_received* alert (warning) is received from the server. However, the first ChangeCipherSpec and Finished messages can be either sent alone or prepend with the Application Data message, if any.

For the full handshake, the server **MUST** retransmit the transport SDU which contains the ServerHello message upon receiving a duplicated ClientHello message. However, if the ClientHello is new, the server **MUST** start a new handshake and SEC-Create.ind service primitive **MUST** be generated. The server **MUST** also retransmit the transport SDU which contains ChangeCipherSpec and Finished messages upon receiving a duplicated Finished message from the client.

For the optimized and abbreviated handshakes, the server behaves the same as that in the full handshake for handling the duplicated or new ClientHello messages. In addition, the server **MUST** ignore duplicated Finished message and keep the committed secure connection intact. If the server has no Application Data to send to the client, it **SHOULD** send *duplicated_finished_received* alert (warning).

10.5 Handshake Protocol

The WTLS Handshake Protocol is one of the defined higher level clients of the WTLS Record Protocol. This protocol is used to negotiate the secure attributes of a secure session. Handshake messages are supplied to the WTLS Record Layer, where they are encapsulated within one or more WTLSPplaintext structures, which are processed and transmitted as specified by the current active connection state.

```
enum {
    hello_request(0), client_hello(1), server_hello(2),
    certificate(11), server_key_exchange(12),
    certificate_request(13), server_hello_done(14),
    certificate_verify(15), client_key_exchange(16),
    finished(20), (255)
} HandshakeType;
```

```
struct {
    HandshakeType msg_type;
    uint16 length;
    select (msg_type) {
        case hello_request:           HelloRequest;
        case client_hello:            ClientHello;
        case server_hello:            ServerHello;
        case certificate:              Certificates;
        case server_key_exchange      ServerKeyExchange;
        case certificate_request:      CertificateRequest;
        case server_hello_done:        ServerHelloDone;
        case certificate_verify:       CertificateVerify;
        case client_key_exchange:      ClientKeyExchange;
        case finished:                 Finished;
    } body;
} Handshake;
```

Item	Description
msg_type	Handshake message type.
length	Indicates the number of bytes of all the following data in the Handshake structure.

The handshake protocol messages are presented below in the order they must be sent; sending handshake messages in an unexpected order results in a fatal error. Unneeded handshake messages can be omitted, however. Note one exception to the ordering: the Certificate message is used twice in the handshake (from server to client, then from client to server), but described only in its first position. The one message which is not bound by these ordering rules is the Hello Request message, which can be sent at any time, but which should be ignored by the client if it arrives in the middle of a handshake.

10.5.1 Hello Messages

The hello phase messages are used to agree on used security parameters between the client and server. When a new secure session begins, the connection state (encryption, hash, and compression algorithms) is initialised to null. The Cipher Spec indicator is set to 0 in the records.

10.5.1.1 Hello Request

When this message will be sent:

The hello request message may be sent by the server at any time.

Meaning of this message:

Hello request is a simple notification that the client should begin the negotiation process anew by sending a client hello message when convenient. This message will be ignored by the client if the client is currently negotiating a secure session. This message MAY be ignored by the client if it does not wish to make a new handshake, or the client may, if it wishes, respond with a *no_renegotiation* alert. Since handshake messages are intended to have transmission precedence over application data, it is expected that the negotiation will begin before no more than a few records are received from the client. If the server sends a hello request but does not receive a client hello in response, it MAY close the secure connection with a fatal alert.

After sending a hello request, servers should not repeat the request until the subsequent handshake negotiation is complete. However, if the client does not respond in a reasonable time, the message MAY be sent again.

Structure of this message:

```
struct { } HelloRequest;
```

In some situations, it may be useful to reuse the existing secure session (session ID, master secret, etc.) and only create a new secure connection, using abbreviated handshake. For that reason, the client MAY, when starting negotiation, include session ID in Client Hello (10.5.1.2). The server then decides whether to proceed with abbreviated, full or optimized handshake.

The client MAY also negotiate a new secure session based on cleartext HelloRequest. The client MUST implement mechanism described in B4.

Note: This message must not be included in the message hashes which are maintained throughout the handshake and used in the finished messages and the certificate verify message.

10.5.1.2 Client Hello

When this message will be sent:

When a client first connects to a server it is required to send the client hello as its first message. The client can also send a client hello in response to a hello request or on its own initiative in order to renegotiate the security parameters in an existing secure connection.

Structure of this message:

The key exchange list contains the cryptographic key exchange algorithms supported by the client in decreasing order of preference. In addition, each entry defines the certificate or public key the client wishes to use. The server will select one or, if no acceptable choices are presented, return a *handshake_failure* alert and close the secure connection. The trusted authorities list with a similar format identifies the trusted certificates known by the client.

```
struct {
    uint32  gmt_unix_time;
    opaque random_bytes[12];
} Random;
```

Item	Description
gmt_unix_time	The current time and date in standard UNIX 32-bit format (seconds since the midnight starting

Item	Description
	Jan 1, 1970, GMT) according to the sender's internal clock. Clocks are not required to be set correctly by the basic WTLS Protocol ; higher level or application protocols may define additional requirements. If the client is not able to produce the time in standard UNIX 32-bit format it SHOULD use here a 32-bit value that has the 8 most significant bits set to zero (to indicate that this value is not the standard UNIX 32-bit format) and the rest of 24 bits set according to alternative date/time source or a random number.
random_bytes	12 bytes generated by a secure random number generator. This value will be used later in the protocol.

```
uint8 KeyExchangeSuite; /* Key exchange suite selector */
```

```
struct {
    uint8 dh_e;
    opaque dh_p<1..2^16-1>;
    opaque dh_g<1..2^16-1>;
} DHParameters;
```

Item	Description
dh_e	The exponent length in bytes. The value 0 indicates that the default length is used (ie, the same length as the prime).
dh_p	The prime modulus used for the Diffie-Hellman operation.
dh_g	The generator used for the Diffie-Hellman operation.

```
enum { ec_prime_p(1), ec_characteristic_two(2), (255) } ECFieldID;
```

```
enum { ec_basis_onb(1), ec_basis_trinomial(2), ec_basis_pentanomial(3),
    ec_basis_polynomial(4) } ECBasisType;
```

```
struct {
    opaque a <1..2^8-1>;
    opaque b <1..2^8-1>;
    opaque seed <0..2^8-1>;
} ECCurve;
```

Item	Description
a, b	These parameters specify the coefficients of the elliptic curve. Each value shall be the octet string representation of a field element following the conversion routine in [X9.62], section 4.3.1.
seed:	This is an optional parameter used to derive the coefficients of a randomly generated elliptic curve.

```
struct {
    opaque point <1..2^8-1>;
} ECPoint;
```

Item	Description
------	-------------

Item	Description
point	This is the octet string representation of an elliptic curve point following the conversion routine in [X9.62], section 4.3.6. The representation format is defined following the definition in [X9.62], section 4.3.6.

```

struct {
    ECFieldID field;
    select (field) {
    case ec_prime_p: opaque prime_p <1..2^8-1>;
    case ec_characteristic_two:
        uint16 m;
        ECBasisType basis;
        select (basis) {
            case ec_basis_onb:
                struct { };
            case ec_trinomial:
                uint16 k;
            case ec_pentanomial:
                uint16 k1;
                uint16 k2;
                uint16 k3;
            case ec_basis_polynomial:
                opaque irreducible <1..2^8-1>
        };
    };
    ECCurve curve;
    ECPPoint base;
    opaque order <1..2^8-1>;
    opaque cofactor <1..2^8-1>;
} ECParameters;

```

Item	Description
field	This identifies the finite field over which the elliptic curve is defined.
prime_p	This is the odd prime defining the field F_p .
m	This is the degree of the characteristic-two field F_{2^m}
k	The exponent k for the trinomial basis representation $x^m + x^k + 1$.
k1, k2, k3	The exponents for the pentanomial representation $x^m + x^{k3} + x^{k2} + x^{k1} + 1$.
irreducible	The irreducible polynomial.
curve	Specifies the coefficients a and b of the elliptic curve E.
base	The base point P on the elliptic curve.
order	The order n of the base point. The order of a point P is the smallest possible integer n such that $nP = 0$ (the point at infinity).
cofactor	The integer $h = \#E(F_q)/n$, where $\#E(F_q)$ represents the number of points on the elliptic curve E defined over the field F_q .

```
uint8 ParameterIndex;
```

```
enum { rsa, diffie_hellman, elliptic_curve } PublicKeyAlgorithm;
```

```
struct {
    uint16 length;
    select (PublicKeyAlgorithm) {
        case rsa: struct {};
        case diffie_hellman: DHParameters params;
        case elliptic_curve: ECParameters params;
    }
} ParameterSet;
```

Item	Description
length	Indicates the number of bytes of all the following data in the ParameterSet structure.

```
struct {
    ParameterIndex parameter_index;
    select (parameter_index) {
        case 255: ParameterSet parameter_set;
        default: struct {};
    }
} ParameterSpecifier;
```

Item	Description
parameter_index	Indicates parameters relevant for this key exchange suite 0 = not applicable, or specified elsewhere. 1...254 = assigned number of a parameter set, defined in Appendix A 255 = explicit parameters are present in the next field
parameter_set	Explicit parameters, eg, Diffie-Hellman or ECDH parameters. Implementations SHOULD use parameter indexes instead of explicit parameters.

```
enum { null(0), text(1), binary(2), key_hash_sha(254), x509_name(255)} IdentifierType;
```

```
uint16 CharacterSet;
```

```

struct {
  IdentifierType identifier_type;
  select (identifier_type) {
    case null: struct {};
    case text:
      CharSet character_set;
      opaque name<1.. 2^8-1>;
    case binary: opaque identifier<1..2^8-1>;
    case key_hash_sha: opaque key_hash[20];
    case x509_name: opaque distinguished_name<1..2^8-1>;
  } Identifier;

```

Item	Description
identifier_type	Type of identifier used 0 = no identity supplied 1 = textual name with character set 2 = binary identity 254 = SHA-1 hash of the public key 255 = X.509 distinguished name
character_set	Maps to IANA defined character set.
name	Textual name.
identifier	Binary identifier.
key_hash	Hash of the public key of the key pair which the client intends to use in the handshake to prove its identity. For RSA, the SHA-1 hash is to be done on the byte string representation of the public modulus [PKCS1]. For ECC, the SHA-1 hash is to be done on the byte string representation of the x-coordinate of the elliptic curve point [X9.62].
distinguished_name	X.509 distinguished name.

```

struct {
  KeyExchangeSuite key_exchange_suite;
  ParameterSpecifier parameter_specifier;
  Identifier identifier;
} KeyExchangeId;

```

Item	Description
key_exchange_suite	Assigned number of the key exchange suite, defined in Appendix A.
parameter_specifier	Specifies parameters relevant for this key exchange suite. Value zero of a parameter index for a key exchange suite using parameters, indicates that the server MUST supply parameters
identifier	Identifies the client in a relevant way for the key exchange suite. The server can use this information to fetch a client certificate from a database.

The CipherSuite list, passed from the client to the server in the client hello message, contains the combinations of symmetric cryptographic algorithms supported by the client in order of the client's preference (favourite choice first). Each CipherSuite defines a bulk encryption algorithm (including secret key length) and a MAC algorithm. The server will select a cipher suite or, if no acceptable choices are presented, return a *handshake_failure* alert and close the secure connection.

```
struct {
    BulkCipherAlgorithm bulk_cipher_algorithm;
    MACAlgorithm        mac_algorithm;
} CipherSuite
```

Item	Description
bulk_cipher_algorithm	Assigned number of the bulk cipher algorithm, defined in Appendix A.
mac_algorithm	Assigned number of the MAC algorithm, defined in Appendix A.

```
opaque SessionID<0..8>;
```

The client hello includes a list of compression algorithms supported by the client, ordered according to the client's preference.

```
uint8 CompressionMethod;
```

```
struct {
    uint8 client_version;
    Random random;
    SessionID session_id;
    KeyExchangeId client_key_ids<0..2^16-1>;
    KeyExchangeId trusted_key_ids<0..2^16-1>;
    CipherSuite cipher_suites<2..2^8-1>;
    CompressionMethod compression_methods<1..2^8-1>;
    SequenceNumberMode sequence_number_mode;
    uint8 key_refresh;
} ClientHello;
```

Item	Description
client_version	The version of the WTLS protocol by which the client wishes to communicate during this secure session. This should be the latest (highest valued) version supported by the client. For this version of the specification, the version will be 1.
random	A client-generated random structure.
session_id	The ID of a secure session the client wishes to use for this secure connection. This field should be empty if no session_id is available or the client wishes to generate new security parameters.
client_key_ids	A list of cryptographic key exchange options and identities supported by the client, with the client's first preference first.
trusted_key_ids	A list of trusted certificates known by the client, with the client's first preference first.

Item	Description
cipher_suites	This is a list of the cryptographic options supported by the client, with the client's first preference first.
compression_methods	This is a list of the compression methods supported by the client, sorted by client preference. This vector MUST contain, and all implementations MUST support, CompressionMethod NULL. Thus, a client and server will always be able to agree on a compression method.
sequence_number_mode	This value indicates how sequence numbering should be used in record layer messages.
key_refresh	Defines how often some connection state parameters (encryption key, MAC secret, and IV) are updated. See Section 9.1. A new key refresh rate MAY be suggested for abbreviated handshake.

After sending the client hello message, the client waits for a server hello message. Any other handshake message returned by the server except for a hello request is treated as a critical or fatal error.

When the client has an existing session_id and is initiating an abbreviated handshake, it **MAY** omit key exchange related items (client_key_ids, trusted_key_ids) from the client hello message. In this case, if the server is not willing to resume the session and is not able to continue with a full handshake, and it **MUST** to return an *unknown_key_id* alert.

10.5.1.3 Server Hello

When this message will be sent:

The server will send this message in response to a client hello message when it was able to find an acceptable set of algorithms. If it cannot find such a match, it must respond with a *handshake_failure* alert.

Structure of this message:

```
struct {
    uint8 server_version;
    Random random;
    SessionID session_id;
    uint8 client_key_id;
    CipherSuite cipher_suite;
    CompressionMethod compression_method;
    SequenceNumberMode sequence_number_mode;
    uint8 key_refresh;
} ServerHello;
```

Item	Description
server_version	This field will contain the lower of that suggested by the client in the client hello and the highest supported by the server. For this version of the specification, the version is 1.
Random	This structure is generated by the server and must be different from (and independent of) ClientHello.random.
session_id	This is the identity of the secure session corresponding to this secure connection. If the

Item	Description
	ClientHello.session_id was non-empty, the server will look in its secure session cache for a match. If a match is found and the server is willing to establish the new secure connection using the specified secure session, the server will respond with the same value as was supplied by the client. This indicates a resumed secure session and dictates that the parties must proceed directly to the finished messages. Otherwise this field will contain a different value identifying the new secure session. The server MAY return an empty session_id to indicate that the secure session will not be cached and therefore cannot be resumed. If a secure session is resumed, it must be using the same cipher suite it was originally negotiated with.
client_key_id	The number of the key exchange suite selected by the server from the list in ClientHello.client_key_ids. For example, value one indicates that the first entry was selected. For abbreviated handshake, value 0 MAY be used to indicate that this field MUST be ignored.
cipher_suite	The single cipher suite selected by the server from the list in ClientHello.cipher_suites.
compression_method	The single compression algorithm selected by the server from the list in ClientHello.compression_methods.
sequence_number_mode	If the client suggested usage of sequence numbers then the server MUST confirm the value. If the client did not suggest usage the server can confirm that choice or indicate that sequence numbering should be used. So, if any party wishes to use sequence numbers then they have to be used.
key_refresh	This value indicates how many bits of the sequence number the server wishes to use to trigger key refresh. The value can be equal to what the client suggested or less . So, lower choice is used resulting in more frequent key refresh and thus higher security. A new key refresh rate MAY be suggested for abbreviated handshake.

10.5.2 Server Certificate

When this message will be sent:

If sent this message must always immediately follow the server hello message.

Meaning of this message:

The certificate type must be appropriate for the selected key exchange suite's algorithm. It can be a X.509v3 certificate [X509], a WTLS certificate which is optimised for size, or a X9.68 certificate (note: this certificate type has not been defined at the point of time of publication of this specification). Other certificate types may be added in the future. It must contain a key which matches the key exchange method, as follows. Unless otherwise specified, the signing algorithm for the certificate must be the same as the algorithm for the key carried in the certificate. Unless otherwise specified, the public key may be of any length.

As KeyExchangeSuites which specify new key exchange methods are specified for the WTLS Protocol, they will imply certificate format and the required encoded keying information.

Structure of this message:

```
enum { WTLSCert(1), X509Cert(2), X968Cert(3), CertURL(4), (255) }
CertificateFormat;
```

```
opaque X509Certificate<1..2^16-1>;
```

```
opaque X968Certificate<1..2^16-1>;
```

```
enum { anonymous(0), ecdsa_sha(1), rsa_sha(2), (255)} SignatureAlgorithm;
```

```
enum { rsa(2), ecdh(3), ecdsa(4), (255) } PublicKeyType;
```

```
ECPublicKey ECPublicKey;
```

Item	Description
ECPublicKey	The EC public key $W = sG$ [P1363].

```
struct {
  opaque rsa_exponent<1..2^16-1>;
  opaque rsa_modulus<1..2^16-1>;
} RSAPublicKey;
```

Item	Description
rsa_exponent	The exponent of the RSA key, using the big-endian (network-byteorder) representation of the integer as octet string.
rsa_modulus	The modulus of the RSA key, using the big-endian (network-byteorder) representation of the integer as octet string.

```
struct {
  select (PublicKeyType) {
    case ecdh: ECPublicKey;
    case ecdsa: ECPublicKey;
    case rsa: RSAPublicKey;
  } PublicKey;
```

```
struct {
  uint8 certificate_version;
  SignatureAlgorithm signature_algorithm;
  Identifier issuer;
  uint32 valid_not_before;
  uint32 valid_not_after;
  Identifier subject;
  PublicKeyType public_key_type;
  ParameterSpecifier parameter_specifier;
  PublicKey public_key;
} ToBeSignedCertificate;
```

Item	Description
certificate_version	Version of the certificate. For this specification, the version is 1.
signature_algorithm	Algorithm used to sign the certificate.

Item	Description
issuer	Issuer of the certificate. Defines who signed the certificate. Certificates are usually signed by Certification Authorities (CA)
valid_not_before	Beginning of the validity period of the certificate, expressed in standard UNIX 32-bit format (seconds since the midnight starting Jan 1, 1970, GMT)
valid_not_after	End of the validity period of the certificate, expressed in standard UNIX 32-bit format (seconds since the midnight starting Jan 1, 1970, GMT)
subject	Owner of the key, associated with the public key being certified.
public_key_type	Type (algorithm) of the public key.
parameter_specifier	Specifies parameter relevant for the public key.
public_key	Public key that is being certified.

The contents of the subject and issuer identifier fields SHOULD be an Identifier value of type “text”, structured as follows:

```
<servicename>; <organization>; <country>[; <commonname>[; <extension>[; <extension>[ ... ]]]]
```

where:

“;” is a 2-character field separator; if a field contains a literal “;” character then that is represented by “;”;

[...] indicates an optional field;

<servicename> identifies a service, CA, subscriber, or other entity within an organization;

<organization> is an organization name;

<country> is a 2-character ISO country name;

<commonname> is a string which, in the case of a server certificate, contains fully-qualified domain name or IP address (the characters used SHOULD be from the ASN.1 PrintableString set);

<extension> is a name component of the form <type>=<value>, where <type> is a 1- or 2-character attribute type as defined in IETF RFC 2253 or the characters “SN” to indicate the attribute Subject Serial Number, and <value> is a value of that type.

Any of the values <servicename>, <organization>, <country>, or <commonname> MAY be a null string.

In the case of a server certificate, upon successful authentication, the client SHOULD display to the subscriber, at least, the <servicename>, <organization>, and <country> fields. A client SHOULD verify that the bearer-address with which it is communicating is the same as or maps to that in the <commonname> field; this may involve use of a mapping based on provisioning information, in accordance with the WAP Provisioning Content Specification.

The following logical mappings of fields in the above name convention to X.500 attributes as used in an X.509 certificate or LDAP address MAY be employed:

Field	Equivalent X.500 Attribute
<servicename>	(First) Organizational Unit (OU), i.e., that closest to the DIT root
<organization>	Organization (O)
<country>	Country (C)
<commonname>	Common Name (CN)
<extension>	Attribute as indicated by <type>. Optionally, <type>= may be omitted, in which case the type defaults to "OU"

Examples of a server name are:

“WAP Online Banking; WAP Bank, Inc.; US; wap.wapbank.com”; or

“WAP Online Banking; WAP Bank, Inc.; GB; 111.55.33.0”.

An example of a CA name would be:

“SecureWAP Service; WAP TrustCo.; FI”.

NOTES:

1. The above X.500 mapping does not accommodate multi-valued X.500 attributes.
2. This convention is only usable with character sets that include a semicolon and space character, and is of limited utility with a character set that does not include the ASN.1 PrintableString characters.

The hash value and the signature is calculated from ToBeSignedCertificate using the algorithms defined in CertificateSignatureAlgorithm.

```
select( SignatureAlgorithm )
{
  case anonymous: { };
  case ecdsa_sha:
    digitally-signed struct {
      opaque sha_hash[20]; /* SHA-1 hash of data to be signed */
    }
  case rsa_sha:
    digitally-signed struct {
      opaque sha_hash[20]; /* SHA-1 hash of data to be signed */
    }
} Signature;
```

```
struct {
    ToBeSignedCertificate to_be_signed_certificate;
    Signature signature;
} WTLSCertificate;
```

```
struct {
    CertificateFormat certificate_format;
    select (certificate_format) {
        case WTLSCert:    WTLSCertificate;
        case X509Cert:   X509Certificate;
        case X968Cert:   X968Certificate;
        case CertURL:    opaque url<0..255>;
    }
} Certificate;
```

```
struct {
    Certificate certificate_list<0..2^16-1>;
} Certificates;
```

Item	Description
certificate_list	<p>This is a sequence (chain) of certificates. The sender's certificate MUST come first in the list. Each following certificate MUST directly certify the one preceding it. Because certificate validation requires that root keys must be distributed independently, the self-signed certificate which specifies the root certificate authority is omitted from the chain, under the assumption that the remote end must already possess it in order to validate it in any case.</p> <p>The certificate URL option is used only for messages sent by the client. In this case, the certificate list parameter contains only one element.</p>

The same message type and structure will be used for the client's response to a certificate request message. Note that a client may send no certificates if it does not have an appropriate certificate to send in response to the server's authentication request.

To optimise the traffic and client processing, the chain should have minimal length. For server certificates, it is possible to have only one certificate: the server certificate certified by a CA public key of which is distributed independently.

Client certificate chain is likely to contain several certificates. However, this is acceptable because this chain is processed by the server. Also, server may get the client certificate from a certificate distribution service.

In a certificate chain, all certificates must use algorithms appropriate for the selected key exchange suite. Eg,

- for RSA, all certificates carry RSA keys signed with RSA
- for ECDH_ECDSA, the first certificate contains an ECDH key signed with ECDSA, and the following certificates carry ECDSA keys signed with ECDSA

10.5.3 Server Key Exchange Message

When this message will be sent:

This message will be sent immediately after the server certificate message (or the server hello message, if this is an anonymous negotiation).

The server key exchange message is sent by the server only when the server certificate message (if sent) does not contain enough data to allow the client to exchange a pre-master secret. This is true for the following key exchange methods:

- ECDH_anon
- RSA_anon
- DH_anon

The server key exchange message **MUST NOT** be sent for the following key exchange methods:

- ECDH_ECDSA (fixed parameters)
- RSA

Meaning of this message:

This message conveys cryptographic information to allow the client to communicate the pre-master secret: either an RSA public key to encrypt a secret with, or EC Diffie-Hellman parameters with which the client can complete a key exchange (with the result being the pre-master secret). As additional Key Exchange Suites are defined for WTLS which include new key exchange algorithms, the server key exchange message will be sent if and only if the certificate type associated with the key exchange algorithm does not provide enough information for the client to exchange a pre-master secret.

Structure of this message:

```
enum { rsa, rsa_anon, dh_anon, ecdh_anon, ecdh_ecdsa } KeyExchangeAlgorithm;
```

```
struct {
    opaque dh_Y<1..2^16-1>;
} DHPublicKey;
```

Item	Description
dh_Y	The Diffie-Hellman public value (Y).

```
struct {
    ParameterSpecifier parameter_specifier;
    select (KeyExchangeAlgorithm) {
        case rsa_anon:
            RSAPublicKey params;
        case dh_anon:
            DHPublicKey params;
        case ecdh_anon:
            ECPublicKey params;
    };
} ServerKeyExchange;
```

Item	Description
parameter_specifier	Specifies parameters relevant for this key exchange suite. Value zero of parameter_index in parameter_specifier for a key exchange suite indicates that the parameters the server is willing to use were specified in ServerHello.client_key_id. Non-zero value of parameter_index indicates that the server is proposing parameters different from ones specified by ServerHello.client_key_id, but using the same key exchange suite. If the client has not indicated parameters then the server MUST indicate them.

Params

The server's key exchange parameters (RSA, ECDH or DH public key).

10.5.4 Certificate Request

When this message will be sent:

A server can optionally request a certificate from the client, if appropriate for the selected cipher suite. This message, if sent, will immediately follow the Server Certificate message and Server Key Exchange message (if sent).

Structure of this message:

```
struct {
    KeyExchangeId trusted_authorities<0..2^16-1>;
} CertificateRequest;
```

Item	Description
trusted_authorities	<p>A list of the names and types of acceptable certificate authorities. These names may specify a desired id for a root CA or for a subordinate CA; thus, this message can be used both to describe known roots and a desired authorisation space. If no authorities are sent, client may send any certificate, or if the client supplied a key identifier in ClientHello.client_key_ids, the client should use the corresponding key for authentication but send no certificates. This corresponds to the case when the client certificate is known to the server by the key identifier. Fetching client certificate by the key identifier (public key hash) may be possible eg, when client certificates are contained in a local cache, or if certificates contain the key identifier (as subject key identifier) and search on this field is enabled.</p> <p>The server may request the client to send any certificate for a particular key exchange suite by sending this message with a KeyExchangeId that has Identifier.identifier_type null.</p>

10.5.5 Server Hello Done

When this message will be sent:

The server hello done message is sent by the server to indicate the end of the server hello and associated messages. After sending this message the server will wait for a client response.

Meaning of this message:

This message means that the server is done sending messages to support the key exchange, and the client can proceed with its phase of the key exchange.

Upon receipt of the server hello done message the client should verify that the server provided a valid certificate if required and check that the server hello parameters are acceptable.

Structure of this message:

```
struct { } ServerHelloDone;
```

10.5.6 Client Certificate

When this message will be sent:

This message the client can be sent after receiving a server hello done message. This message is only sent if the server requests a certificate. If no suitable certificate is available, the client must send a certificate message containing no certificates. If client authentication is required by the server for the handshake to continue, it MAY respond with a fatal *handshake_failure* alert. Client certificates are sent using the Certificate structure defined previously for server certificates.

If the server has indicated in Certificate Request message that it requests client authentication and the client certificate is known to the server, this message should contain no certificates.

Instead of an actual certificate, the client MAY send a certificate URL. The server SHOULD implement a protection mechanism against denial-of-service attacks based on client sending an invalid URL.

10.5.7 Client Key Exchange Message

When this message will be sent:

This message will immediately follow the client certificate message, if it is sent. Otherwise it will be the first message sent by the client after it receives the server hello done message.

Meaning of this message:

With this message, the pre-master secret is set, either through direct transmission of the RSA-encrypted secret, or by the transmission of EC Diffie-Hellman public key which will allow each side to agree upon the same pre-master secret. When the key exchange method is ECDH, client certification has been requested, and the client was able to respond with a certificate that contained EC Diffie-Hellman parameters matched those specified by the server in its certificate, this message is omitted.

Structure of this message:

The structure of the message depends on which key exchange method has been selected.

```
struct {
  select (KeyExchangeAlgorithm) {
    case rsa: RSAEncryptedSecret param;
    case rsa_anon: RSAEncryptedSecret param;
    case dh_anon: DHPublicKey param; /* client public value*
    case ecdh_anon: ECPublicKey param; /* client public value */
    case ecdh_ecdsa: ECPublicKey param; /* client public value */
  } exchange_keys;
} ClientKeyExchange;
```

10.5.7.1 RSA Encrypted Secret Message

Meaning of this message:

If RSA is being used for key agreement and authentication, the client generates a 20 byte secret, encrypts it using the public key from the server's certificate and sends the result in an encrypted secret message.

Structure of this message:

```
struct {
    uint8 client_version;
    opaque random[19];
} Secret;
```

Item	Description
client_version	The latest (newest) version supported by the client. This is used to detect version roll-back attacks. Upon receiving the secret, the server should check that this value matches the value transmitted by the client in the client hello message.
random	19 securely-generated random bytes.

```
struct {
    public-key-encrypted Secret secret;
} EncryptedSecret;
```

Item	Description
secret	This random value is generated by the client. This value appended with the public key is used as the pre-master secret which is used to generate the master secret, as specified in Chapter 11.

An attack discovered by Daniel Bleichenbacher [BLEI] can be used to attack protocols using PKCS#1 encoded RSA encryption. The attack is based on the fact that the server reveals whether a particular message, when decrypted, is properly PKCS#1 formatted or not.

A good method to ensure that the server is not vulnerable to this attack is described in [TLS]. Following this method, the WTLS server when it receives an incorrectly formatted RSA block, generates a random 20 byte value and proceeds using it for the premaster secret. Thus, the server will act identically (meaning both protocol data content and timing) whether the received RSA block is correctly encoded or not.

10.5.7.2 Client EC Diffie-Hellman Public Value

Meaning of this message:

This message conveys the client's EC Diffie-Hellman public key if it was not already included in the client's certificate. This structure is a variant of the client key exchange message, not a message in itself.

10.5.7.3 Client Diffie-Hellman Public Value

Meaning of this message:

This message conveys the client's Diffie-Hellman public key. This structure is a variant of the client key exchange message, not a message in itself.

10.5.8 Certificate Verify

When this message will be sent:

This message is used to provide explicit verification of a client certificate. This message is only sent by the client following a client certificate that has signing capability (ie, RSA certificates). When sent, it will immediately follow the client key exchange message.

Structure of this message:

```
struct {
    Signature signature;
} CertificateVerify;
```

Item	Description
signature	<p>The hash value to be signed is calculated as follows:</p> <p>$H(\text{handshake_messages})$;</p> <p>Here handshake_messages refers to all handshake messages sent or received starting at client hello up to but not including this message, in the order they were sent by the client or by the server, including the data visible at the handshake layer, ie, also the type and length fields of the handshake messages. This is the concatenation of all the Handshake structures as defined in Section 10.5 exchanged this far.</p> <p>The hash algorithm used is the one agreed during the handshake.</p>

10.5.9 Finished

When this message will be sent:

A finished message is always sent at the end of the handshake to verify that the key exchange and authentication processes were successful. Both ends must change finished messages immediately after a change cipher spec message.

Meaning of this message:

The finished message is the first protected with the just-negotiated algorithms, keys, and secrets. Recipients of finished messages MUST verify that the contents are correct. Once a side has sent its Finished message and received and validated the Finished message from its peer, it may begin to send and receive application data over the secure connection.

Structure of this message:

```
struct {
    opaque verify_data[12];
} Finished;
```

Item	Description
verify_data	The value is calculated as follows: $PRF(\text{master_secret}, \text{finished_label}, H(\text{handshake_messages})) [0..11];$
	finished_label For Finished messages sent by the client, the string "client finished". For Finished messages sent by the server, the string "server finished". handshake_messages All of the data from all handshake messages up to but not including this message, in the order they were sent by the client or by the server. This is only data visible at the handshake layer and does not include record layer headers. This is the concatenation of all the Handshake structures as defined in Section 10.5 exchanged thus far.

It is a critical or fatal error if a finished message is not preceded by a change cipher spec message at the appropriate point in the handshake.

The value handshake_messages includes all handshake messages starting at client hello up to, but not including, this finished message. The handshake_messages for the finished message sent by the client will be different from that for the finished message sent by the server, because the one which is sent second will include the prior one.

Note: Change cipher spec messages, alerts and any other record types are not handshake messages and are not included in the hash computations. Also, Hello Request messages are omitted from handshake hashes.

11 Cryptographic Computations

11.1 Computing the Master Secret

In order to begin message protection, the WTLS Record Protocol requires specification of a suite of algorithms, a master secret, and the client and server random values. The encryption and MAC algorithms are determined by the `cipher_suite` selected by the server and revealed in the server hello message. The key exchange and authentication algorithms are determined by the `key_exchange_suite` also revealed in the server hello. The compression algorithm is negotiated in the hello messages, and the random values are exchanged in the hello messages. All that remains is to calculate the master secret.

For all key exchange methods, the same algorithm is used to convert the `pre_master_secret` into the `master_secret`. The `pre_master_secret` SHOULD be deleted from memory once the `master_secret` has been computed.

```
master_secret = PRF( pre_master_secret, "master secret",
                    ClientHello.random + ServerHello.random ) [0..19];
```

The master secret is always exactly 20 bytes in length. The length of the pre-master secret will vary depending on key exchange method.

11.1.1 RSA Encryption Scheme

When RSA is used for server authentication and key exchange, a 20-byte secret value is generated by the client, encrypted under the server's public key, and sent to the server. The server uses its private key to decrypt the secret value. The `pre_master_secret` is the secret value appended with the server's public key. Both parties then convert the `pre_master_secret` into the `master_secret`, as specified above.

In RSA signing, a 20-byte structure of SHA-1 [SHA] hash is signed (encrypted with the private key), using PKCS #1 [PKCS1] block type 1.

RSA public key encryption is performed using PKCS #1 block type 2.

11.1.2 Diffie-Hellman

The conventional Diffie-Hellman computation is performed. The negotiated key (`Z`) is used as the `pre_master_secret`, and is converted into the `master_secret`, as specified above.

11.1.3 EC Diffie-Hellman

The EC Diffie-Hellman computation is performed. The negotiated key (`Z`) is used as the `pre_master_secret`, and is converted into the `master_secret`, as specified above.

Elliptic curve calculations are performed according to [P1363].

EC parameters may be transmitted explicitly or using an algorithm definition which specifies pre-defined parameters (see Appendix A).

EC points are represented according to [P1363] Elliptic Curve Point to Octet String Primitive (EC2OSP).

ECDSA signature and verification is performed according to [P1363] Elliptic Curve Signature Scheme with Appendix (ECSSA) using

- EMSA-hash with SHA-1, for calculating the hash of the data to be signed
- the Elliptic Curve Signature Primitive, DSA version (ECSP-DSA) for signature, and the Elliptic Curve Verification Primitive, DSA version (ECVP-DSA) for verification
- output format for ECSSA, for output of the signature as an octet string

ECDH calculation of the key Z is performed according to [P1363]

- using the Elliptic Curve Secret Value Derivation Primitive, Diffie-Hellman version (ECSVDP-DH), for generating a shared secret value z as a field element
- converting the shared secret value z to an octet string Z using Field Element to Octet String Conversion Primitive (FE2OSP)

11.1.4 Session resume

In a session resume, the `master_secret` is not recalculated. This means that a resumed session uses the same `master_secret` as the previous one.

Note that although the same `master_secret` is used, new `ClientHello.random` and `ServerHello.random` values are exchanged in the abbreviated handshake. These randoms are taken into account in key block generation (see Section 11.2) meaning that each secure connection starts up with different key material.

11.2 Key Calculation

A connection state (see Section 9.1) is the operating environment of the Record Protocol. An algorithm is required to generate the connection state (encryption keys, IVs, and MAC secrets) from the secure session parameters provided by the handshake protocol.

A new connection state is calculated in the following way:

The master secret is hashed into a sequence of secure bytes, which are assigned to the MAC secrets, encryption keys, and IVs. To generate the key material, compute

```
key_block = PRF (SecurityParameters.master_secret,
                expansion_label, seq_num +
                SecurityParameters.server_random +
                SecurityParameters.client_random);
```

until the needed amount of output has been generated. `key_block` can be either for client write or server write.

`seq_num` can be either Client Write Sequence Number or Server Write Sequence Number. When a `key_block` is calculated for client write, Client Write Sequence Number is used. When a `key_block` is calculated for server write, Server Write Sequence Number is used. The first `key_block` is calculated right after the `ChangeCipherSpec` message is sent or received and `seq_num` is set to 0.

A new key block generation takes place at intervals of the sequence number, corresponding to key refresh frequency. The sequence number used in the calculation is the first one that mandates key refresh. For instance, if the key refresh frequency is every 8 messages, the possible `seq_num` that may be used in `key_block` calculation is 0, 8, 16, 24,

When a client receives a record with a sequence number 19 from the server, the client uses 16 as `seq_num` in calculating `key_block` for server write to decrypt the record.

Different value of `expansion_label` is used for client write keys and server write keys. So, the `key_block` generated with "client expansion" as `expansion_label`, is partitioned as follows:

```
client_write_MAC_secret[SecurityParameters.mac_key_size]
client_write_encryption_key[SecurityParameters.key_material_length]
client_write_IV[SecurityParameters.IV_size]
```

The `key_block` generated with "server expansion" as `expansion_label`, is partitioned as follows:

```
server_write_MAC_secret[SecurityParameters.mac_key_size]
server_write_encryption_key[SecurityParameters.key_material_length]
server_write_IV[SecurityParameters.IV_size]
```

In WTLS many connection state parameters can be recalculated during a secure connection. This feature is called the key refresh. It is performed in order to minimise the need for new handshakes. In the key refresh, the values of MAC secret, encryption key, and IV will change due to the sequence number. The frequency of these updates depends on the key refresh parameter. For example, the key refresh may be performed for every four records. The `seq_num` parameters used in the above calculation is the sequence number of the record that triggers key refresh.

Exportable encryption algorithms (for which `SecurityParameters.is_exportable` is true) require additional processing as follows to derive their final write keys:

```
final_client_write_encryption_key =
    PRF(SecurityParameters.client_write_encryption_key, "client write key",
        SecurityParameters.client_random + SecurityParameters.server_random);

final_server_write_encryption_key =
    PRF(SecurityParameters.server_write_encryption_key, "server write key",
        SecurityParameters.client_random + SecurityParameters.server_random);
```

Exportable encryption algorithms derive their IVs solely from the random values from the hello messages:

```
client_write_iv = PRF("", "client write IV", client_write_seq_num +
    SecurityParameters.client_random + SecurityParameters.server_random);

server_write_iv = PRF("", "server write IV", server_write_seq_num +
    SecurityParameters.client_random + SecurityParameters.server_random);
```

Note that the PRF is used without a secret in this case: this just means that the secret has a length of zero bytes and contributes nothing to the hashing in the PRF.

For CBC mode block ciphers, the IV (initialisation vector) for each record is calculated in the following way:

```
record_IV = IV XOR S
```

where IV is the original IV (`client_write_IV` or `server_write_IV`) and S is obtained by concatenating the 2-byte sequence number of the record needed number of times to obtain as many bytes as in IV. It is also possible that an encryption

algorithm supports using a sequence number as input. Then the record sequence number is used as the algorithm sequence number.

11.3 HMAC and the Pseudorandom Function

A number of operations in the WTLS record and handshake layer require a keyed MAC; this is a secure digest of some data protected by a secret.

In addition, a construction is required to do expansion of secrets into blocks of data for the purposes of key generation or validation. This pseudo-random function (PRF) takes as input a secret, a seed, and an identifying label and produces an output of arbitrary length.

11.3.1 MAC Calculation

HMAC [HMAC] can be used with a variety of different hash algorithms. For example, SHA-1 [SHA] or MD5 [MD5] could be used. The cryptographic hash function is denoted by H. In addition, a secret key K is required. We assume H to be a cryptographic hash function where data is hashed by iterating a basic compression function on blocks of data. We denote by B the byte-length of such blocks (B=64 for all the above mentioned examples of hash functions), and by L the byte-length of hash outputs (L=16 for MD5, L=20 for SHA-1). The authentication key K can be of any length up to B, the block length of the hash function. Applications that use keys longer than B bytes will first hash the key using H and then use the resultant L byte string as the actual key to HMAC. In any case, the minimal recommended length for K is L bytes (as the hash output length).

We define two fixed and different strings ipad and opad as follows (the 'i' and 'o' are mnemonics for inner and outer):

ipad = the byte 0x36 repeated B times
opad = the byte 0x5C repeated B times.

To compute HMAC over the data, we use HMAC_hash(K, data) function as defined below,

$$\text{HMAC_hash}(K, \text{data}) = \text{H}(K \text{ XOR opad} + \text{H}(K \text{ XOR ipad} + \text{data}))$$

where + indicates concatenation. XOR has higher precedence than +. K is also known as HMAC key.

Namely,

1. Append zeros to the end of K to create a B byte string (eg, if K is of length 20 bytes and B=64, then K will be appended with 44 zero bytes 0x00).
2. XOR (bitwise exclusive-OR) the B byte string computed in step (1) with ipad.
3. Append the data to the B byte string resulting from step (2).
4. Apply H to the data generated in step (3).
5. XOR (bitwise exclusive-OR) the B byte string computed in step (1) with opad.
6. Append the H result from step (4) to the B byte string resulting from step (5).
7. Apply H to the data generated in step (6) and output the result.

11.3.2 Pseudo-random Function

In the TLS standard, two hash algorithms were used in order to make the PRF as secure as possible. In order to save resources, WTLS can be implemented using only one hash algorithm. Which hash algorithm is actually used, is agreed during the handshake as a part of the cipher spec.

First, we define a data expansion function, $P_hash(secret, data)$ using a single hash function to expand a secret and seed into an arbitrary quantity of output:

$$P_hash(secret, seed) = HMAC_hash(secret, A(1) + seed) + \\ HMAC_hash(secret, A(2) + seed) + \\ HMAC_hash(secret, A(3) + seed) + \dots$$

Where + indicates concatenation.

$$A(0) = seed \\ A(i) = HMAC_hash(secret, A(i-1))$$

P_hash can be iterated as many times as is necessary to produce the required quantity of data. For example, if P_SHA was being used to create 64 bytes of data, it would have to be iterated 4 times (through A(4)), creating 80 bytes of output data; the last 16 bytes of the final iteration would then be discarded, leaving 64 bytes of output data.

Then,

$$PRF(secret, label, seed) = P_hash(secret, label + seed)$$

Appendix A Algorithm Definitions

Table 4. The Available Key Exchange Suites

Key Exchange Suite	Assigned Number	Description	Key Size Limit (bits)
NULL	0	No key exchange is done. A zero length pre-master secret is used. Master secret and Finished messages are used for error checking purposes only.	N/A
SHARED_SECRET	1	Symmetric-key based handshake. Parties share a secret key that is used as the pre-master key as such.	None
DH_anon	2	Diffie-Hellman key exchange without authentication. Parties send each other (temporary) DH public keys. Each party calculates the pre-master secret based on one's own private key and counterpart's public key .	None
DH_anon_512	3	As DH_anon, but subject to the key size limit.	512
DH_anon_768	4	As DH_anon, but subject to the key size limit.	768
RSA_anon	5	RSA key exchange without authentication. The server sends its RSA public key. The client generates a secret value, encrypts it with the server's public key and sends it to the server. The pre-master secret is the secret value appended with the server's public key.	None
RSA_anon_512	6	As RSA_anon, but subject to the key size limit.	512
RSA_anon_768	7	As RSA_anon, but subject to the key size limit.	768
RSA	8	RSA key exchange with RSA based certificates. The server sends a certificate that contains its RSA public key. The server certificate is signed with RSA by a third party trusted by the client. The client extracts server's public key from received certificate, generates a secret value , encrypts it with the server's public key and sends it to the server. The pre-master secret is the secret value appended with the server's public key. If the client is to be authenticated it signs some data (messages send during the handshake) with its RSA private key and sends its certificate and the signed data.	None
RSA_512	9	As RSA, but subject to the key size limit.	512

Key Exchange Suite	Assigned Number	Description	Key Size Limit (bits)
RSA_768	10	As RSA, but subject to the key size limit.	768
ECDH_anon	11	EC Diffie-Hellman key exchange without authentication. Parties send each other (temporary) ECDH public keys. Each party calculates the pre-master secret based on one's own private key and counterpart's public key. It is assumed that each peer supports point compression/decompression. All Public keys SHOULD be compressed points.	None
ECDH_anon_113	12	As ECDH_anon, but subject to the key size limit.	113
ECDH_anon_131	13	As ECDH_anon, but subject to the key size limit.	131
ECDH_ECDSA	14	EC Diffie-Hellman key exchange with ECDSA based certificates. The server sends a certificate that contains its ECDH public key. The server certificate is signed with ECDSA by a third party trusted by the client. Depending whether the client is to be authenticated or not, it sends its certificate containing its ECDH public key signed with ECDSA by a third party trusted by the server, or just its (temporary) ECDH public key. Each party calculates the pre-master secret based on one's own private key and counterpart's public key received as such or contained in a certificate. It is assumed that each peer supports point compression/decompression. All Public keys SHOULD be compressed points.	None
ECDH_anon_uncomp	15	EC Diffie-Hellman key exchange without authentication. Parties send each other (temporary) ECDH public keys. Each party calculates the pre-master secret based on one's own private key and counterpart's public key. All Public keys MUST be uncompressed points.	None
ECDH_anon_uncomp_113	16	As ECDH_anon, but subject to the key size limit.	113
ECDH_anon_uncomp_131	17	As ECDH_anon, but subject to the key size limit.	131
ECDH_ECDSA_uncomp	18	EC Diffie-Hellman key exchange with ECDSA based certificates. The server sends a certificate that contains its ECDH public key. The server certificate is signed with ECDSA by a third party trusted by the client. Depending whether the client is to be authenticated or not, it sends its certificate containing its ECDH public key signed with ECDSA by a third party trusted by the server, or just its (temporary) ECDH public key. Each party calculates the pre-master secret based on one's own private key and counterpart's public key received as such or contained in a	None

Key Exchange Suite	Assigned Number	Description	Key Size Limit (bits)
		certificate. All Public keys MUST be uncompressed points.	

Field	Description
KeySizeLimit	The size of the largest public key that can be used.

Note that regarding to some key exchange suites, export restrictions may apply.

Keys (RSA moduli and discrete log primes) smaller than 1024 bits SHOULD NOT be used for RSA and DSA signature operations.

Table 5. The Available Bulk Encryption Algorithms

Cipher	Assigned Number	Is Exportable	Type	Key Material (bytes)	Expanded Key Material (bytes)	Effective Key Bits (bits)	IV Size (bytes)	Block Size (bytes)
NULL	0	True	Stream	0	0	0	0	N/A
RC5_CBC_40	1	True	Block	5	16	40	8	8
RC5_CBC_56	2	True	Block	7	16	56	8	8
RC5_CBC	3	False	Block	16	16	128	8	8
DES_CBC_40	4	True	Block	5	8	40	8	8
DES_CBC	5	False	Block	8	8	56	8	8
3DES_CBC_EDE	6	False	Block	24	24	168	8	8
IDEA_CBC_40	7	True	Block	5	16	40	8	8
IDEA_CBC_56	8	True	Block	7	16	56	8	8
IDEA_CBC	9	False	Block	16	16	128	8	8

Field	Description
IsExportable	Encryption algorithms for which IsExportable is true have a limited effective key length in order to comply with certain export regulations. For them, an additional key expansion is performed and the initialization vector is derived in a special way (Chapter 11.2). This specification does not imply whether it is actually legal to export these algorithms (or illegal to export algorithms for which IsExportable is false) from one specific country to another.
Type	Indicates whether this is a stream cipher or a block cipher running in CBC mode.
Key Material	The number of bytes from the key_block that are used for generating the write keys.
Expanded Key Material	The number of bytes in the write keys.
Effective Key Bits	How much entropy material is in the key material being fed into the encryption routines.
IV Size	How much data needs to be generated for the initialization vector. Zero for stream ciphers; equal to the block size for block ciphers.
Block Size	The amount of data a block cipher enciphers in one chunk; a block cipher running in CBC mode can only encrypt a multiple of its block size.

RC5 [RC5] is a family of block cipher algorithms. RC5 implementations can be designated as RC5-w/r/b, where w is the word size in bits (and also the half of the block size), r is the number of rounds, and b is the length of the key in bytes. Using this notation, the cipher RC5_CBC is RC5-32/16/16. The cipher RC5_CBC_40 is implemented as an export cipher,

using 5 bytes as key material and expanding that to 16 bytes, and then applying RC5-32/12/16. The cipher RC5_CBC_56 is implemented as an export cipher, using 7 bytes as key material and expanding that to 16 bytes, and then applying RC5-32/12/16.

Data Encryption Standard (DES) is a very widely used symmetric encryption algorithm. DES is a block cipher with a 56 bit key and an 8 byte block size. Note that in WTLS, for key generation purposes, DES is treated as having an 8 byte key length (64 bits), but it still only provides 56 bits of protection. DES can also be operated in a mode where three independent keys and three encryptions are used for each block of data; this uses 168 bits of key (24 bytes in the WTLS key generation method) and provides the equivalent of 112 bits of security. [DES], [3DES]

IDEA is a 64-bit block cipher designed by Xuejia Lai and James Massey. [IDEA]

Table 6. The Available Keyed MAC Algorithms

Hash Function	Assigned Number	Description	Key Size (bytes)	MAC Size (bytes)
SHA_0	0	No keyed MAC is calculated. Note than in other than keyed MAC operations (eg, PRF) the full-length SHA-1 is used.	0	0
SHA_40	1	The keyed MAC is calculated using SHA-1 but only the first 5 bytes of the output are used. Note that in other than keyed MAC operations (eg, PRF) the full-length SHA-1 is used.	20	5
SHA_80	2	The keyed MAC is calculated using SHA-1 but only the first half of the output (10 bytes) is used. Note that in other than keyed MAC operations (eg, PRF) the full-length SHA-1 is used.	20	10
SHA	3	The keyed MAC is calculated using SHA-1.	20	20
SHA_XOR_40	4	<p>A 5-byte XOR checksum.</p> <p>The input data is first divided into the multiple blocks of 5 bytes. Then all blocks are XOR'ed one after another. If the last block is less than 5 bytes, it is padded with 0x00.</p> <p>SHA is much stronger than XOR for generating MAC's, although there were no significant attacks reported on XOR MAC's, which must be encrypted and is only used for CBC mode block ciphers. XOR is only intended for some devices with very limited CPU resources.</p> <p>Warning: XOR can not provide as strong message integrity protection as SHA can. It is recommended that the security consequence should be carefully evaluated before XOR MAC is adopted.</p> <p>In other than MAC operations for message integrity (eg, PRF) the full-length SHA-1 is used.</p>	0	5
MD5_40	5	The keyed MAC is calculated using MD5 but only the first 5 bytes of the output are used. Note than in other than keyed MAC operations (eg, PRF) the full-length MD5 is used.	16	5
MD5_80	6	The keyed MAC is calculated using MD5 but only the first 10 bytes of the output are used. Note than in other than keyed MAC operations (eg, PRF) the full-length MD5 is used.	16	10
MD5	7	The keyed MAC is calculated using MD5.	16	16

Hash Function	Assigned Number	Description	Key Size (bytes)	MAC Size (bytes)

Field	Description
Key Size	The number of bytes used as the HMAC key.
MAC Size	The number of bytes used in the MAC.

Table 7. The Available Compression Algorithms

Compression Algorithm	Assigned Number	Description
NULL	0	No compression.

Table 8. Elliptic Curve Parameters For Selected Curves

All implementations using ECC MUST support at least one of the curves marked as Basic. All server implementations SHOULD support all curves marked as Basic. Other curves MAY be used.

Curves with field size smaller than 160 bits MUST NOT be used for ECDSA operations. They MAY be used for ECDH operations in circumstances when a longer field size is not permitted by export or other regulations.

All implementations using ECDSA verification, SHOULD support verification for curves marked as Basic and with field size not smaller than 160 bits.

Sign bits (\tilde{y}_p), the compressed one-bit representation of the y-coordinate, have been included as octet string values following the y-coordinate of the generator points in the following curves. Note that the appropriate encoding rule (see IEEE 1363) should be followed when representing curve points in a portable manner.

Assigned number	1
Basic	No
Field size	113
Irreducible polynomial	$x^{113} + x^9 + 1$
Elliptic curve E	$y^2 + xy = x^3 + ax^2 + b$; over $GF(2^{113})$
Parameter a	01
Parameter b	01
Generating point G	016679 79A40BA4 97E5D5C2 70780617, 00F44B 4AF1ECC2 630E0878 5CEBCC15 ($\tilde{y}_p = 01$)
Order of G	00FFFF FFFFFFFF FFFDBF91 AF6DEA73
Cofactor K	02

(Number 2 has intentionally been left unassigned.)

Assigned number	3
Basic	No
Field size	163
Irreducible polynomial	$x^{163} + x^7 + x^6 + x^3 + 1$
Elliptic curve E	$y^2 + xy = x^3 + ax^2 + b$; over $GF(2^{163})$
Parameter a	01
Parameter b	01
Generating point G	02 FE13C053 7BBC11AC AA07D793 DE4E6D5E 5C94EEE8, 02 89070FB0 5D38FF58 321F2E80 0536D538 CCDAA3D9 ($\tilde{y}_p = 01$)
Order of G	04 00000000 00000000 00020108 A2E0CC0D 99F8A5EF
Cofactor K	02

Assigned number	4
Basic	Yes
Field size	113
Irreducible polynomial	$x^{113} + x^9 + 1$
Elliptic curve E	$y^2 + xy = x^3 + ax^2 + b$; over $GF(2^{113})$
Seed	10E723AB 14D696E6 76875615 1756FEBF 8FCB49A9
Parameter a	003088 250CA6E7 C7FE649C E85820F7
Parameter b	00E8BE E4D3E226 0744188B E0E9C723
Generating point G	009D73 616F35F4 AB1407D7 3562C10F, 00A528 30277958 EE84D131 5ED31886 ($\tilde{y}_p = 01$)
Order of G	010000 00000000 00D9CCEC 8A39E56F
Cofactor K	02

Assigned number	5
Basic	Yes
Field size	163
Irreducible polynomial	$x^{163} + x^8 + x^2 + x + 1$
Elliptic curve E	$y^2 + xy = x^3 + ax^2 + b$; over $GF(2^{163})$
Seed	D2C0FB15 760860DE F1EEF4D6 96E67687 56151754
Parameter a	07 2546B543 5234A422 E0789675 F432C894 35DE5242
Parameter b	00 C9517D06 D5240D3C FF38C74B 20B6CD4D 6F9DD4D9
Generating point G	07 AF699895 46103D79 329FCC3D 74880F33 BBE803CB, 01 EC23211B 5966ADEA 1D3F87F7 EA5848AE F0B7CA9F ($\tilde{y}_p = 01$)
Order of G	04 00000000 00000000 0001E60F C8821CC7 4DAEAF C1
Cofactor K	02

Assigned number	6
Basic	Yes
Field size	112
Elliptic curve E	$y^2 = x^3 + ax + b$; over $GF(p)$
Prime p	DB7C 2ABF62E3 5E668076 BEAD208B
Seed	S = 00F50B02 8E4D696E 67687561 51752904 72783FB1; r = 29E4 9E36F941 C1B2DC1F B82B5BCE
Parameter a	DB7C 2ABF62E3 5E668076 BEAD2088
Parameter b	659E F8BA0439 16EEDE89 11702B22
Generating point G	0948 7239995A 5EE76B55 F9C2F098, A89C E5AF8724 C0A23E0E 0FF77500 ($\tilde{y}_p = 00$)
Order of G	DB7C 2ABF62E3 5E7628DF AC6561C5
Cofactor K	01

Assigned number	7
Basic	Yes
Field size	160
Elliptic curve E	$y^2 = x^3 + ax + b$; over GF(p)
Prime p	FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF 7FFFFFFF
Seed	S = 1053CDE4 2C14D696 E6768756 1517533B F3F83345; r = 2DA6C4D7 0B90FF91 2E725E25 E90AF631 C18F0D2F
Parameter a	FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF 7FFFFFFC
Parameter b	1C97BEFC 54BD7A8B 65ACF89F 81D4D4AD C565FA45
Generating point G	4A96B568 8EF57328 46646989 68C38BB9 13CBFC82, 23A62855 3168947D 59DCC912 04235137 7AC5FB32 ($\tilde{y}_p = 00$)
Order of G	01 00000000 00000000 0001F4C8 F927AED3 CA752257
Cofactor K	01

Assigned number	8
Basic	No
Field size	112
Elliptic curve E	$y^2 = x^3 + ax + b$; over GF(p)
Prime p	FFFF FFFFFFFF FFFFFFFF FFFFFDE7
Parameter a	0
Parameter b	3
Generating point G	(1, 2)
Order of G	010000 00000000 01ECEA55 1AD837E9
Cofactor K	1

Assigned number	9
Basic	No
Field size	160
Elliptic curve E	$y^2 = x^3 + ax + b$; over GF(p)
Prime p	FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF FFFC808F
Parameter a	0
Parameter b	3
Generating point G	(1, 2)
Order of G	01 00000000 00000000 0001CDC9 8AE0E2DE 574ABF33
Cofactor K	1

Table 9. Predefined Diffie-Hellman Parameters

Parameter	Value
Assigned number	1
Exponent bits	160
Prime modulus (512 bits)	FAF30C63D171E54A8131CD331D7C8D6C 8AED41B0354E1A29D8DAD03E2E67FF8E 00053A07FD28A1EE6AF199FD70330EA8 C4C602B86EDFBF47FD1D7BFB6456BD57
Generator (512 bits)	E7734EBBCF50893C760181B2AA2DB0AC F2D5B6E775EE88BAFC7AA5A6BB20A64E B9F54301141F90291B7B375135394504 81C9F9CB2BA3E67B4580E2153FD22B80

Parameter	Value
Assigned number	2
Exponent bits	160
Prime modulus (768 bits)	85DB5DB185090AED3BDB3BABFCB46669F9563E681EDB4359 9241FEF6AA9B5DF9EFE39C0CB7994A04F2BD8F57B5B22AF7 5E360526216420BCA08FCDF98FF6417DCFDD1C40E4FFB183 260E3B28EF0B31A3633788C988B1BC6734A81B31A28CD6FB
Generator (760 bits)	1B15C3C57263B0DD1A9D996768B88370ED458D7B0081A220 054EFDD23B9CD8298B719FD3B67CB093817332D033642D21 130F83D9CB2CC5ACDD36E6E6DDB2410AB30311CDBEE9222C CFE644443B0C7204F2D12F7A3719C8866A20A0E778EBBA

Appendix B Implementation Notes

The following implementation notes are provided to identify areas where implementation choices may impact the security, performance and effectiveness of the WTLS protocols. The implementation notes provide guidance to implementers of the protocols.

B.1 Negotiating Null Cipher Spec

Null cipher spec can be negotiated to be used in a session. The NULL key exchange suite may be used for that purpose, so that no key exchange actually takes place. The master secret is calculated with a zero length pre-master secret. The message flow is like in the abbreviated handshake.

Implementations **MUST** be careful when suggesting or accepting a null key exchange or cipher spec since it offers no security. In all normal circumstances, ie, when a secure connection is to be negotiated, implementations should suggest (client) or accept (server) only non-null key exchange and MAC. Additionally, when confidentiality is required, a non-null encryption must be used.

B.2 Anonymous handshakes

Completely anonymous sessions can be established using RSA or Diffie-Hellman for key exchange. With anonymous RSA, the client generates a secret value and encrypts it with the server's uncertified public key extracted from the server key exchange message. The result is sent in a client key exchange message. Since eavesdroppers do not know the server's private key, it will be infeasible for them to decode the secret value. (The `pre_master_secret` is this value appended with server's public key.)

With Diffie-Hellman, the server's public value is contained in the server key exchange message and the client's is sent in the client key exchange message. Eavesdroppers who do not know the private values are not able to find the Diffie-Hellman result (ie, the `pre_master_secret`).

Warning: Completely anonymous handshakes (ie, where neither the client nor the server is authenticated) only provide protection against passive eavesdropping. The active eavesdroppers, or the active man-in-the-middle attackers may replace the finished messages with their own during the handshaking process for creating sessions. However, there are known methods that may effectively defeat those active attacks in environments where those attacks are a concern. For instance, server authentication, or using an independent tamper-proof channel to verify that the finished messages were not replaced by the attacker. When the handshaking process is complete and authenticated or verified, the established sessions should be secure and protected against both passive and active man-in-the-middle attacks or eavesdroppers.

Warning. Under certain circumstances, the Diffie-Hellman and elliptic curve Diffie-Hellman key agreement schemes are susceptible to a class of attacks known as "small-subgroup" attacks. Specifically in all WTLS cases there exists the threat that a small subgroup attack can lead to exposure of an entity's private key. This threat can be prevented by checking that received public keys do not lie in a small subgroup of the group, or it can be mitigated by selecting a group to have few if any small subgroups (as is the case with the elliptic curves specified in WTLS 1.1). Furthermore, in the anonymous DH and ECDH cases there exists the threat that a small subgroup attack can lead communicating parties to share a session key which is known to an attacker. This threat can be prevented by using a predetermined group and checking that received public keys do not lie in a small subgroup of the group, or by not re-using ordinary Diffie-Hellman key pairs. For more information on description and methods of protection against the attack, see [X9.42] and [X9.63], and [Zuc99].

B.3 Key refresh

The passive key refresh mechanism of WTLS makes it possible to update keys in a secure connection without handshaking.

Key refresh makes cryptanalysis less attractive for an attacker because keys will be invalidated regularly and the material that can be gained is limited. This is particularly useful in environments, where export-restricted encryption is used and handshaking is expensive (ie, connections with long lifetimes are desirable).

The frequency of key refresh is agreed on during the handshake. This parameter defines how many messages are sent before key refresh is triggered. For example, key refresh may be triggered after each four messages.

In key refresh, a new key block is generated using the master secret as a source of entropy and the message sequence number as an additional parameter (along with other parameters) in the pseudorandom function. The generated key block is used for message protection keys: MAC keys, encryption keys and initialization vectors.

B.4 Denial-of-Service Attacks

Since WTLS operates on top of datagrams, the implementation should pay special attention to preventing denial-of-service attacks. It should take into account that in some networks transport addresses may be forged relatively easy.

In order to make denial-of-service attacks harder to accomplish, it should not be possible for an attacker to break up an existing connection/session by sending a single message in plaintext from a forged address.

In addition, the server should be careful in accepting new connection requests in plain text within an existing secure connection. Note that the server cannot just ignore them because eg, ClientHello in plain text may be sent by a client whose connection state was lost. Special care must be taken with arbitrated and optimized handshakes in which the server switches the pending state current immediately after responding to ClientHello message. In such a case, the old active state should be kept intact until the new handshake is accomplished. In other words, the server should not discard the old active state until the client responds with Finished and the handshake is completed successfully. The old active state should be restored to the current state if it is evidenced that the handshake started is invalid.

For the same reason, when a client receives a plaintext ServerHello on its secure connection, it should not cause the existing secure connection broken because of the unexpected message. It should keep the existing secure connection and send the *unexpected_message* as a warning.

When receiving plaintext HelloRequest, the client MUST implement a protection mechanism: ClientHello MUST NOT be sent without checking the the validity of the sender address (provisioned to the client before). Client SHOULD ignore HelloRequest if received too frequently from the same address.

When using explicit sequence numbers, an implementation needs to take special precautions against an attacker inserting a record into the datastream that could cause future records from the intended sender to be discarded as duplicates. When receiving an encrypted record, the record should be successfully decrypted before accepting the sequence number as valid. When receiving a plaintext alert, the checksum should be validated before accepting the sequence number as valid.

Appendix C Implementation Classes

WTLS implementations may have support for various features. This appendix defines classes guiding implementors to select these features. A class may have mandatory (M) or optional (O) support for a certain feature. Certain features are not yet defined in the current version of the specification.

The current version of the WTLS specification covers all features in class 1.

Table 10. WTLS Classes

Feature	Class 1	Class 2	Class 3
Public-key exchange	M	M	M
Server certificates	O	M	M
Client certificates	O	O	M
Shared-secret handshake	O	O	O
Compression	-	O	O
Encryption	M	M	M
MAC	M	M	M
Smart card interface	-	O	O

Appendix D Requirements for the WTLS Protocol

The common requirements set by wireless mobile networks are described below.

Item	Description
Datagram transport protocol	Both datagram and connection oriented transport layer protocols must be supported. It must be possible to cope with, for example, lost, duplicated, or out of order datagrams without breaking the connection state.
Slow interactions	The protocol must take into account that round-trip times with some bearers (eg, SMS [GSM03.40]) can be long. For example, sending a query and receiving a response might require more than 10 seconds. This must be taken into account in the protocol design.
Low transfer rate	The slowness of some bearers is a major constraint. Therefore, the amount of overhead must be kept in the minimum. For example, with SMS the effective transfer rate may be lower than 100 bit/s.
Limited processing power	The processing power of many mobile terminals is quite limited. This must be taken into account when cryptographic algorithms are chosen.
Limited memory capacity	The memory capacity of most mobile terminals is very modest. Therefore, the number of cryptographic algorithms must be minimised and small-sized algorithms must be chosen. Especially the RAM requirements must be as low as possible.
Restrictions on exporting and using cryptography	International restrictions and rules for using, exporting, and importing cryptography must be taken into account. This means that it must be possible to achieve the best permitted security level according to the legislation of each area. For example, in many cases, strong authentication can be used although strong encryption is prohibited.

Appendix E Static Conformance Requirement

This static conformance requirement lists a minimum set of functions that can be implemented to help ensure that WTLS implementations will be able to inter-operate. The "Status" column indicates if the function is mandatory (M) or optional (O).

E.1 WTLS Server Options

Item	Function	Subfunction	Reference	Status
WTLS-S001	Session management	Full handshake (eg, needed for the anonymous handshake)	10.3	M
WTLS-S002		Abbreviated handshake (ie, resume)	10.3	M
WTLS-S003		Optimised public key handshake	10.3	O
WTLS-S004		Session sharing (multiple connections)	11.1.4	O
WTLS-S005		Record concatenation for handshake messages	10.4	M
WTLS-S006		Handshake reliability over datagrams	10.4	M
WTLS-S007		Sending of hello_request	10.5.1	O
WTLS-S010	Record protocol	Explicit sequence numbering	9.2.3.1	M
WTLS-S011		Implicit sequence numbering	9.2.3.1	O
WTLS-S012		Duplicate removal	9.2.3.1	M
WTLS-S013		Key refresh	Appendix B.3	M
WTLS-S020	Alerting	Critical alerts (close connection)	10.2	M
WTLS-S021		Fatal alerts (close connection, invalidate session if not in cleartext)	10.2	M
WTLS-S022		Checking of checksums	10.2	M
WTLS-S025	Change Cipher Spec		10.1	M
WTLS-S026	Application Data		9.2	M
WTLS-S030	Anonymous handshaking options; at least one supported.		Appendix A	M
WTLS-S031		DH_ANON	Appendix A	O
WTLS-S032		DH_ANON_768	Appendix A	O
WTLS-S033		DH_ANON_512	Appendix A	O
WTLS-S034		RSA_ANON	Appendix A	O
WTLS-S035		RSA_ANON_768	Appendix A	O
WTLS-S036		RSA_ANON_512	Appendix A	O
WTLS-S037		ECDH_ANON	Appendix A	O
WTLS-S038		ECDH_ANON_131	Appendix A	O
WTLS-S049		ECDH_ANON_113	Appendix A	O

Item	Function	Subfunction	Reference	Status
WTLS-S060	Non-anonymous (server authenticated) handshake options; at least one supported.		Appendix A	O
WTLS-S061		RSA	Appendix A	O
WTLS-S062		RSA_768	Appendix A	O
WTLS-S063		RSA_512	Appendix A	O
WTLS-S064		ECDH_ECDSA	Appendix A	O
WTLS-S070	Client authentication options; at least one supported.		Appendix A	O
WTLS-S071		RSA	Appendix A	O
WTLS-S072		ECDH_ECDSA	Appendix A	O
WTLS-S080	Shared secret handshake		Appendix A	O
WTLS-S090	NULL key exchange		Appendix A	O
WTLS-S100	Data encryption options; at least one supported.		Appendix A	M
WTLS-S101		RC5_CBC	Appendix A	O
WTLS-S102		RC5_CBC_56	Appendix A	O
WTLS-S103		DES_CBC	Appendix A	O
WTLS-S104		3DES_CBC_EDE	Appendix A	O
WTLS-S105		IDEA_CBC	Appendix A	O
WTLS-S106		IDEA_CBC_56	Appendix A	O
WTLS-S120	NULL encryption		Appendix A	O
WTLS-S130	MAC options; at least one supported.		Appendix A	M
WTLS-S131		SHA	Appendix A	O
WTLS-S132		SHA_80	Appendix A	O
WTLS-S133		SHA_40	Appendix A	O
WTLS-S134		SHA_XOR_40	Appendix A	O
WTLS-S135		MD5	Appendix A	O
WTLS-S136		MD5_80	Appendix A	O
WTLS-S137		MD5_40	Appendix A	O
WTLS-S140	NULL MAC (SHA_0)		Appendix A	O
WTLS-S141	NULL compression		Appendix A	M
WTLS-S151	Predefined Diffie-Hellman parameters	Parameters 1	Appendix A	O
WTLS-S152		Parameters 2	Appendix A	O

Item	Function	Subfunction	Reference	Status
WTLS-S164	ECC basic curves; if ECC is used, at least one MUST be supported and all SHOULD be supported.	Curve 4 (113 bits)	Appendix A	O
WTLS-S165		Curve 5 (163 bits)	Appendix A	O
WTLS-S166		Curve 6 (112 bits)	Appendix A	O
WTLS-S167		Curve 7 (160 bits)	Appendix A	O
WTLS-S161	ECC non-basic curves	Curve 1 (113 bits)	Appendix A	O
WTLS-S163		Curve 3 (163 bits)	Appendix A	O
WTLS-S168		Curve 8 (112 bits)	Appendix A	O
WTLS-S169		Curve 9 (160 bits)	Appendix A	O
WTLS-S180	ECC point compression		11.1.3	O
WTLS-S191	Verification of certificates; WTLS certificate verification MUST be supported if non-anonymous handshake is supported	WTLS certificate	10.5.2	O
WTLS-S192		X.509 certificate	10.5.2	O
WTLS-S193		X9.68 certificate	10.5.2	O
WTLS-S200	GMT UNIX time support		10.5.1	M

E.2 WTLS Client Options

Item	Function	Subfunction	Reference	Status
WTLS-C001	Session management	Full handshake (eg, needed for the anonymous handshake)	10.3	M
WTLS-C002		Abbreviated handshake (ie, resume)	10.3	M
WTLS-C003		Optimised public key handshake	10.3	O
WTLS-C004		Session sharing (multiple connections)	11.1.4	O
WTLS-C005		Record concatenation for handshake messages	10.4	M
WTLS-C006		Handshake reliability over datagrams	10.4	M
WTLS-C010		Record protocol	Explicit sequence numbering	9.2.3.1
WTLS-C011	Implicit sequence numbering		9.2.3.1	O
WTLS-C012	Duplicate removal		9.2.3.1	M
WTLS-C013	Key refresh		Appendix B.3	M
WTLS-C020	Alerting	Critical alerts (close connection)	10.2	M
WTLS-C021		Fatal alerts (close connection, invalidate session if not in cleartext)	10.2	M
WTLS-C022		Checking of checksums	10.2	M
WTLS-C025	Change Cipher Spec		10.1	M
WTLS-C026	Application Data		9.2	M
WTLS-C030	Anonymous handshaking options; at least one supported.		Appendix A	M
WTLS-C031		DH_ANON	Appendix A	O
WTLS-C032		DH_ANON_768	Appendix A	O
WTLS-C033		DH_ANON_512	Appendix A	O
WTLS-C034		RSA_ANON	Appendix A	O
WTLS-C035		RSA_ANON_768	Appendix A	O
WTLS-C036		RSA_ANON_512	Appendix A	O
WTLS-C037		ECDH_ANON	Appendix A	O
WTLS-C038		ECDH_ANON_131	Appendix A	O
WTLS-C039		ECDH_ANON_113	Appendix A	O
WTLS-C049				Appendix A

Item	Function	Subfunction	Reference	Status
WTLS-C060	Non-anonymous (server authenticated) handshake options; at least one supported.		Appendix A	O
WTLS-C061		RSA	Appendix A	O
WTLS-C062		RSA_768	Appendix A	O
WTLS-C063		RSA_512	Appendix A	O
WTLS-C064		ECDH_ECDSA	Appendix A	O
WTLS-C070	Client authentication options; at least one supported.		Appendix A	O
WTLS-C071		RSA	Appendix A	O
WTLS-C072		ECDH_ECDSA	Appendix A	O
WTLS-C080	Shared secret handshake		Appendix A	O
WTLS-C090	NULL key exchange		Appendix A	O
WTLS-C100	Data encryption options; at least one supported.		Appendix A	O
WTLS-C101		RC5_CBC	Appendix A	O
WTLS-C102		RC5_CBC_56	Appendix A	O
WTLS-C103		DES_CBC	Appendix A	O
WTLS-C104		3DES_CBC_EDE	Appendix A	O
WTLS-C105		IDEA_CBC	Appendix A	O
WTLS-C106		IDEA_CBC_56	Appendix A	O
WTLS-C120	NULL encryption		Appendix A	O
WTLS-C130	MAC options; at least one supported.		Appendix A	M
WTLS-C131		SHA	Appendix A	O
WTLS-C132		SHA_80	Appendix A	O
WTLS-C133		SHA_40	Appendix A	O
WTLS-C134		SHA_XOR_40	Appendix A	O
WTLS-C135		MD5	Appendix A	O
WTLS-C136		MD5_80	Appendix A	O
WTLS-C137		MD5_40	Appendix A	O
WTLS-C140	NULL MAC (SHA_0)		Appendix A	O
WTLS-C141	NULL compression		Appendix A	M
WTLS-C151	Predefined Diffie-Hellman parameters	Parameters 1	Appendix A	O
WTLS-C152		Parameters 2	Appendix A	O

Item	Function	Subfunction	Reference	Status
WTLS-C164	ECC basic curves; if ECC is used, at least one MUST be supported. Verification SHOULD be supported with all basic curves that have field size not less than 160 bits	Curve 4 (113 bits)	Appendix A	O
WTLS-C165		Curve 5 (163 bits)	Appendix A	O
WTLS-C166		Curve 6 (112 bits)	Appendix A	O
WTLS-C167		Curve 7 (160 bits)	Appendix A	O
WTLS-C161	ECC non-basic curves	Curve 1 (113 bits)	Appendix A	O
WTLS-C163		Curve 3 (163 bits)	Appendix A	O
WTLS-C168		Curve 8 (112 bits)	Appendix A	O
WTLS-C169		Curve 9 (160 bits)	Appendix A	O
WTLS-C180	ECC point compression		11.1.3	O
WTLS-C191	Verification of certificates; WTLS certificate verification MUST be supported if non-anonymous handshake is supported	WTLS certificate	10.5.2	O
WTLS-C192		X.509 certificate	10.5.2	O
WTLS-C193		X9.68 certificate	10.5.2	O
WTLS-C200	GMT UNIX time support		10.5.1	O