Cloud Security risks and countermeasures

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In general terms, security controls in cloud computing are similar to the security controls in any IT environment. However, because of the operational models and technologies used to enable cloud service, cloud computing may present risks that are specific to the cloud environment. The essential concept in this regard is that the enterprise loses a substantial amount of control over resources, services, and applications but must maintain accountability for security and privacy policies.

The Cloud Security Alliance [CSA10] lists the following as the top cloud-specific security threats, together with suggested countermeasures:

- **Abuse and nefarious use of cloud computing:** For many CPs, it is relatively easy to register and begin using cloud services, some even offering free limited trial periods. This enables attackers to get inside the cloud to conduct various attacks, such as spamming, malicious code attacks, and denial of service. PaaS providers have traditionally suffered most from this kind of attacks; however, recent evidence shows that hackers have begun to target IaaS vendors as well. The burden is on the CP to protect against such attacks, but cloud service clients must monitor activity with respect to their data and resources to detect any malicious behavior.

  Countermeasures include (1) stricter initial registration and validation processes; (2) enhanced credit card fraud monitoring and coordination; (3) comprehensive introspection of customer network traffic; and (4) monitoring public blacklists for one's own network blocks.
- **Insecure interfaces and APIs:** CPs expose a set of software interfaces or APIs that customers use to manage and interact with cloud services. The security and availability of general cloud services are dependent upon the security of these basic APIs. From authentication and access control to encryption and activity monitoring, these interfaces must be designed to protect against both accidental and malicious attempts to circumvent policy.

  Countermeasures include (1) analyzing the security model of CP interfaces; (2) ensuring that strong authentication and access controls are implemented in concert with encrypted transmission; and (3) understanding the dependency chain associated with the API.
- **Malicious insiders:** Under the cloud computing paradigm, an organization relinquishes direct control over many aspects of security and, in doing so, confers an unprecedented level of trust onto the CP. One grave concern is the risk of malicious insider activity. Cloud architectures necessitate certain roles that are extremely high risk. Examples include CP system administrators and managed security service providers.

  Countermeasures include the following: (1) enforce strict supply chain management and conduct a comprehensive supplier assessment; (2) specify human resource requirements as part of legal contract; (3) require transparency into overall information security and management practices, as well as compliance reporting; and (4) determine security breach notification processes.
- **Shared technology issues:** IaaS vendors deliver their services in a scalable way by sharing infrastructure. Often, the underlying components that make up this infrastructure (CPU caches, GPUs, etc.) were not designed to offer strong isolation properties for a multi-tenant architecture. CPs typically approach this risk by the use of isolated virtual machines for individual clients. This approach is still vulnerable to attack, by both insiders and outsiders, and so can only be a part of an overall security strategy.

  Countermeasures include the following: (1) implement security best practices for installation/configuration; (2) monitor environment for unauthorized changes/activity; (3) promote strong authentication and access control for administrative access and operations; (4) enforce SLAs for patching and vulnerability remediation; and (5) conduct vulnerability scanning and configuration audits.

- **Data loss or leakage:** For many clients, the most devastating impact from a security breach is the loss or leakage of data. We address this issue in the next subsection.

  Countermeasures include the following: (1) implement strong API access control; (2) encrypt and protect integrity of data in transit; (3) analyze data protection at both design and run time; and (4) implement strong key generation, storage and management, and destruction practices.

- **Account or service hijacking:** Account or service hijacking, usually with stolen credentials, remains a top threat. With stolen credentials, attackers can often access critical areas of deployed cloud computing services, allowing them to compromise the confidentiality, integrity, and availability of those services.

  Countermeasures include the following: (1) prohibit the sharing of account credentials between users and services; (2) leverage strong two-factor authentication techniques where possible; (3) employ proactive monitoring to detect unauthorized activity; and (4) understand CP security policies and SLAs.

- **Unknown risk profile:** In using cloud infrastructures, the client necessarily cedes control to the CP on a number of issues that may affect security. Thus the client must pay attention to and clearly define the roles and responsibilities involved for managing risks. For example, employees may deploy applications and data resources at the CP without observing the normal policies and procedures for privacy, security, and oversight.

  Countermeasures include (1) disclosure of applicable logs and data; (2) partial/full disclosure of infrastructure details (e.g., patch levels and firewalls); and (3) monitoring and alerting on necessary information.

Data Protection in Cloud

As can be seen from the previous section, there are numerous aspects to cloud security and numerous approaches to providing cloud security measures. A further example is seen in the NIST guidelines for cloud security, specified in SP-800-14 and listed in Table 5.3. Thus, the topic of cloud security is well beyond the scope of this chapter. In this section, we focus on one specific element of cloud security.

There are many ways to compromise data. Deletion or alteration of records without a backup of the original content is an obvious example. Unlinking a record from a larger context may render it unrecoverable, as can storage on unreliable media. Loss of an encoding key may result in effective destruction. Finally, unauthorized parties must be prevented from gaining access to sensitive data.

Data Protection in Cloud

Table 5.3 NIST Guidelines on Security and Privacy Issues and Recommendations

Governance

Extend organizational practices pertaining to the policies, procedures, and standards used for application development and service provisioning in the cloud, as well as the design, implementation, testing, use, and monitoring of deployed or engaged services.

Put in place audit mechanisms and tools to ensure organizational practices are followed throughout the system life cycle.

Compliance

Understand the various types of laws and regulations that impose security and privacy obligations on the organization and potentially impact cloud computing initiatives, particularly those involving data location, privacy and security controls, records management, and electronic discovery requirements.

Review and assess the cloud provider's offerings with respect to the organizational requirements to be met and ensure that the contract terms adequately meet the requirements.

Ensure that the cloud provider's electronic discovery capabilities and processes do not compromise the privacy or security of data and applications.

Trust

Ensure that service arrangements have sufficient means to allow visibility into the security and privacy controls and processes employed by the cloud provider, and their performance over time.

Establish clear, exclusive ownership rights over data.

Institute a risk management program that is flexible enough to adapt to the constantly evolving and shifting risk landscape for the life cycle of the system.

Continuously monitor the security state of the information system to support ongoing risk management decisions.

Architecture

Understand the underlying technologies that the cloud provider uses to provision services, including the implications that the technical controls involved have on the security and privacy of the system, over the full system life cycle and across all system components.

Identity and access management

Ensure that adequate safeguards are in place to secure authentication, authorization, and other identity and access management functions, and are suitable for the organization.

Software isolation

Understand virtualization and other logical isolation techniques that the cloud provider employs in its multi-tenant software architecture, and assess the risks involved for the organization.

Data protection

Evaluate the suitability of the cloud provider's data management solutions for the organizational data concerned and the ability to control access to data, to secure data while at rest, in transit, and in use, and to sanitize data.

Take into consideration the risk of collating organizational data with those of other organizations whose threat profiles are high or whose data collectively represent significant concentrated value.

Fully understand and weigh the risks involved in cryptographic key management with the facilities available in the cloud environment and the processes established by the cloud provider.

Availability

Understand the contract provisions and procedures for availability, data backup and recovery, and disaster recovery, and ensure that they meet the organization's continuity and contingency planning requirements.

Ensure that during an intermediate or prolonged disruption or a serious disaster, critical operations can be immediately resumed, and that all operations can be eventually reinstituted in a timely and organized manner.

Incident response

Understand the contract provisions and procedures for incident response and ensure that they meet the requirements of the organization.

Table 5.3 Continued

Ensure that the cloud provider has a transparent response process in place and sufficient mechanisms to share information during and after an incident. Ensure that the organization can respond to incidents in a coordinated fashion with the cloud provider in accordance with their respective roles and responsibilities for the computing environment.

The threat of data compromise increases in the cloud, due to the number of and interactions between risks and challenges that are either unique to the cloud or more dangerous because of the architectural or operational characteristics of the cloud environment.

Database environments used in cloud computing can vary significantly. Some providers support a **multi-instance model**, which provides a unique DBMS running on a virtual machine instance for each cloud subscriber. This gives the subscriber complete control over role definition, user authorization, and other administrative tasks related to security. Other providers support a **multi-tenant model**, which provides a predefined environment for the cloud subscriber that is shared with other tenants, typically through tagging data with a subscriber identifier. Tagging gives the appearance of exclusive use of the instance, but relies on the CP to establish and maintain a sound secure database environment.

Data must be secured while at rest, in transit, and in use, and access to the data must be controlled. The client can employ encryption to protect data in transit, though this involves key management responsibilities for the CP. The client can enforce access control techniques but, again, the CP is involved to some extent depending on the service model used.

For data at rest, the ideal security measure is for the client to encrypt the database and only store encrypted data in the cloud, with the CP having no access to the encryption key. So long as the key remains secure, the CP has no ability to read the data, although corruption and other denial-of-service attacks remain a risk.

A straightforward solution to the security problem in this context is to encrypt the entire database and not provide the encryption/decryption keys to the service provider. This solution by itself is inflexible. The user has little ability to access individual data items based on searches or indexing on key parameters, but rather would have to download entire tables from the database, decrypt the tables, and work with the results. To provide more flexibility, it must be possible to work with the database in its encrypted form.

An example of such an approach, depicted in Figure 5.10, is reported in [DAMI05] and [DAMI03]. A similar approach is described in [HACI02]. Four entities are involved:

- **Data owner:** An organization that produces data to be made available for controlled release, either within the organization or to external users.
- **User:** Human entity that presents requests (queries) to the system. The user could be an employee of the organization who is granted access to the database via the server, or a user external to the organization who, after authentication, is granted access.
- **Client:** Frontend that transforms user queries into queries on the encrypted data stored on the server.

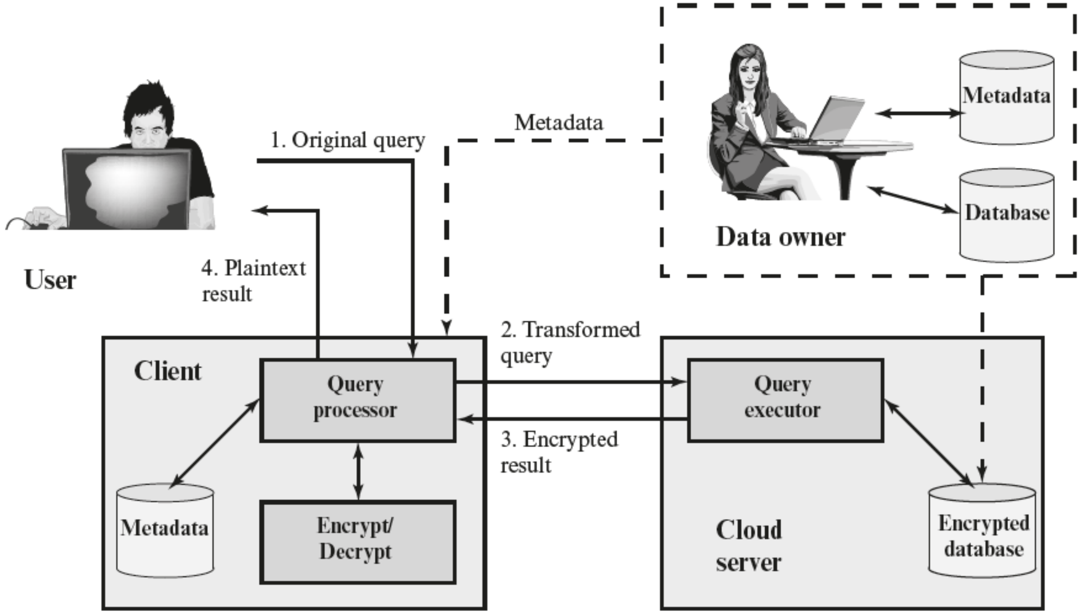


Figure 5.10 An Encryption Scheme for a Cloud-Based Database

- **Server:** An organization that receives the encrypted data from a data owner and makes them available for distribution to clients. The server could in fact be owned by the data owner but, more typically, is a facility owned and maintained by an external provider. For our discussion, the server is a cloud server.

Before continuing this discussion, we need to define some database terms. In relational database parlance, the basic building block is a **relation**, which is a flat table. Rows are referred to as **tuples**, and columns are referred to as **attributes**. A **primary key** is defined to be a portion of a row used to uniquely identify a row in a table; the primary key consists of one or more column names.[2] For example, in an employee table, the employee ID is sufficient to uniquely identify a row in a particular table.

Let us first examine the simplest possible arrangement based on this scenario. Suppose that each individual item in the database is encrypted separately, all using the same encryption key. The encrypted database is stored at the server, but the server does not have the encryption key. Thus, the data are secure at the server. Even if someone were able to hack into the server's system, all he or she would have access to is encrypted data. The client system does have a copy of the encryption key. A user at the client can retrieve a record from the database with the following sequence:

1. The user issues a query for fields from one or more records with a specific value of the primary key.

2. The query processor at the client encrypts the primary key, modifies the query accordingly, and transmits the query to the server.
3. The server processes the query using the encrypted value of the primary key and returns the appropriate record or records.
4. The query processor decrypts the data and returns the results.

This method is certainly straightforward but is quite limited. For example, suppose the Employee table contains a salary attribute and the user wishes to retrieve all records for salaries less than $70K. There is no obvious way to do this, because the attribute value for salary in each record is encrypted. The set of encrypted values does not preserve the ordering of values in the original attribute.

There are a number of ways to extend the functionality of this approach. For example, an unencrypted index value can be associated with a given attribute and the table can be partitioned based on these index values, enabling a user to retrieve a certain portion of the table. The details of such schemes are beyond our scope.

The TLS Record Protocol provides basic security services to various higher-layer protocols. In particular, the **Hypertext Transfer Protocol (HTTP)**, which provides the transfer service for Web client/server interaction, can operate on top of TLS. Three higher-layer protocols are defined as part of TLS: the Handshake Protocol; the Change Cipher Spec Protocol; and the Alert Protocol. These TLS-specific protocols are used in the management of TLS exchanges and are examined later in this section. A fourth protocol, the Heartbeat Protocol, is defined in a separate RFC and is also discussed subsequently in this section.

Two important TLS concepts are the TLS session and the TLS connection, which are defined in the specification as follows:

- **Connection:** A connection is a transport (in the OSI layering model definition) that provides a suitable type of service. For TLS, such connections are peer-to-peer relationships. The connections are transient. Every connection is associated with one session.
- **Session:** A TLS session is an association between a client and a server. Sessions are created by the Handshake Protocol. Sessions define a set of cryptographic security parameters, which can be shared among multiple connections. Sessions are used to avoid the expensive negotiation of new security parameters for each connection.

Between any pair of parties (applications such as HTTP on client and server), there may be multiple secure connections. In theory, there may also be multiple simultaneous sessions between parties, but this feature is not used in practice.

There are a number of states associated with each session. Once a session is established, there is a current operating state for both read and write (i.e., receive and send). In addition, during the Handshake Protocol, pending read and write states are created. Upon successful conclusion of the Handshake Protocol, the pending states become the current states.

A session state is defined by the following parameters:

- **Session identifier:** An arbitrary byte sequence chosen by the server to identify an active or resumable session state.
- **Peer certificate:** An X509.v3 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, AES, etc.) and a hash algorithm (such as MD5 or SHA-1) used for MAC calculation. It also defines cryptographic attributes such as the hash_size.
- **Master secret:** 48-byte secret shared between the client and server.
- **Is resumable:** A flag indicating whether the session can be used to initiate new connections.

A connection state is defined by the following parameters:

- **Server and client random:** Byte sequences that are chosen by the server and client for each connection.
- **Server write MAC secret:** The secret key used in MAC operations on data sent by the server.
- **Client write MAC secret:** The symmetric key used in MAC operations on data sent by the client.
- **Server write key:** The symmetric encryption key for data encrypted by the server and decrypted by the client.
- **Client write key:** The symmetric encryption key for data encrypted by the client and decrypted by the server.
- **Initialization vectors:** When a block cipher in CBC mode is used, an initialization vector (IV) is maintained for each key. This field is first initialized by the TLS Handshake Protocol. Thereafter, the final ciphertext block from each record is preserved for use as the IV with the following record.
- **Sequence numbers:** Each party maintains separate sequence numbers for transmitted and received messages for each connection. When a party sends or receives a "change cipher spec message," the appropriate sequence number is set to zero. Sequence numbers may not exceed $2^{64} - 1$.

TLS Record Protocol

The TLS Record Protocol provides two services for TLS connections:

- **Confidentiality:** The Handshake Protocol defines a shared secret key that is used for conventional encryption of TLS payloads.
- **Message Integrity:** The Handshake Protocol also defines a shared secret key that is used to form a message authentication code (MAC).

Figure 6.3 indicates the overall operation of the TLS Record Protocol. The Record Protocol takes an application message to be transmitted, fragments the data into manageable blocks, optionally compresses the data, applies a MAC, encrypts, adds a header, and transmits the resulting unit in a TCP segment. Received data are decrypted, verified, decompressed, and reassembled before being delivered to higher-level users.

The first step is **fragmentation**. Each upper-layer message is fragmented into blocks of 2^{14} bytes (16,384 bytes) or less. Next, **compression** is optionally applied. Compression must be lossless and may not increase the content length by more than

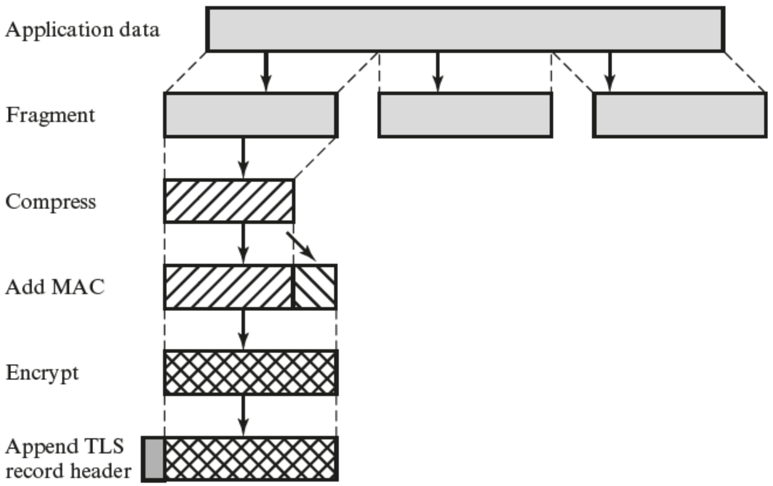


Figure 6.3 TLS Record Protocol Operation

1024 bytes.[1] In TLSv2, no compression algorithm is specified, so the default compression algorithm is null.

The next step in processing is to compute a **message authentication code** over the compressed data. TLS makes use of the HMAC algorithm defined in RFC 2104. Recall from Chapter 3 that HMAC is defined as

$$\mathrm{HMAC}_K(M) = \mathrm{H}[(K^+ \oplus \mathrm{opad}) \| \mathrm{H}[(K^+ \oplus \mathrm{ipad}) \| M]]$$

where

H	=	embedded hash function (for TLS, either MD5 or SHA-1)
M	=	message input to HMAC
K^+	=	secret key padded with zeros on the left so that the result is equal to the block length of the hash code (for MD5 and SHA-1, block length $= 512$ bits)
ipad	=	00110110 (36 in hexadecimal) repeated 64 times (512 bits)
opad	=	01011100 (5C in hexadecimal) repeated 64 times (512 bits)

For TLS, the MAC calculation encompasses the fields indicated in the following expression:

HMAC_hash(MAC_write_secret, seq_num || TLSCompressed.type ||
TLSCompressed.version || TLSCompressed.length || TLSCompressed.fragment)

The MAC calculation covers all of the fields XXX, plus the field `TLSCompressed.version`, which is the version of the protocol being employed.

Next, the compressed message plus the MAC are **encrypted** using symmetric encryption. Encryption may not increase the content length by more than 1024 bytes, so that the total length may not exceed $2^{14} + 2048$. The following encryption algorithms are permitted:

Block Cipher		Stream Cipher	
Algorithm	**Key Size**	**Algorithm**	**Key Size**
AES 3DES	128, 256 168	RC4-128	128

For stream encryption, the compressed message plus the MAC are encrypted. Note that the MAC is computed before encryption takes place and that the MAC is then encrypted along with the plaintext or compressed plaintext.

For block encryption, padding may be added after the MAC prior to encryption. The padding is in the form of a number of padding bytes followed by a one-byte indication of the length of the padding. The padding can be any amount that results in a total that is a multiple of the cipher's block length, up to a maximum of 255 bytes. For example, if the cipher block length is 16 bytes (e.g., AES) and if the plaintext (or compressed text if compression is used) plus MAC plus padding length byte is 79 bytes long, then the padding length (in bytes) can be 1, 17, 33, and so on, up to 161. At a padding length of 161, the total length is $79 + 161 = 240$. A variable padding length may be used to frustrate attacks based on an analysis of the lengths of exchanged messages.

The final step of TLS Record Protocol processing is to prepend a header consisting of the following fields:

- **Content Type (8 bits):** The higher-layer protocol used to process the enclosed fragment.
- **Major Version (8 bits):** Indicates major version of TLS in use. For TLSv2, the value is 3.
- **Minor Version (8 bits):** Indicates minor version in use. For TLSv2, the value is 1.
- **Compressed Length (16 bits):** The length in bytes of the plaintext fragment (or compressed fragment if compression is used). The maximum value is $2^{14} + 2048$.

The content types that have been defined are `change_cipher_spec`, `alert`, `handshake`, and `application_data`. The first three are the TLS-specific protocols, discussed next. Note that no distinction is made among the various applications (e.g., HTTP) that might use TLS; the content of the data created by such applications is opaque to TLS.

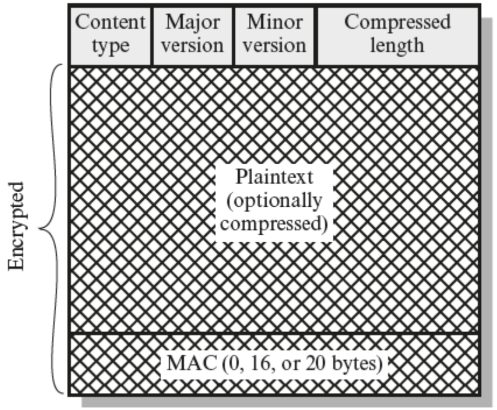


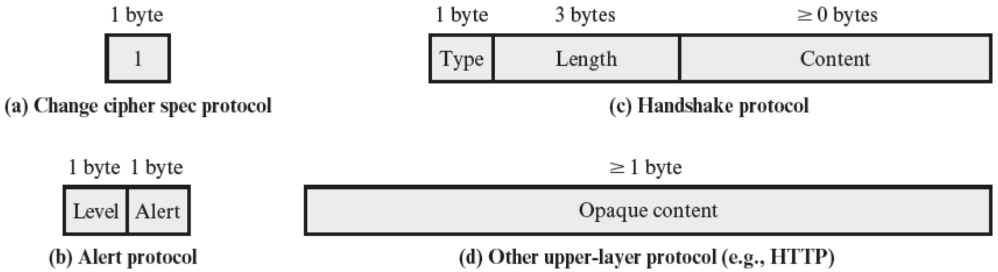
Figure 6.4 TLS Record Format

Alert Protocol

The Alert Protocol is used to convey TLS-related alerts to the peer entity. As with other applications that use TLS, alert messages are compressed and encrypted, as specified by the current state.

Each message in this protocol consists of two bytes (Figure 6.5b). The first byte takes the value warning (1) or fatal (2) to convey the severity of the message. If the level is fatal, TLS immediately terminates the connection. Other connections on the same session may continue, but no new connections on this session may be established. The second byte contains a code that indicates the specific alert. The following alerts are always fatal:

- **unexpected_message:** An inappropriate message was received.
- **bad_record_mac:** An incorrect MAC was received.
- **decompression_failure:** The decompression function received improper input (e.g., unable to decompress or decompress to greater than maximum allowable length).
- **handshake_failure:** Sender was unable to negotiate an acceptable set of security parameters given the options available.
- **illegal_parameter:** A field in a handshake message was out of range or inconsistent with other fields.



- **decryption_failed:** A ciphertext decrypted in an invalid way; either it was not an even multiple of the block length or its padding values, when checked, were incorrect.
- **record_overflow:** A TLS record was received with a payload (ciphertext) whose length exceeds $2^{14} + 2048$ bytes, or the ciphertext decrypted to a length of greater than $2^{14} + 1024$ bytes.
- **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 could not be matched with a known, trusted CA.
- **access_denied:** A valid certificate was received, but when access control was applied, the sender decided not to proceed with the negotiation.
- **decode_error:** A message could not be decoded, because either a field was out of its specified range or the length of the message was incorrect.
- **export_restriction:** A negotiation not in compliance with export restrictions on key length was detected.
- **protocol_version:** The protocol version the client attempted to negotiate is recognized but not supported.
- **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.
- **internal_error:** An internal error unrelated to the peer or the correctness of the protocol makes it impossible to continue.

The remaining alerts are the following.

- **close_notify:** Notifies the recipient that the sender will not send any more messages on this connection. Each party is required to send a close_notify alert before closing the write side of a connection.
- **bad_certificate:** A received certificate was corrupt (e.g., contained a signature that did not verify).
- **unsupported_certificate:** The type of the received certificate is not supported.
- **certificate_revoked:** A certificate has been revoked by its signer.
- **certificate_expired:** A certificate has expired.
- **certificate_unknown:** Some other unspecified issue arose in processing the certificate, rendering it unacceptable.
- **decrypt_error:** A handshake cryptographic operation failed, including being unable to verify a signature, decrypt a key exchange, or validate a finished message.
- **user_canceled:** This handshake is being canceled for some reason unrelated to a protocol failure.
- **no_renegotiation:** Sent by a client in response to a hello request or by the server in response to a client hello after initial handshaking. Either of these messages would normally result in renegotiation, but this alert indicates that the sender is not able to renegotiate. This message is always a warning.

Handshake Protocol

The most complex part of TLS is the **Handshake Protocol**. This protocol allows the server and client to authenticate each other and to negotiate an encryption and MAC algorithm and cryptographic keys to be used to protect data sent in a TLS record. The Handshake Protocol is used before any application data is transmitted.

The Handshake Protocol consists of a series of messages exchanged by client and server. All of these have the format shown in Figure 6.5c. Each message has three fields:

- **Type (1 byte):** Indicates one of 10 messages. Table 6.2 lists the defined message types.
- **Length (3 bytes):** The length of the message in bytes.
- **Content (≥ 0 bytes):** The parameters associated with this message; these are listed in Table 6.2.

Figure 6.6 shows the initial exchange needed to establish a logical connection between client and server. The exchange can be viewed as having four phases.

Phase 1. Establish Security Capabilities Phase 1 initiates a logical connection and establishes the security capabilities that will be associated with it. The exchange is initiated by the client, which sends a **client_hello message** with the following parameters:

- **Version:** The highest TLS version understood by the client.
- **Random:** A client-generated random structure consisting of a 32-bit timestamp and 28 bytes generated by a secure random number generator. These values serve as nonces and are used during key exchange to prevent replay attacks.
- **Session ID:** A variable-length session identifier. A nonzero value indicates that the client wishes to update the parameters of an existing connection or to create a new connection on this session. A zero value indicates that the client wishes to establish a new connection on a new session.

Table 6.2 TLS Handshake Protocol Message Types

Message Type	Parameters
hello_request	null
client_hello	version, random, session id, cipher suite, compression method
server_hello	version, random, session id, cipher suite, compression method
certificate	chain of X.509v3 certificates
server_key_exchange	parameters, signature
certificate_request	type, authorities
server_done	null
certificate_verify	signature
client_key_exchange	parameters, signature
finished	hash value

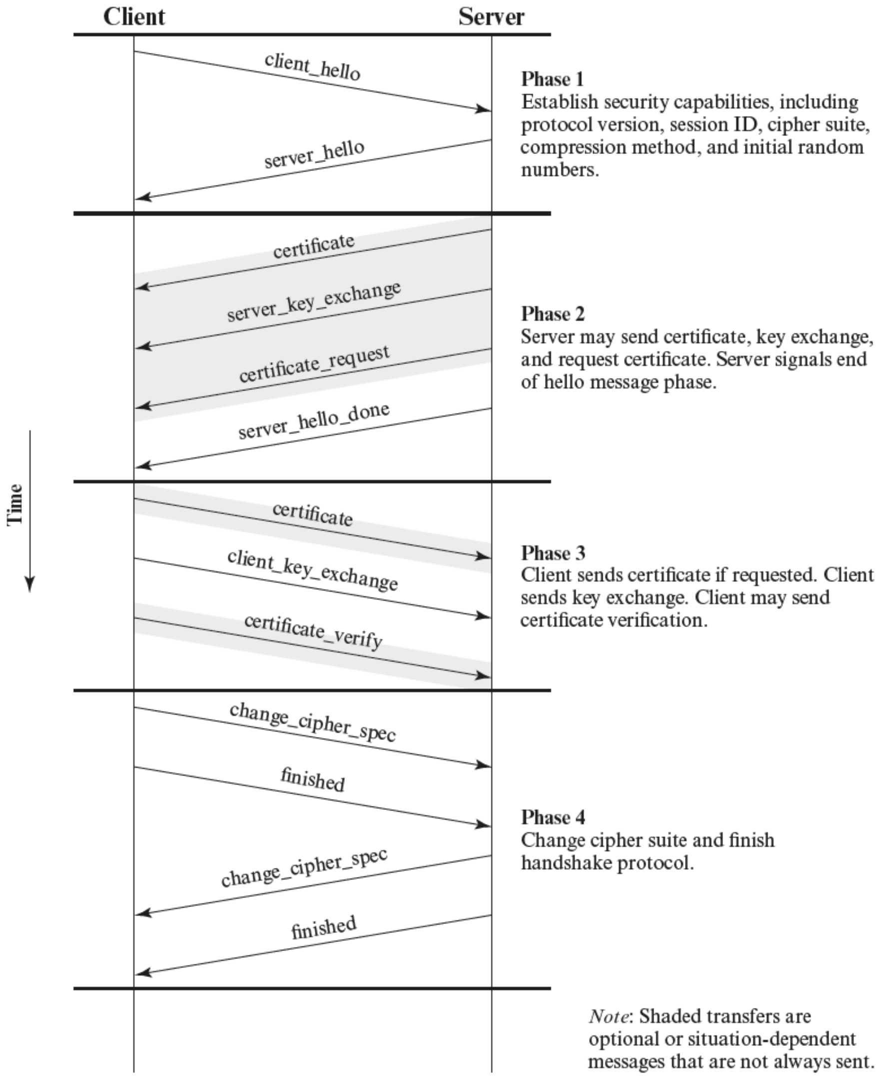


Figure 6.6 Handshake Protocol Action

- **CipherSuite:** This is a list that contains the combinations of cryptographic algorithms supported by the client, in decreasing order of preference. Each element of the list (each cipher suite) defines both a key exchange algorithm and a CipherSpec; these are discussed subsequently.
- **Compression Method:** This is a list of the compression methods the client supports.

After sending the `client_hello` message, the client waits for the **`server_hello` message**, which contains the same parameters as the `client_hello` message. For the `server_hello` message, the following conventions apply. The Version field contains the lowest of the version suggested by the client and the highest supported by the server. The Random field is generated by the server and is independent of the client's Random field. If the SessionID field of the client was nonzero, the same value is used by the server; otherwise the server's SessionID field contains the value for a new session. The CipherSuite field contains the single cipher suite selected by the server from those proposed by the client. The Compression field contains the compression method selected by the server from those proposed by the client.

The first element of the Ciphersuite parameter is the key exchange method (i.e., the means by which the cryptographic keys for conventional encryption and MAC are exchanged). The following key exchange methods are supported.

- **RSA:** The secret key is encrypted with the receiver's RSA public key. A public-key certificate for the receiver's key must be made available.
- **Fixed Diffie–Hellman:** This is a Diffie–Hellman key exchange in which the server's certificate contains the Diffie–Hellman public parameters signed by the certificate authority (CA). That is, the public-key certificate contains the Diffie–Hellman public-key parameters. The client provides its Diffie–Hellman public-key parameters either in a certificate, if client authentication is required, or in a key exchange message. This method results in a fixed secret key between two peers based on the Diffie–Hellman calculation using the fixed public keys.
- **Ephemeral Diffie–Hellman:** This technique is used to create ephemeral (temporary, one-time) secret keys. In this case, the Diffie–Hellman public keys are exchanged and signed using the sender's private RSA or DSS key. The receiver can use the corresponding public key to verify the signature. Certificates are used to authenticate the public keys. This would appear to be the most secure of the three Diffie–Hellman options because it results in a temporary, authenticated key.
- **Anonymous Diffie–Hellman:** The base Diffie–Hellman algorithm is used with no authentication. That is, each side sends its public Diffie–Hellman parameters to the other with no authentication. This approach is vulnerable to man-in-the-middle attacks, in which the attacker conducts anonymous Diffie–Hellman with both parties.

Following the definition of a key exchange method is the CipherSpec, which includes the following fields:

- **CipherAlgorithm:** Any of the algorithms mentioned earlier: RC4, RC2, DES, 3DES, DES40, or IDEA
- **MACAlgorithm:** MD5 or SHA-1
- **CipherType:** Stream or Block
- **IsExportable:** True or False
- **HashSize:** 0, 16 (for MD5), or 20 (for SHA-1) bytes
- **Key Material:** A sequence of bytes that contain data used in generating the write keys
- **IV Size:** The size of the Initialization Value for Cipher Block Chaining (CBC) encryption

SSL/TLS ATTACKS

Since the first introduction of SSL in 1994, and the subsequent standardization of TLS, numerous attacks have been devised against these protocols. The appearance of each attack has necessitated changes in the protocol, the encryption tools used, or some aspect of the implementation of SSL and TLS to counter these threats.

Attack Categories We can group the attacks into four general categories:

- **Attacks on the handshake protocol:** As early as 1998, an approach to compromising the handshake protocol based on exploiting the formatting and implementation of the RSA encryption scheme was presented [BLEI98]. As countermeasures were implemented the attack was refined and adjusted to not only thwart the countermeasures but also speed up the attack [e.g., BARD12].
- **Attacks on the record and application data protocols:** A number of vulnerabilities have been discovered in these protocols, leading to patches to counter the new threats. As a recent example, in 2011, researchers Thai Duong and Juliano Rizzo demonstrated a proof of concept called BEAST (Browser Exploit Against SSL/TLS) that turned what had been considered only a theoretical vulnerability

into a practical attack [GOOD11]. BEAST leverages a type of cryptographic attack called a chosen-plaintext attack. The attacker mounts the attack by choosing a guess for the plaintext that is associated with a known ciphertext. The researchers developed a practical algorithm for launching successful attacks. Subsequent patches were able to thwart this attack. The authors of the BEAST attack are also the creators of the 2012 CRIME (Compression Ratio Info-leak Made Easy) attack, which can allow an attacker to recover the content of web cookies when data compression is used along with TLS [GOOD12]. When used to recover the content of secret authentication cookies, it allows an attacker to perform session hijacking on an authenticated web session.

- **Attacks on the PKI:** Checking the validity of X.509 certificates is an activity subject to a variety of attacks, both in the context of SSL/TLS and elsewhere. For example, [GEOR12] demonstrated that commonly used libraries for SSL/TLS suffer from vulnerable certificate validation implementations. The authors revealed weaknesses in the source code of OpenSSL, GnuTLS, JSSE, ApacheHttpClient, Weberknecht, cURL, PHP, Python and applications built upon or with these products.
- **Other attacks:** [MEYE13] lists a number of attacks that do not fit into any of the preceding categories. One example is an attack announced in 2011 by the German hacker group The Hackers Choice, which is a DoS attack [KUMA11]. The attack creates a heavy processing load on a server by overwhelming the target with SSL/TLS handshake requests. Boosting system load is done by establishing new connections or using renegotiation. Assuming that the majority of computation during a handshake is done by the server, the attack creates more system load on the server than on the source device, leading to a DoS. The server is forced to continuously recompute random numbers and keys.

The history of attacks and countermeasures for SSL/TLS is representative of that for other Internet-based protocols. A "perfect" protocol and a "perfect" implementation strategy are never achieved. A constant back-and-forth between threats and countermeasures determines the evolution of Internet-based protocols.

TLSv1.3

In 2014, the IETF TLS working group began work on a version 1.3 of TLS. The primary aim is to improve the security of TLS. As of this writing, TLSv1.3 is still in a draft stage, but the final standard is likely to be very close to the current draft. Among the significant changes from version 1.2 are the following:

- TLSv1.3 removes support for a number of options and functions. Removing code that implements functions no longer needed reduces the chances of potentially dangerous coding errors and reduces the attack surface. The deleted items include:

  –Compression
  –Ciphers that do not offer authenticated encryption
  –Static RSA and DH key exchange
  –32-bit timestamp as part of the Random parameter in the client_hello message

–Renegotiation
–Change Cipher Spec Protocol
–RC4
–Use of MD5 and SHA-224 hashes with signatures

- TLSv1.3 uses Diffie–Hellman or Elliptic Curve Diffie–Hellman for key exchange and does not permit RSA. The danger with RSA is that if the private key is compromised, all handshakes using these cipher suites will be compromised. With DH or ECDH, a new key is negotiated for each handshake.
- TLSv1.3 allows for a "1 round trip time" handshake by changing the order of message sent with establishing a secure connection. The client sends a Client Key Exchange message containing its cryptographic parameters for key establishment before a cipher suite has been negotiated. This enables a server to calculate keys for encryption and authentication before sending its first response. Reducing the number of packets sent during this handshake phase speeds up the process and reduces the attack surface.