Chapter 17

Transport-Level Security

Web Security Considerations

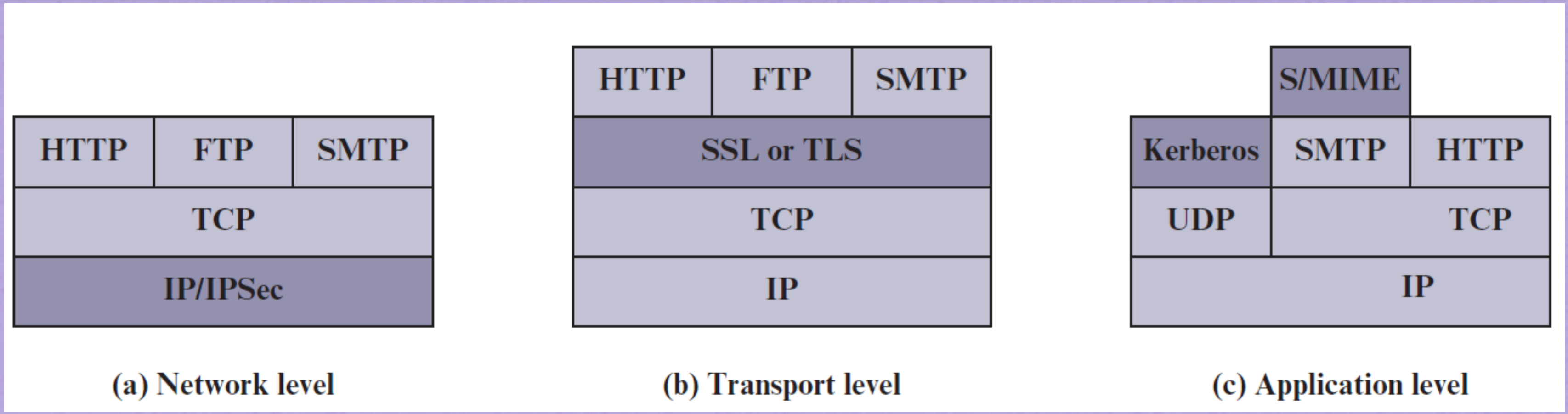
- The World Wide Web is fundamentally a client/server application running over the Internet and TCP/IP intranets
- The following characteristics of Web usage suggest the need for tailored security tools:
  - Web servers are relatively easy to configure and manage
  - Web content is increasingly easy to develop
  - The underlying software is extraordinarily complex
    - May hide many potential security flaws
  - A Web server can be exploited as a launching pad into the corporation's or agency's entire computer complex
  - Casual and untrained (in security matters) users are common clients for Web-based services
    - Such users are not necessarily aware of the risks that exist and do not have the tools or knowledge to take effective countermeasures

A Comparison of Threats on the Web

	Threats	Consequences	Countermeasures
Integrity	• Modification of user data • Trojan horse browser • Modification of memory • Modification of message traffic in transit	• Loss of information • Compromise of machine • Vulnerability to all other threats	Cryptographic checksums
Confidentiality	• Eavesdropping on the net • Theft of info from server • Theft of data from client • Info about network configuration • Info about which client talks to server	• Loss of information • Loss of privacy	Encryption, Web proxies
Denial of Service	• Killing of user threads • Flooding machine with bogus requests • Filling up disk or memory • Isolating machine by DNS attacks	• Disruptive • Annoying • Prevent user from getting work done	Difficult to prevent
Authentication	• Impersonation of legitimate users • Data forgery	• Misrepresentation of user • Belief that false information is valid	Cryptographic techniques

(Table is on page 515 in the textbook)

Relative Location of Security Facilities in the TCP/IP Protocol Stack



SSL and TLS

- SSL was originally created by Netscape, specifically to secure web traffic
- TLS working group was formed within IETF
- First version of TLS can be viewed as an SSLv3.1

Transport Layer Security (TLS)

One of the most widely used security services

Defined in RFC 5246

Is an Internet standard that evolved from a commercial protocol known as Secure Sockets Layer (SSL)

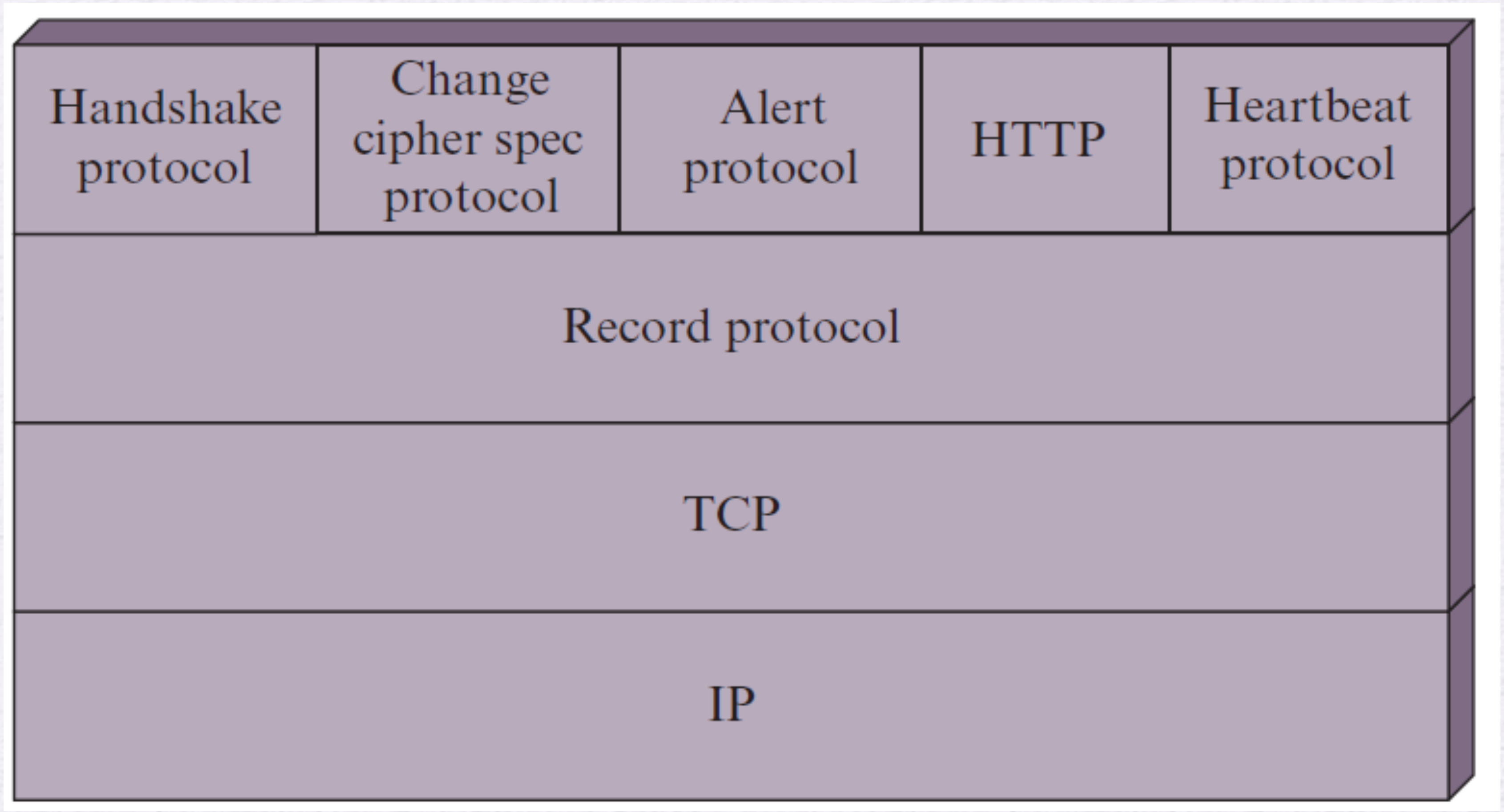
Is a general purpose service implemented as a set of protocols that rely on TCP

Could be provided as part of the underlying protocol suite and therefore be transparent to applications

Can be embedded in specific packages

Most browsers come equipped with TLS, and most Web servers have implemented the protocol

TLS Protocol Stack



SSL/TLS Architecture

- Two important TLS concepts are:

TLS connection

- A transport that provides a suitable type of service
- For TLS such connections are peer-to-peer relationships
- Connections are transient
- Every connection is associated with one session

TLS session

- An association between a client and a server
- Created by the Handshake Protocol
- Define a set of cryptographic security parameters which can be shared among multiple connections
- Are used to avoid the expensive negotiation of new security parameters for each connection

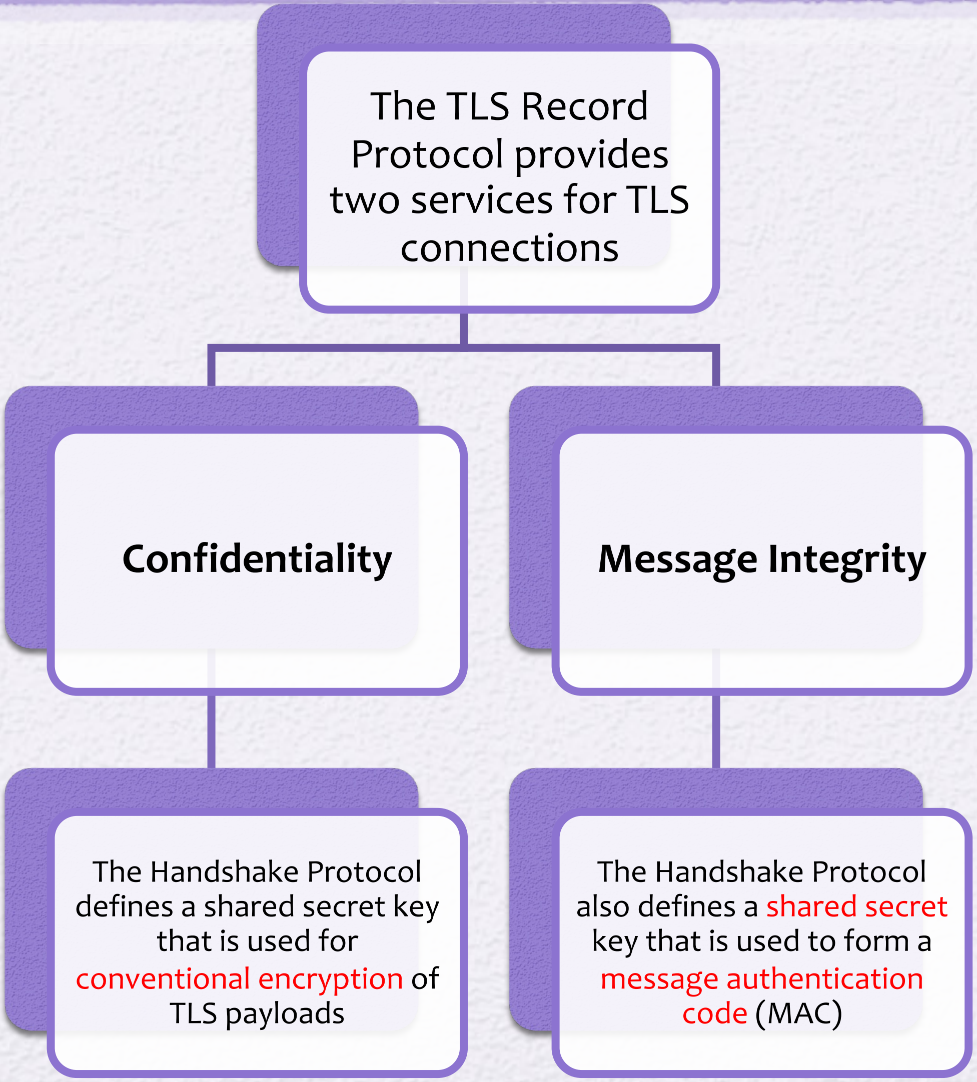
A session state is defined by the following parameters:

Session identifier	Peer certificate	Compression method	Cipher spec	Master secret	Is resumable
An arbitrary byte sequence chosen by the server to identify an active or resumable session state	An X509.v3 certificate of the peer; this element of the state may be null	The algorithm used to compress data prior to encryption	Specifies the bulk data encryption algorithm and a hash algorithm used for MAC calculation; also defines cryptographic attributes such as the hash_size	48-byte secret shared between the client and the server	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 secret key used in MAC operations on data sent by the client
Server write key	• The secret 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 • 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 $2^{64} - 1$

SSL/TLS Record Protocol



The TLS Record Protocol provides two services for TLS connections

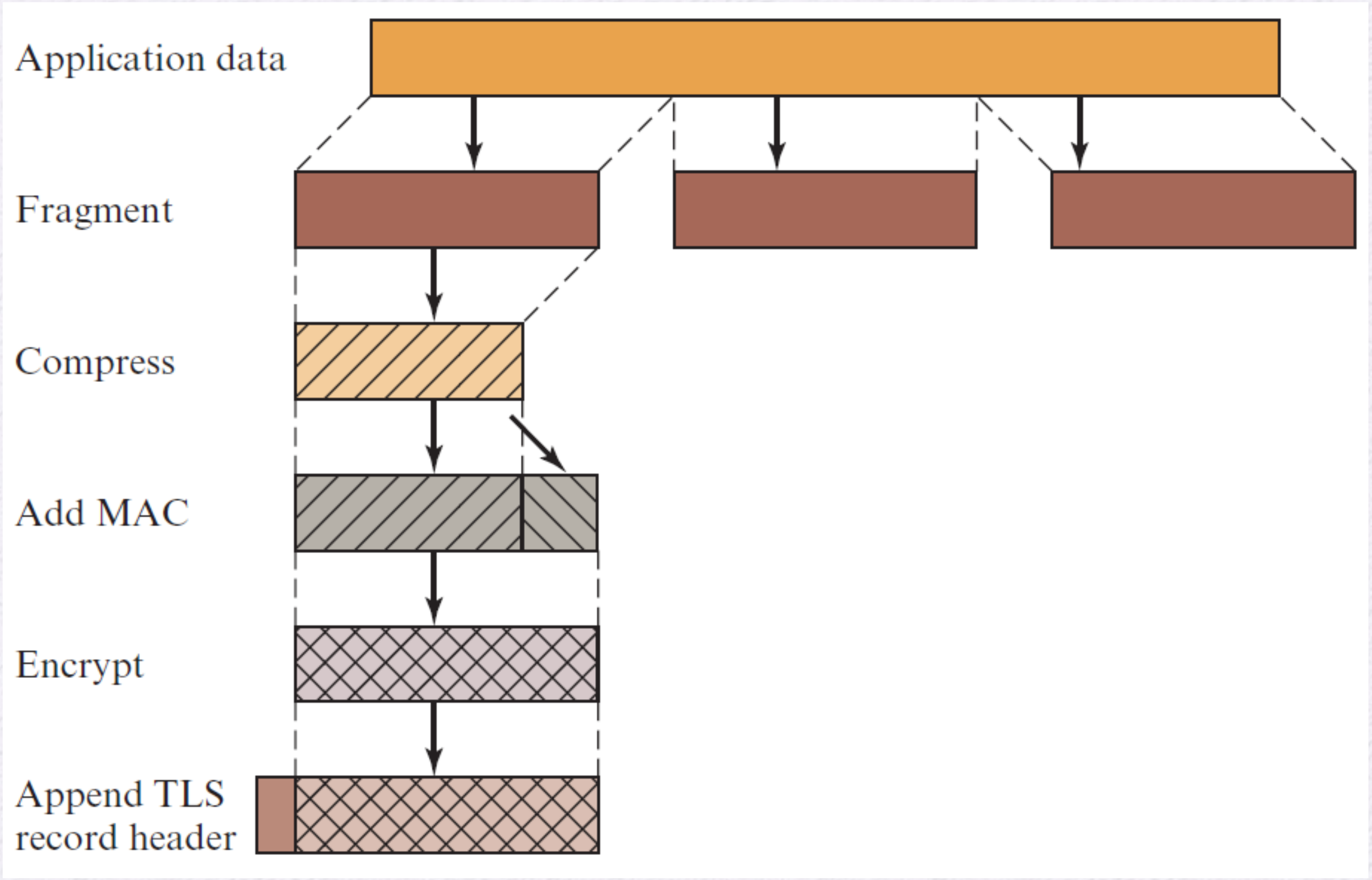
Confidentiality

The Handshake Protocol defines a shared secret key that is used for conventional encryption of TLS payloads

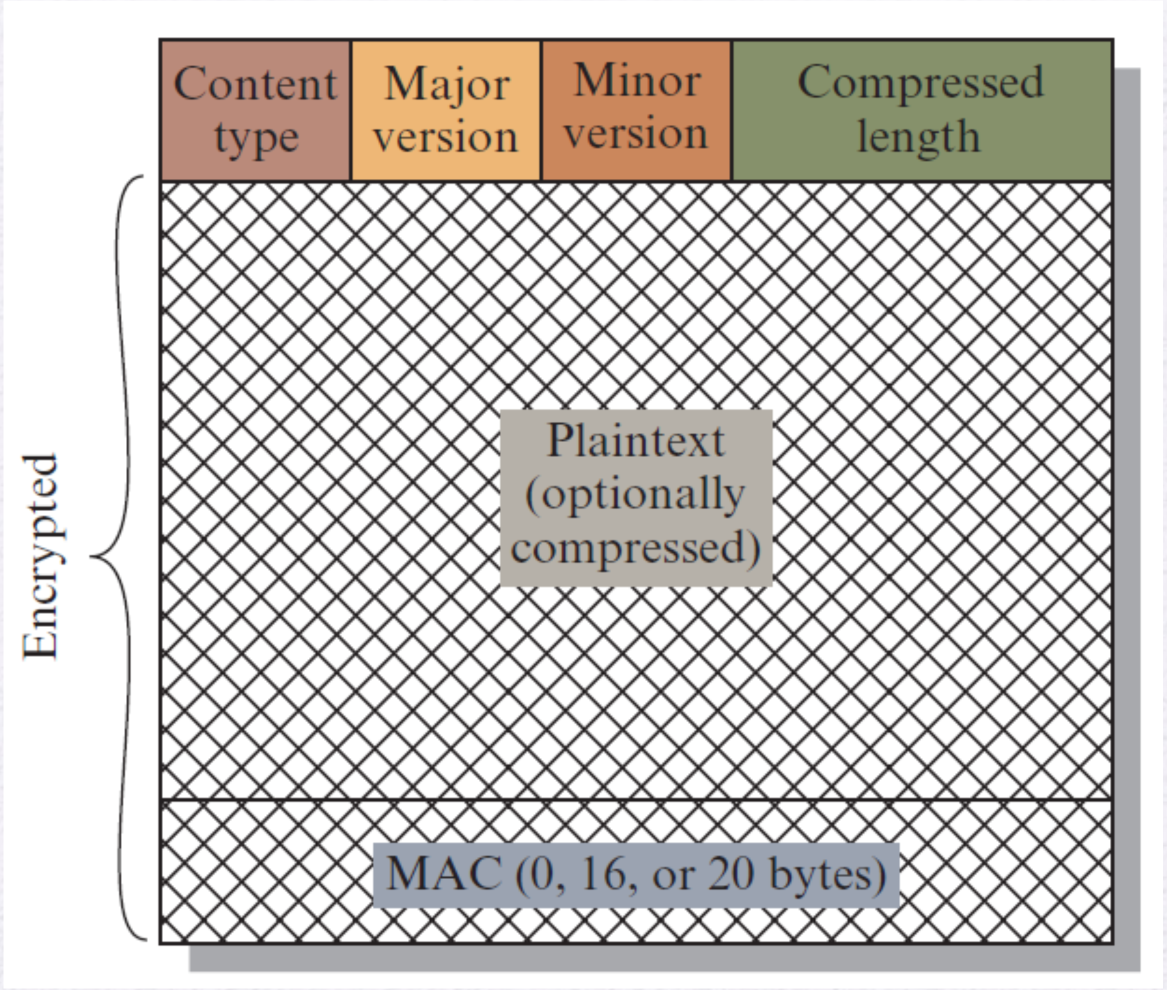
Message Integrity

The Handshake Protocol also defines a shared secret key that is used to form a message authentication code (MAC)

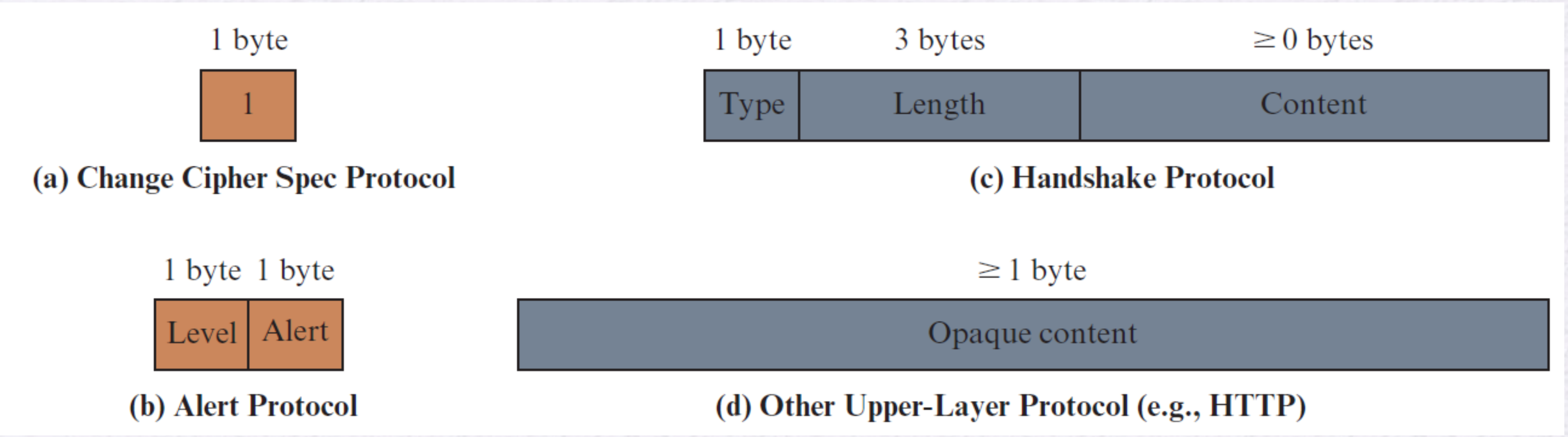
SSL/TLS Record Protocol Operation



SSL/TLS Record Format

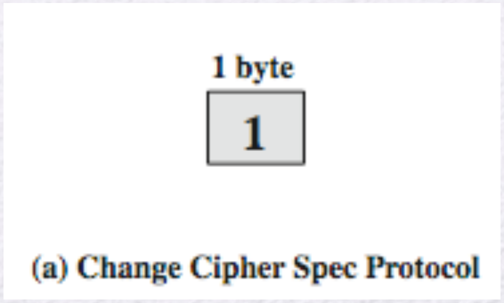


SSL/TLS Record Protocol Payload



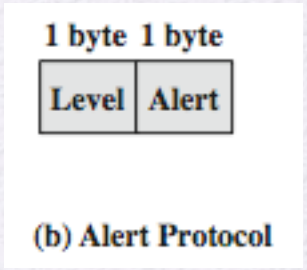
SSL/TLS
Change Cipher Spec Protocol

- one of 3 SSL specific protocols which uses the SSL Record protocol
- a single message
- causes pending state to become current
- hence updating the cipher suite in use



SSL/TLS Alert Protocol

- conveys SSL-related alerts to peer entity
- severity
  - warning or fatal
- specific alert
  - fatal: unexpected message, bad record mac, decompression failure, handshake failure, illegal parameter
  - warning: close notify, no certificate, bad certificate, unsupported certificate, certificate revoked, certificate expired, certificate unknown
- compressed & encrypted like all SSL data



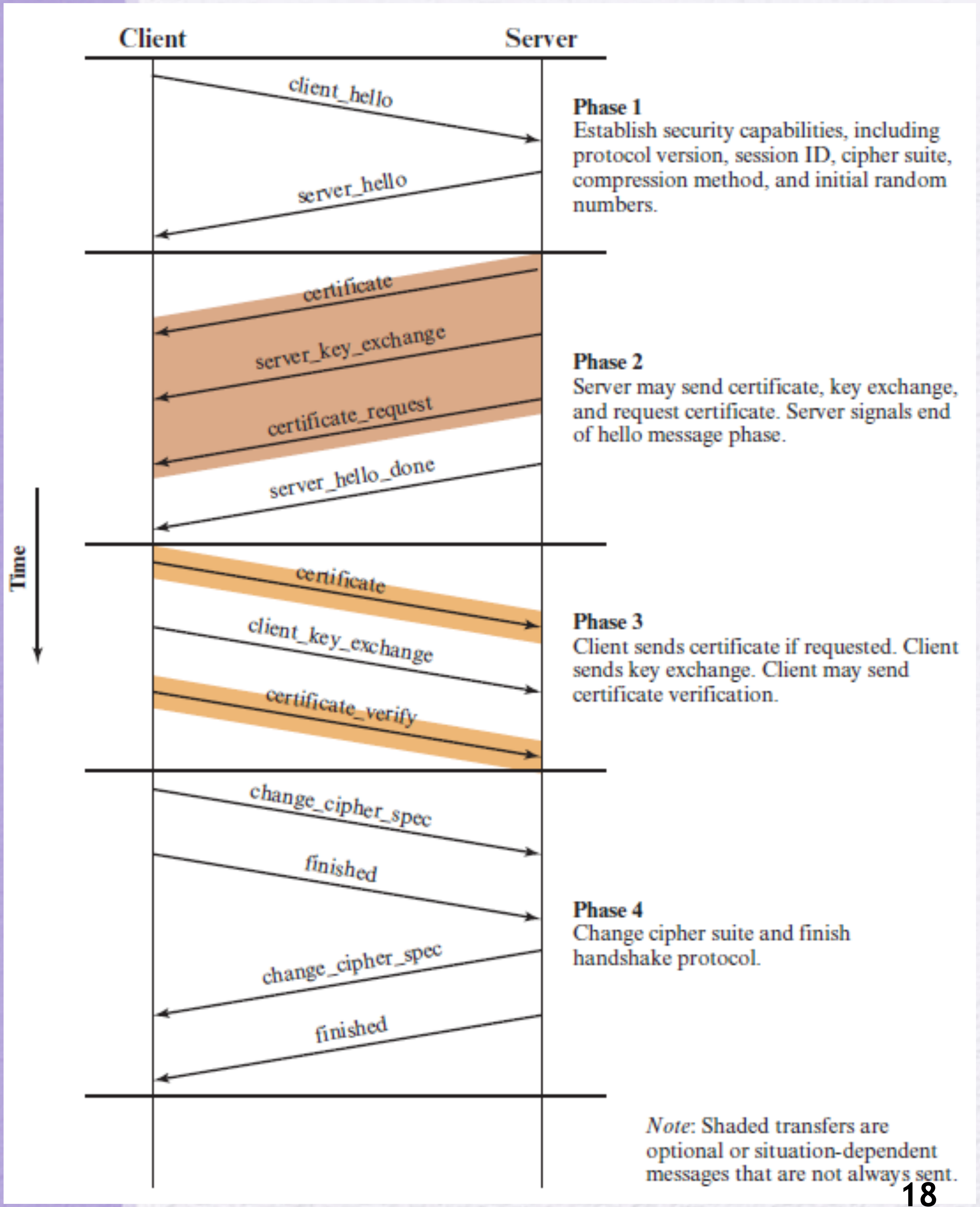
(b) Alert Protocol

SSL/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

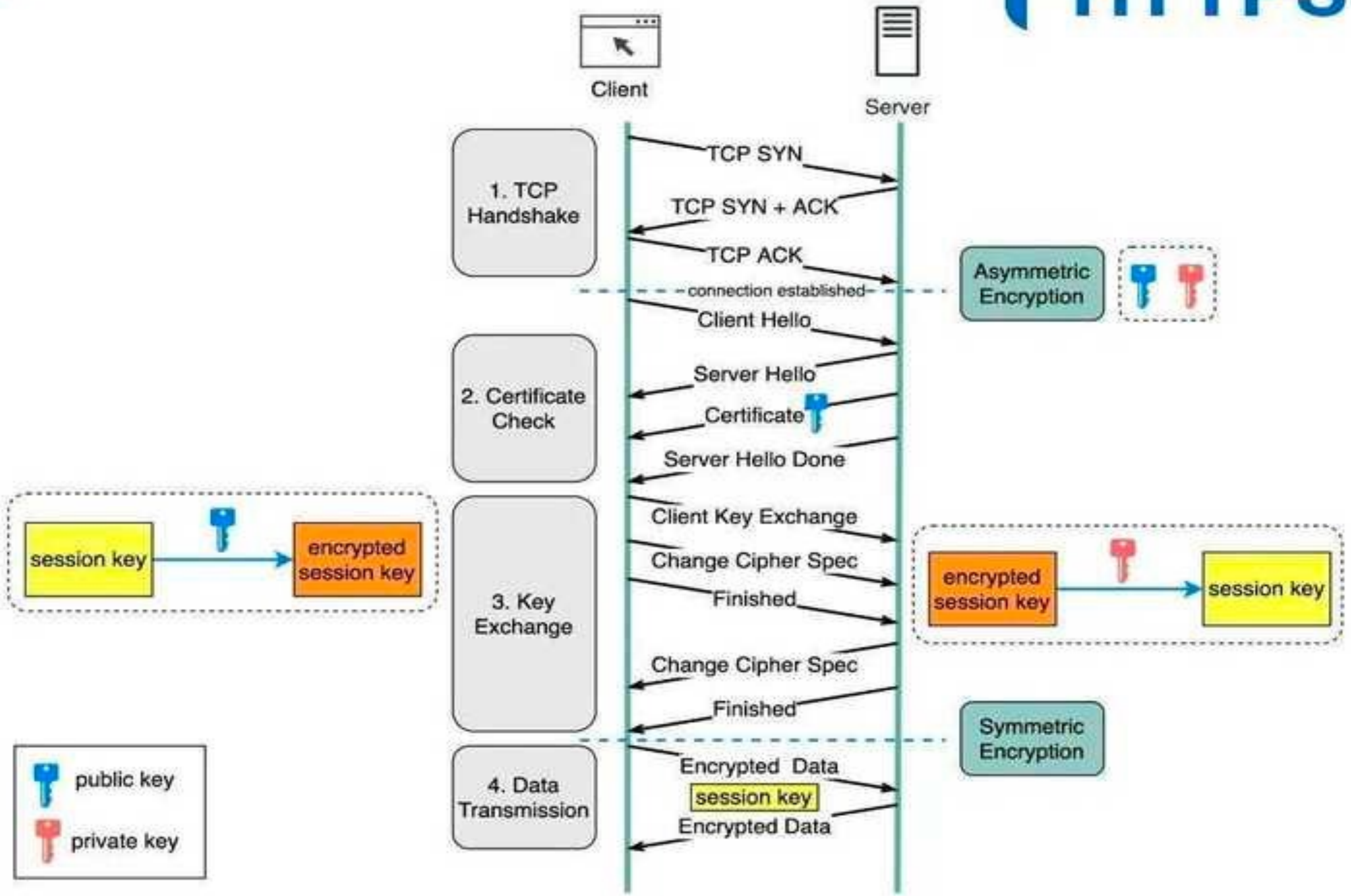
(Table is on page 522 in the textbook)

Handshake Protocol Action


Client
Server
client_hello
server_hello
Phase 1
Establish security capabilities, including protocol version, session ID, cipher suite, compression method, and initial random numbers.
certificate
server_key_exchange
certificate_request
server_hello_done
Phase 2
Server may send certificate, key exchange, and request certificate. Server signals end of hello message phase.
Time
certificate
client_key_exchange
certificate_verify
Phase 3
Client sends certificate if requested. Client sends key exchange. Client may send certificate verification.
change_cipher_spec
finished
change_cipher_spec
finished
Phase 4
Change cipher suite and finish handshake protocol.
Note: Shaded transfers are optional or situation-dependent messages that are not always sent.

How does HTTPS Work?

HTTPS



Heartbeat Protocol

- A heartbeat is a periodic signal generated by hardware or software to indicate normal operation or to synchronize other parts of a system

- A heartbeat protocol is typically used to monitor the availability of a protocol entity

- The heartbeat protocol runs on top of the TLS Record Protocol
  - Consists of two message types: heartbeat_request and heartbeat_response

- The heartbeat serves two purposes:
  - It assures the sender that the recipient is still alive, even though there may not have been any activity over the underlying TCP connection
  - It generates activity across the connection during idle periods, which avoids closure by a firewall that does not tolerate idle connections

Cryptographic Computations

- Two further items are of interest:
  - The creation of a shared master secret by means of the key exchange
    - The shared master secret is a one-time 48-byte value generated for this session by means of secure key exchange
    - The creation is in two stages
      - First, a pre_master_secret is exchanged
      - Second, the master_secret is calculated by both parties
  - The generation of cryptographic parameters from the master secret

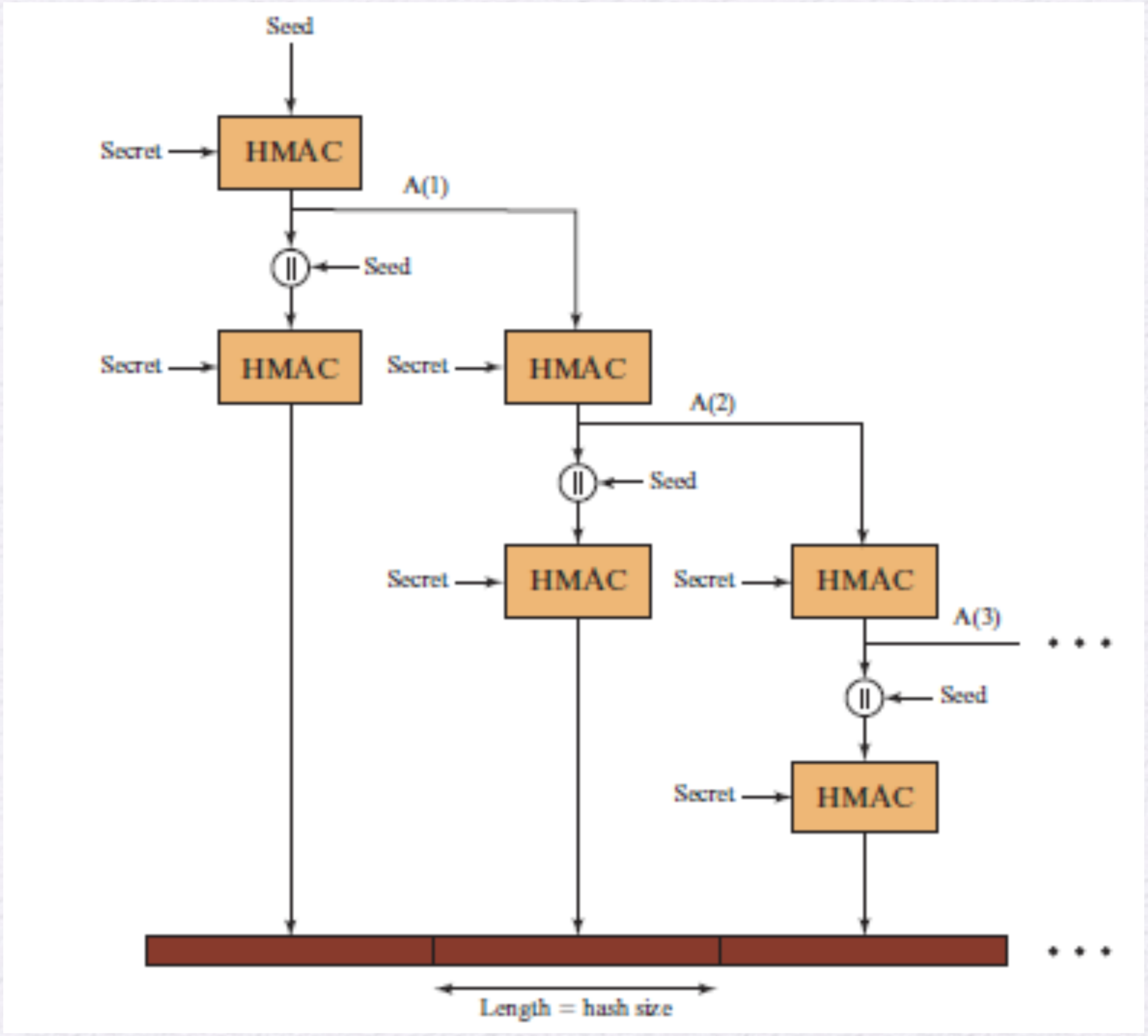
Generation of Cryptographic Parameters

- CipherSpecs require:
  - A client write MAC secret
  - A server write MAC secret
  - A client write key
  - A server write key
  - A client write IV
  - A server write IV

------Which are generated from the master secret in that order

- These parameters are generated from the master secret by hashing the master secret into a sequence of secure bytes of sufficient length for all needed parameters

Function P_hash



The output of the function give the client write MAC secret, the server write MAC secret etc.

Transport Layer Security (RFC 2246)

- The same record format as the SSL record format and very similar to SSLv3.
- Differences in the protocols:
  - message authentication code (now HMAC)
  - pseudorandom function (to expand the shared secret)
  - Additional alert codes
  - cipher suites (e.g. Fortezza removed)
  - client certificate types (to sign some parameters)
  - Certificate verify and finished message (minor changes)
  - cryptographic computations (calculation of master secret)
  - Padding

TLSv1.3

- Primary aim is to improve the security of TLS
- Significant changes from version 1.2 are:
  - TLSv1.3 removes support for a number of options and functions
    - 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 Elleptic Curve Diffie-Hellman for key exchange and does not permit RSA
  - TLSv1.3 allows for a "1 round trip time" handshake by changing the order of message sent with establishing a secure connection

Hyper Text Transfer Protocol Secure (HTTPS)

- The secure version of HTTP
- use https:// URL rather than http://
  - and port 443 rather than 80
- HTTPS encrypts all communications between the browser and the website
- Data sent using HTTPS provides three important areas of protection:
  - Encryption
  - Data integrity
  - Authentication

Connection Initiation

For HTTPS, the agent acting as the HTTP client also acts as the TLS client

The client initiates a connection to the server on the appropriate port and then sends the TLS ClientHello to begin the TLS handshake

When the TLS handshake has finished, the client may then initiate the first HTTP request

All HTTP data is to be sent as TLS application data

There are three levels of awareness of a connection in HTTPS:

At the HTTP level, an HTTP client requests a connection to an HTTP server by sending a connection request to the next lowest layer

- Typically the next lowest layer is TCP, but is may also be TLS/SSL

At the level of TLS, a session is established between a TLS client and a TLS server

- This session can support one or more connections at any time

A TLS request to establish a connection begins with the establishment of a TCP connection between the TCP entity on the client side and the TCP entity on the server side

Connection Closure

- An HTTP client or server can indicate the closing of a connection by including the line `Connection: close` in an HTTP record

- The closure of an HTTPS connection requires that TLS close the connection with the peer TLS entity on the remote side, which will involve closing the underlying TCP connection

- TLS implementations must initiate an exchange of closure alerts before closing a connection
  - A TLS implementation may, after sending a closure alert, close the connection without waiting for the peer to send its closure alert, generating an "incomplete close"

- An unannounced TCP closure could be evidence of some sort of attack so the HTTPS client should issue some sort of security warning when this occurs

Adoption of HTTPS

Website protocol support (April 2023)

Protocol version	Website support	Security
SSL 2.0	0.2%	Insecure
SSL 3.0	2.0%	Insecure
TLS 1.0	32.3%	Deprecated
TLS 1.1	35.2%	Deprecated
TLS 1.2	99.9%	Depends on cipher and client mitigations
TLS 1.3	61.0%	Secure

Web browsers support

The latest versions of all major web browsers support TLS 1.3

Ref: https://www.ssllabs.com/ssl-pulse/
http://en.wikipedia.org/wiki/Transport_Layer_Security (2022-04-06)

SSL/TLS Attacks

- The attacks can be grouped into four general categories:
  - Attacks on the handshake protocol
  - Attacks on the record and application data protocols
  - Attacks on the PKI
  - Other attacks
- The constant back-and-forth between threats and countermeasures determines the evolution of Internet-based protocols

Heartbleed attack

- Heartbleed was a security bug in the OpenSSL cryptography library, which is a widely used implementation of the Transport Layer Security (TLS) protocol. It was introduced into the software in 2012 and publicly disclosed in April 2014.

- Heartbleed may be exploited regardless of whether the party is using a vulnerable OpenSSL instance for TLS as a server or a client. It results from improper input validation (due to a missing bounds check) in the implementation of the TLS heartbeat extension, thus the bug's name derives from heartbeat. The vulnerability is classified as a buffer over-read, a situation where more data can be read than should be allowed.

Källa: https://en.wikipedia.org/wiki/Heartbleed (2017-09-08)

HTTP Strict Transport Security (HSTS)

- HSTS is a web security policy mechanism which helps to protect websites against protocol downgrade attacks and cookie hijacking. It allows web servers to declare that web browsers should only interact with it using secure HTTPS connections, and never via the insecure HTTP protocol.

- When a web application issues HSTS Policy to user agents, conformant user agents behave as follows:
  1. Automatically turn any insecure links referencing the web application into secure links. (For instance, http://example.com/some/page/ will be modified to https://example.com/some/page/ before accessing the server.)
  2. If the security of the connection cannot be ensured (e.g. the server's TLS certificate is not trusted), show an error message and do not allow the user to access the web application.

- Entire DNS domains (even top domains) can also require the use of HTTPS by being added to a preload list for HSTS. [1]

- Most browsers today enforce HTTPS making HSTS less needed.

[1] https://www.grc.com/sn/sn-909-notes.pdf

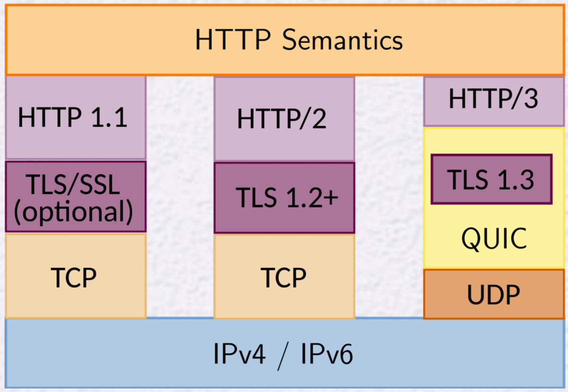
Datagram Transport Layer Security (DTLS)

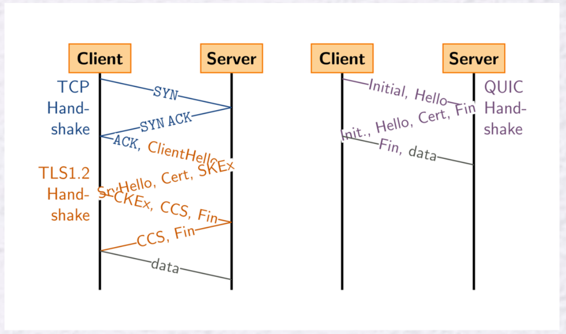
- Datagram Transport Layer Security is a communications protocol that provides security for datagram-based applications by allowing them to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery.
- The DTLS protocol is based on the stream-oriented Transport Layer Security (TLS) protocol and is intended to provide similar security guarantees.
- The DTLS protocol datagram preserves the semantics of the underlying transport—the application does not suffer from the delays associated with stream protocols, but because it uses UDP, the application has to deal with packet reordering, loss of datagram and data larger than the size of a datagram network packet.

Source: https://en.wikipedia.org/wiki/Datagram_Transport_Layer_Security

HTTP/3

- HTTP/3 is the third major version of the Hypertext Transfer Protocol used to exchange information on the World Wide Web, alongside HTTP/1.1 and HTTP/2. Internet standard 2021.
- HTTP semantics are consistent across versions: the same request methods, status codes, and message fields are typically applicable to all versions.
- The differences are in the mapping of these semantics to underlying transports. Both HTTP/1.1 and HTTP/2 use TCP as their transport. HTTP/3 uses QUIC, a transport layer network protocol developed initially by Google where user space congestion control is used over the User Datagram Protocol (UDP)



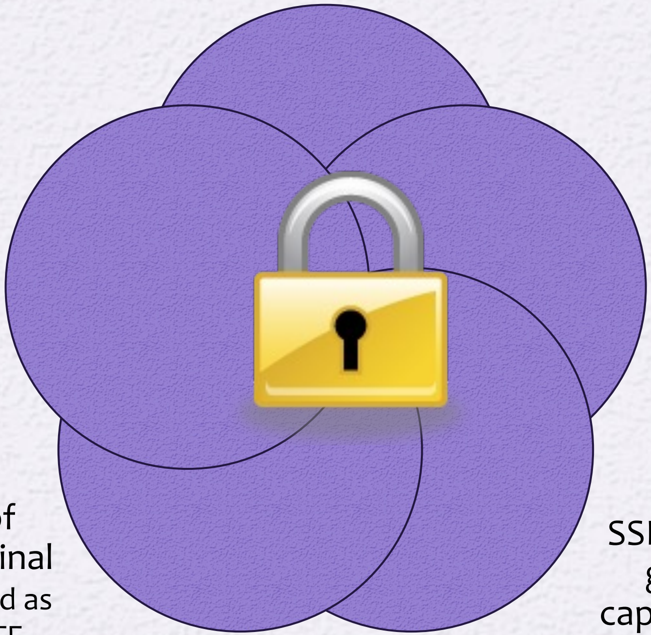


Secure Shell (SSH)

A protocol for secure network communications designed to be relatively simple and inexpensive to implement

SSH client and server applications are widely available for most operating systems

- Has become the method of choice for remote login and X tunneling
- Is rapidly becoming one of the most pervasive applications for encryption technology outside of embedded systems



The initial version, SSH1 was focused on providing a secure remote logon facility to replace TELNET and other remote logon schemes that provided no security

SSH2 fixes a number of security flaws in the original scheme and is documented as a proposed standard in IETF RFCs 4250 through 4256

SSH also provides a more general client/server capability and can be used for such network functions as file transfer and e-mail

Secure Shell (SSH)

- Designed in 1995 by Tatu Ylonen
- Replaced in 1996 by SSHv2
  - Fixed security holes
  - Eventually standardized
- Less popular than SSL
  - But completely dominates a niche of the market - remote login and port forwarding

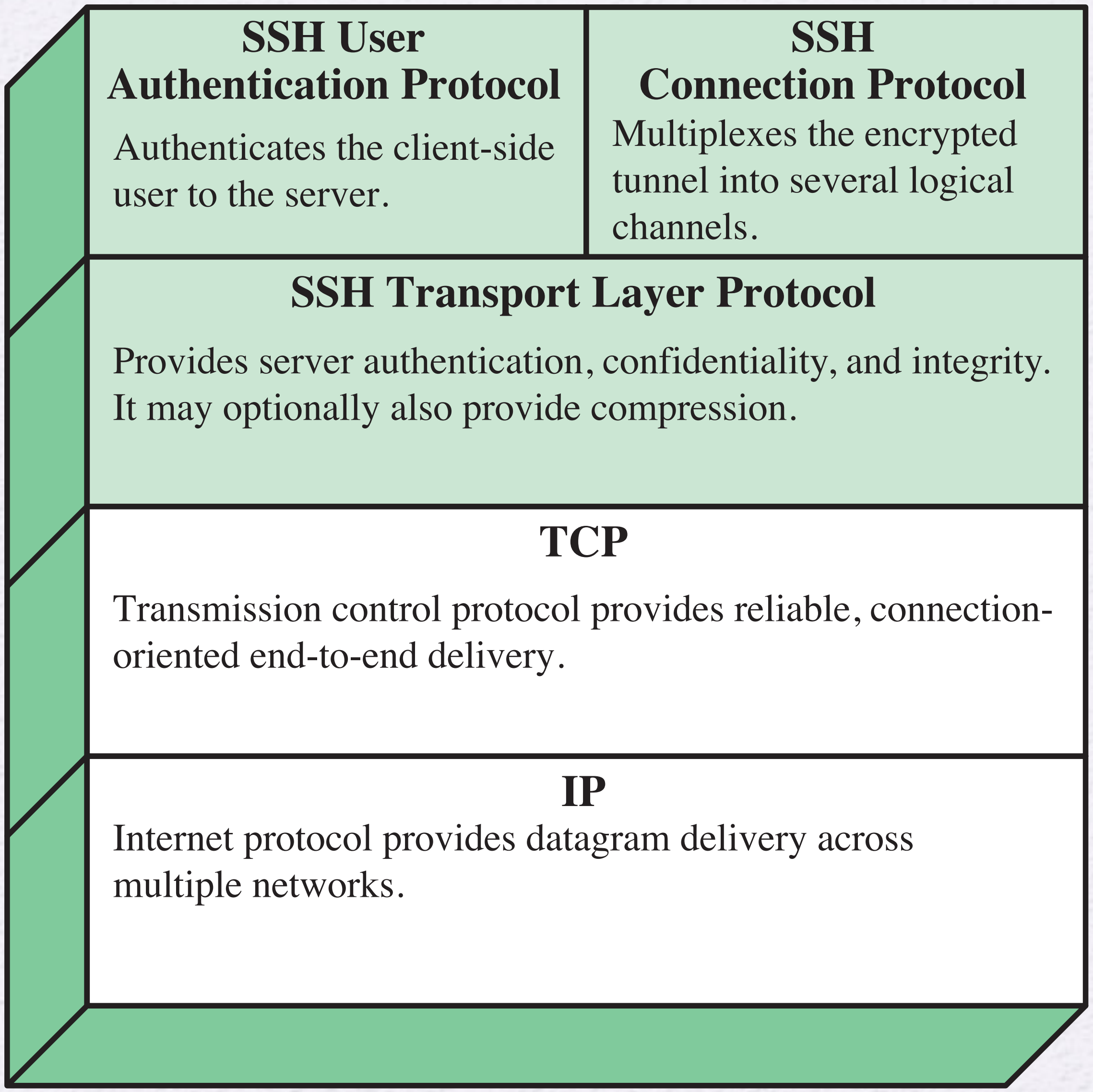

SSH User
Authentication Protocol
Authenticates the client-side user to the server.
SSH
Connection Protocol
Multiplexes the encrypted tunnel into several logical channels.
SSH Transport Layer Protocol
Provides server authentication, confidentiality, and integrity. It may optionally also provide compression.
TCP
Transmission control protocol provides reliable, connection-oriented end-to-end delivery.
IP
Internet protocol provides datagram delivery across multiple networks.

Figure 17.8 SSH Protocol Stack

Transport Layer Protocol

- Server authentication occurs at the transport layer, based on the server possessing a public/private key pair
- A server may have multiple host keys using multiple different asymmetric encryption algorithms
- Multiple hosts may share the same host key
- The server host key is used during key exchange to authenticate the identity of the host
- RFC 4251 dictates two alternative trust models:
    - The client has a local database that associates each host name with the corresponding public host key
    - The host name-to-key association is certified by a trusted certification authority (CA); the client only knows the CA root key and can verify the validity of all host keys certified by accepted CAs

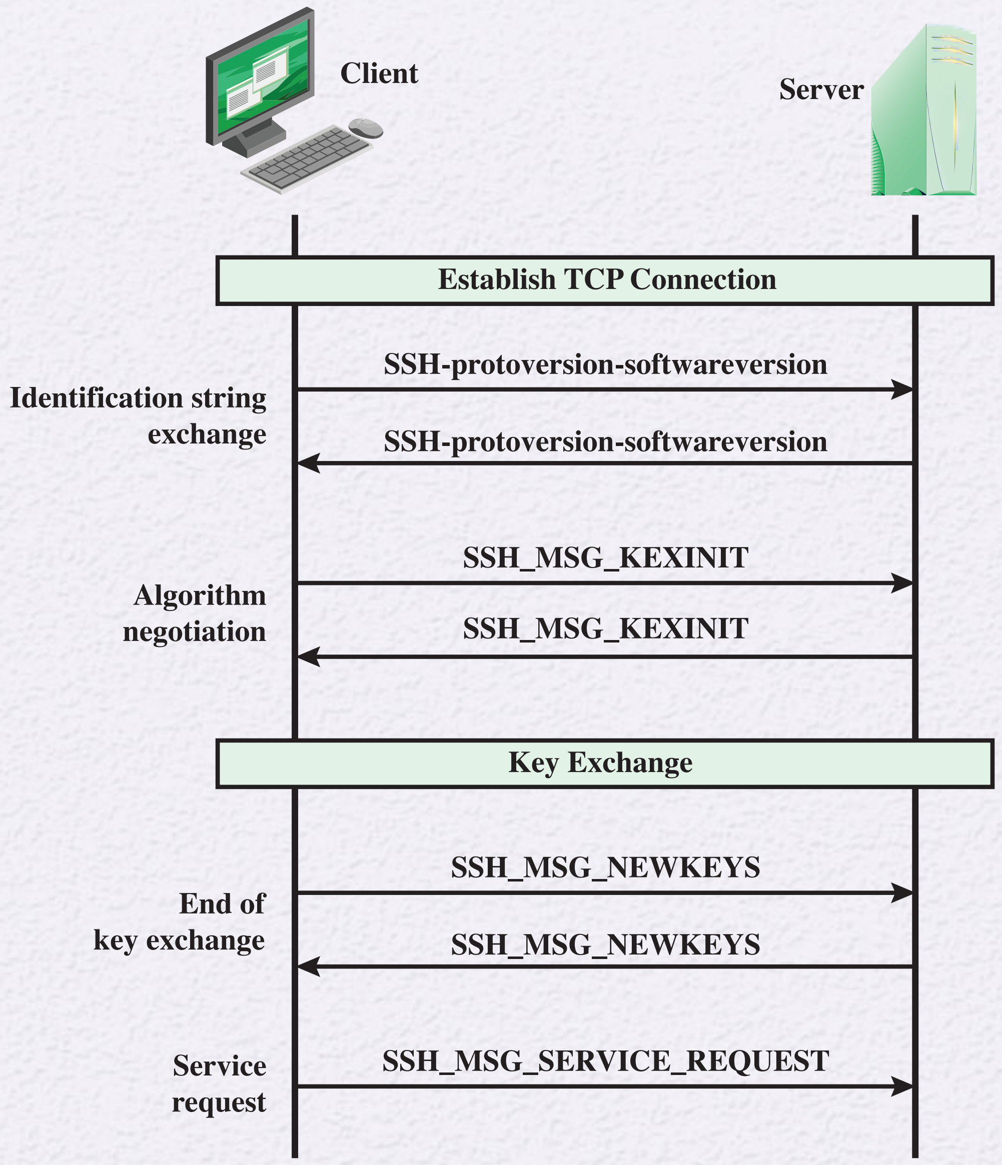
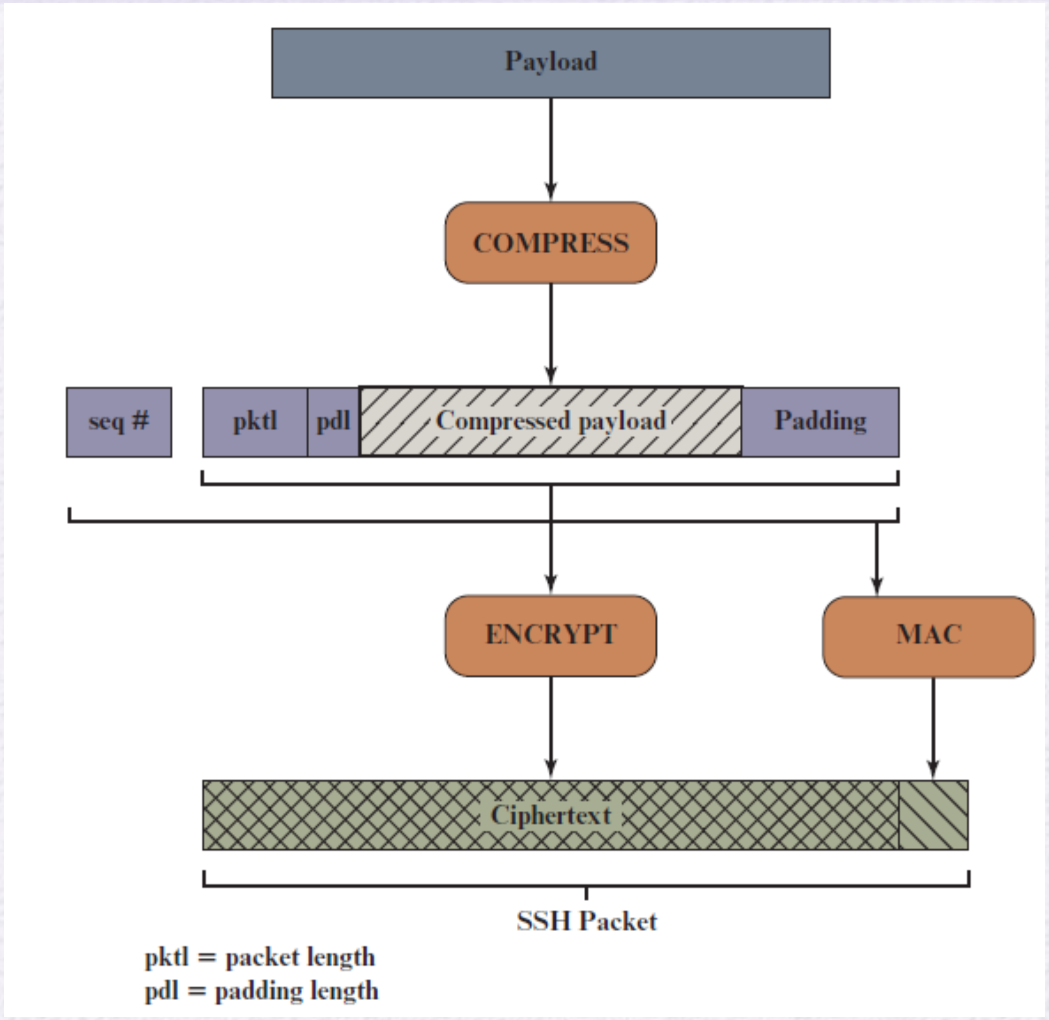
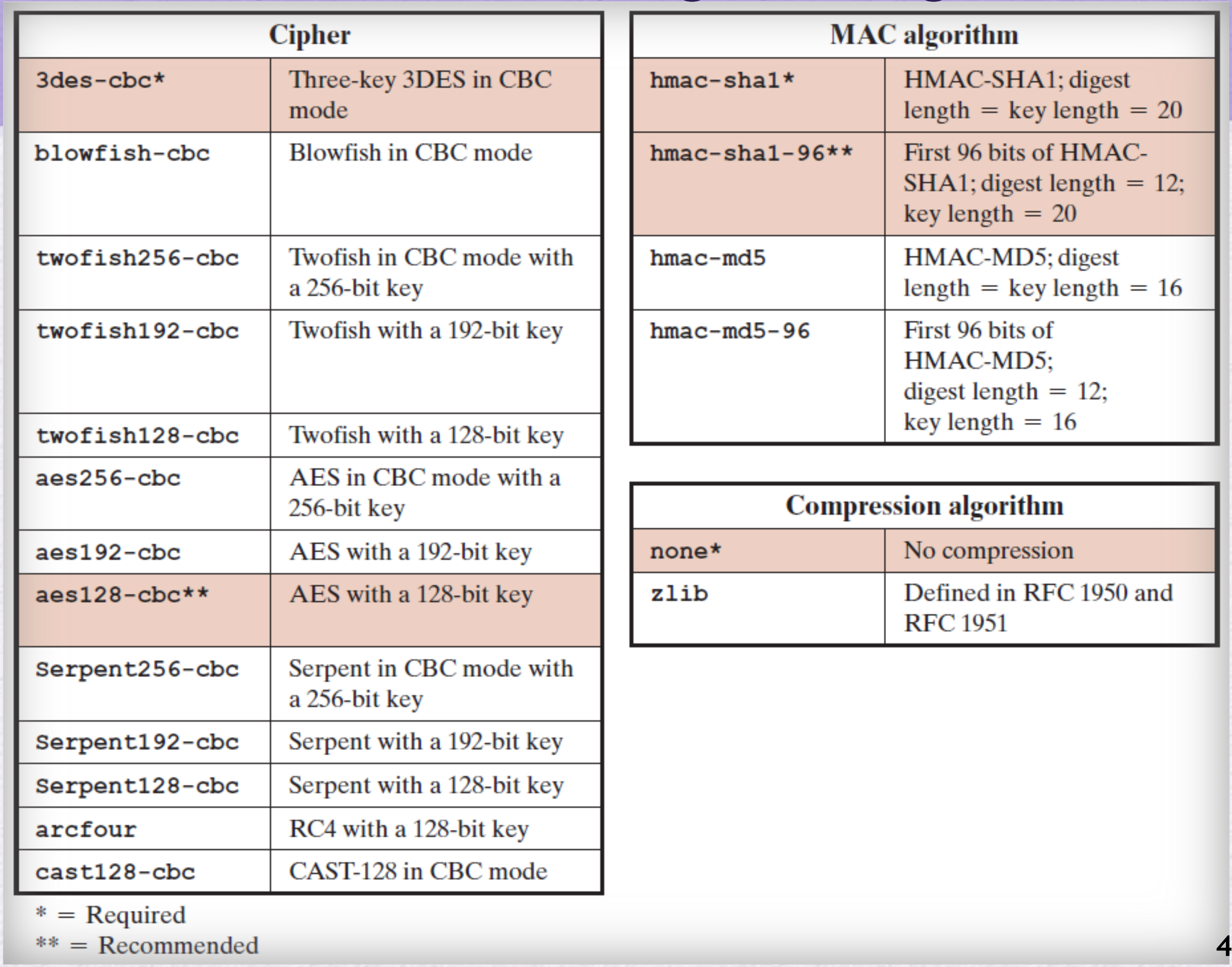


Figure 17.9 SSH Transport Layer Protocol Packet Exchanges

SSH Transport Layer Protocol Packet Formation



SSH Transport Layer Cryptographic Algorithms



Cipher	
3des-cbc*	Three-key 3DES in CBC mode
blowfish-cbc	Blowfish in CBC mode
twofish256-cbc	Twofish in CBC mode with a 256-bit key
twofish192-cbc	Twofish with a 192-bit key
twofish128-cbc	Twofish with a 128-bit key
aes256-cbc	AES in CBC mode with a 256-bit key
aes192-cbc	AES with a 192-bit key
aes128-cbc**	AES with a 128-bit key
Serpent256-cbc	Serpent in CBC mode with a 256-bit key
Serpent192-cbc	Serpent with a 192-bit key
Serpent128-cbc	Serpent with a 128-bit key
arcfour	RC4 with a 128-bit key
cast128-cbc	CAST-128 in CBC mode

MAC algorithm	
hmac-sha1*	HMAC-SHA1; digest length = key length = 20
hmac-sha1-96**	First 96 bits of HMAC-SHA1; digest length = 12; key length = 20
hmac-md5	HMAC-MD5; digest length = key length = 16
hmac-md5-96	First 96 bits of HMAC-MD5; digest length = 12; key length = 16

Compression algorithm	
none*	No compression
zlib	Defined in RFC 1950 and RFC 1951

* = Required
** = Recommended

Key Generation

- The keys used for encryption and MAC (and any needed IVs) are generated from the shared secret key *K*, the hash value from the key exchange *H*, and the session identifier, which is equal to *H* unless there has been a subsequent key exchange after the initial key exchange

User Authentication Protocol

- The User Authentication Protocol provides the means by which the client is authenticated to the server
- Three types of messages are always used in the User Authentication Protocol
- User name is the authorization identity the client is claiming, service name is the facility to which the client is requesting access, and method name is the authentication method being used in this request

Message Exchange

- The message exchange involves the following steps.
  - The client sends a SSH_MSG_USERAUTH_REQUEST with a requested method of none
  - The server checks to determine if the user name is valid. If not, the server returns SSH_MSG_USERAUTH_FAILURE with the partial success value of false. If the user name is valid, the server proceeds to step 3
  - The server returns SSH_MSG_USERAUTH_FAILURE with a list of one or more authentication methods to be used
  - The client selects one of the acceptable authentication methods and sends a SSH_MSG_USERAUTH_REQUEST with that method name and the required method-specific fields. At this point, there may be a sequence of exchanges to perform the method
  - If the authentication succeeds and more authentication methods are required, the server proceeds to step 3, using a partial success value of true. If the authentication fails, the server proceeds to step 3, using a partial success value of false
  - When all required authentication methods succeed, the server sends a SSH_MSG_USERAUTH_SUCCESS message, and the Authentication Protocol is over

Authentication Methods

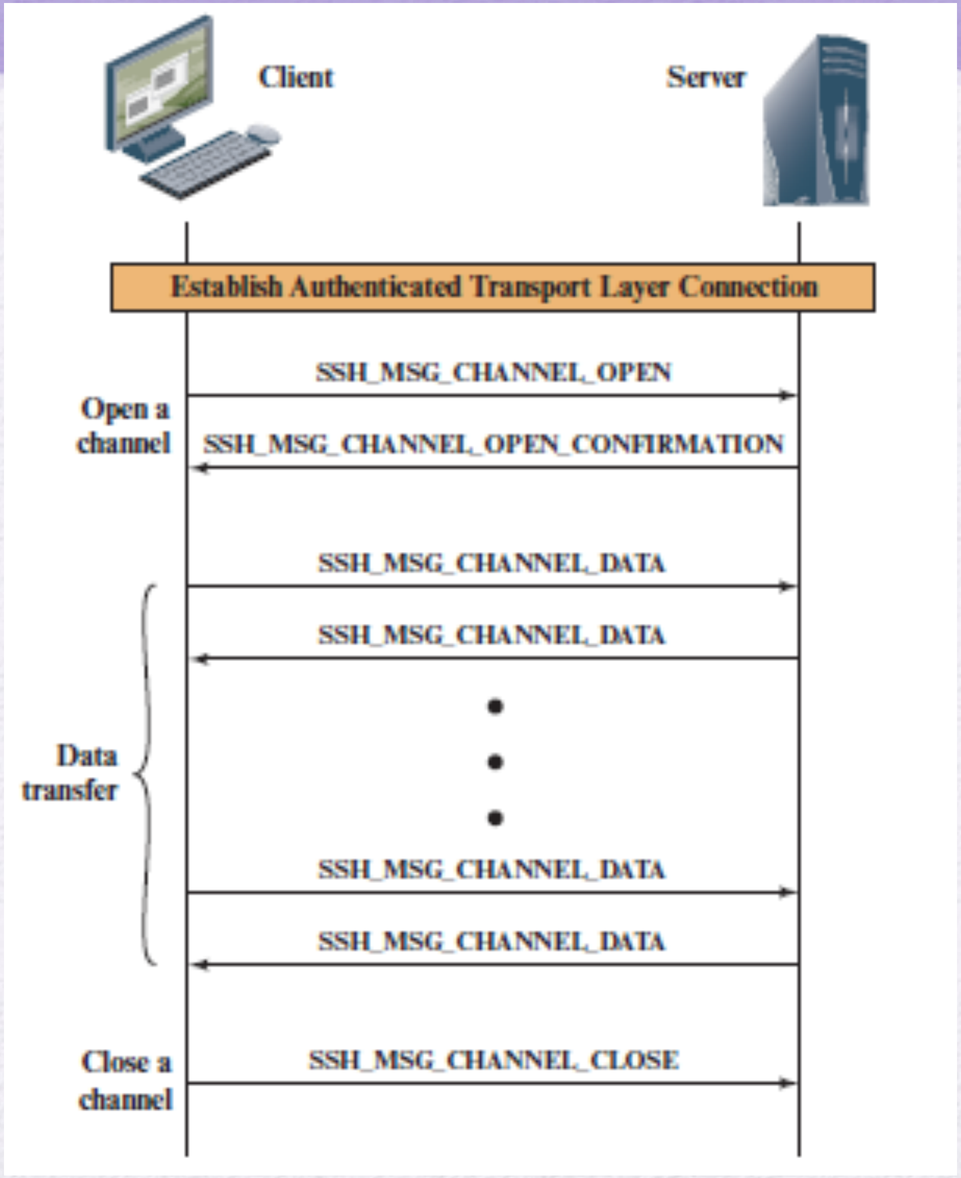
- Publickey
  - The client sends a message to the server that contains the client’s public key, with the message signed by the client’s private key
  - When the server receives this message, it checks whether the supplied key is acceptable for authentication and, if so, it checks whether the signature is correct
- Password
  - The client sends a message containing a plaintext password, which is protected by encryption by the Transport Layer Protocol
- Hostbased
  - Authentication is performed on the client’s host rather than the client itself
  - This method works by having the client send a signature created with the private key of the client host
  - Rather than directly verifying the user’s identity, the SSH server verifies the identity of the client host

Connection Protocol

- The SSH Connection Protocol runs on top of the SSH Transport Layer Protocol and assumes that a secure authentication connection is in use
  - The secure authentication connection, referred to as a *tunnel,* is used by the Connection Protocol to multiplex a number of logical channels

- Channel mechanism
  - All types of communication using SSH are supported using separate channels
  - Either side may open a channel
  - For each channel, each side associates a unique channel number
  - Channels are flow controlled using a window mechanism
  - No data may be sent to a channel until a message is received to indicate that window space is available
  - The life of a channel progresses through three stages: opening a channel, data transfer, and closing a channel

Example of SSH Connection Protocol Message Exchange



Channel Types

Four channel types are recognized in the SSH Connection Protocol specification

Session

- The remote execution of a program
- The program may be a shell, an application such as file transfer or e-mail, a system command, or some built-in subsystem
- Once a session channel is opened, subsequent requests are used to start the remote program

X11

- Refers to the X Window System, a computer software system and network protocol that provides a graphical user interface (GUI) for networked computers
- X allows applications to run on a network server but to be displayed on a desktop machine

Forwarded-tcpip

- Remote port forwarding

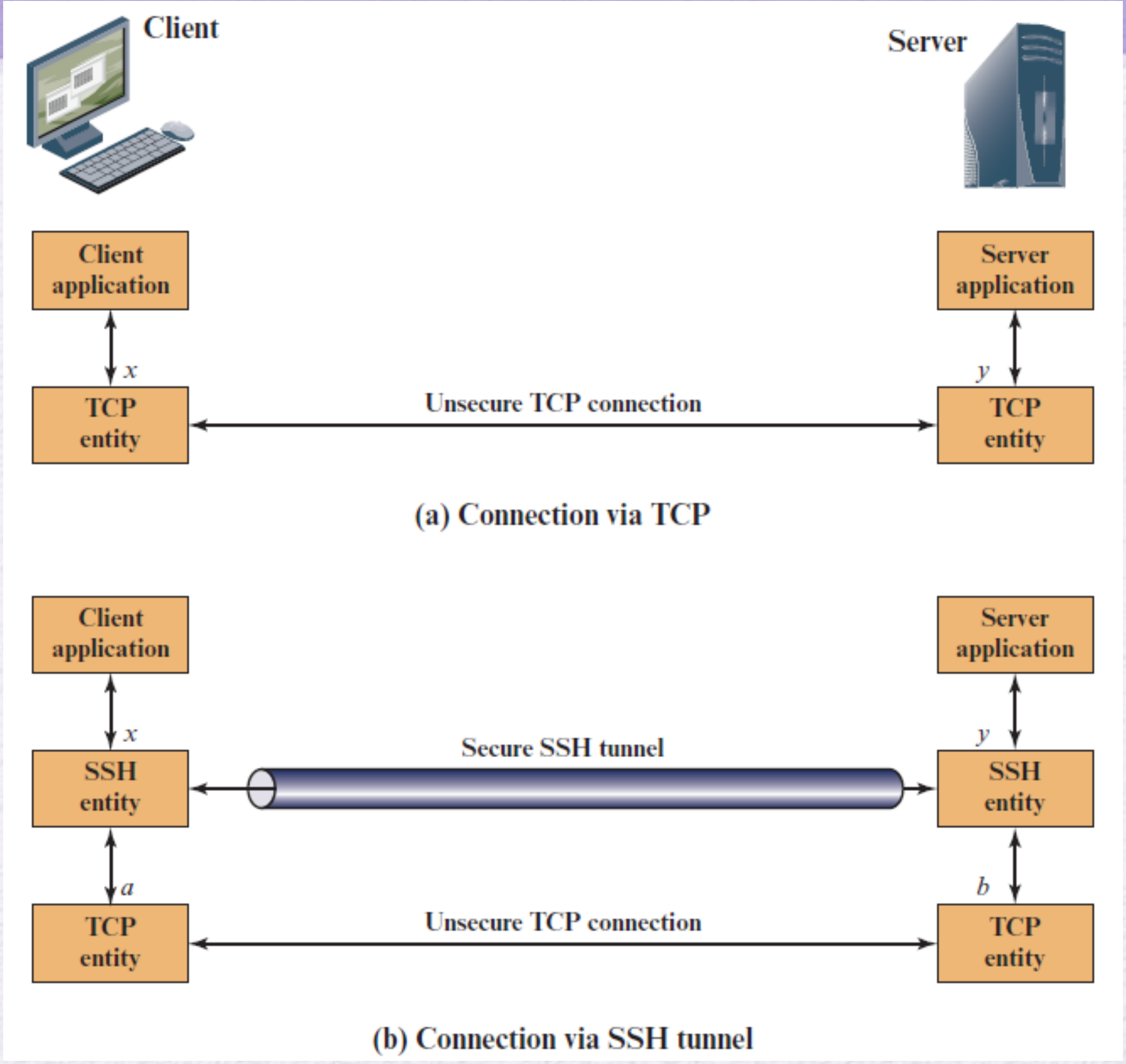
Direct-tcpip

- Local port forwarding

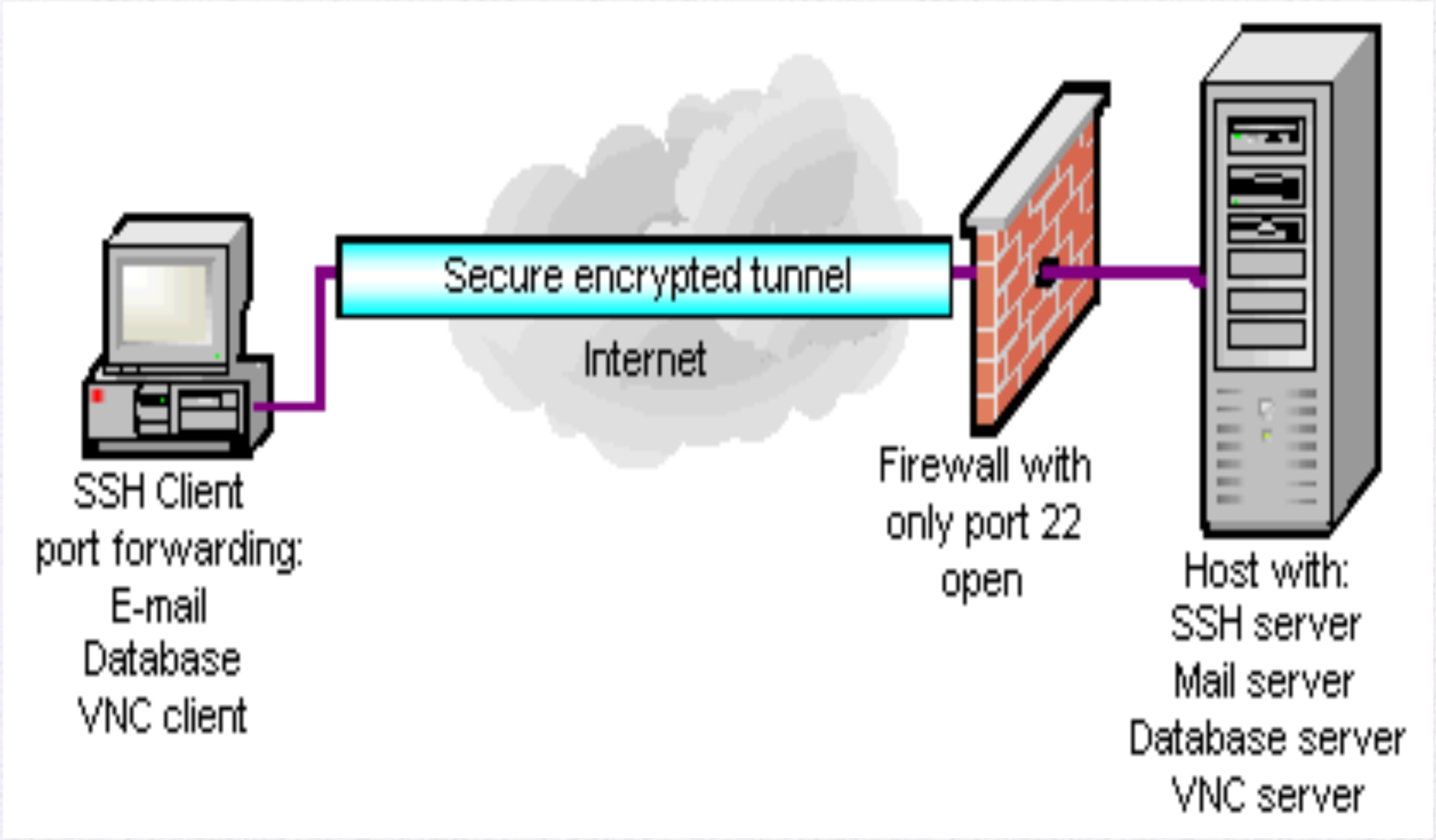
Port Forwarding

- One of the most useful features of SSH
- Provides the ability to convert any insecure TCP connection into a secure SSH connection (also referred to as SSH tunneling)
- Incoming TCP traffic is delivered to the appropriate application on the basis of the port number (a port is an identifier of a user of TCP)
- An application may employ multiple port numbers

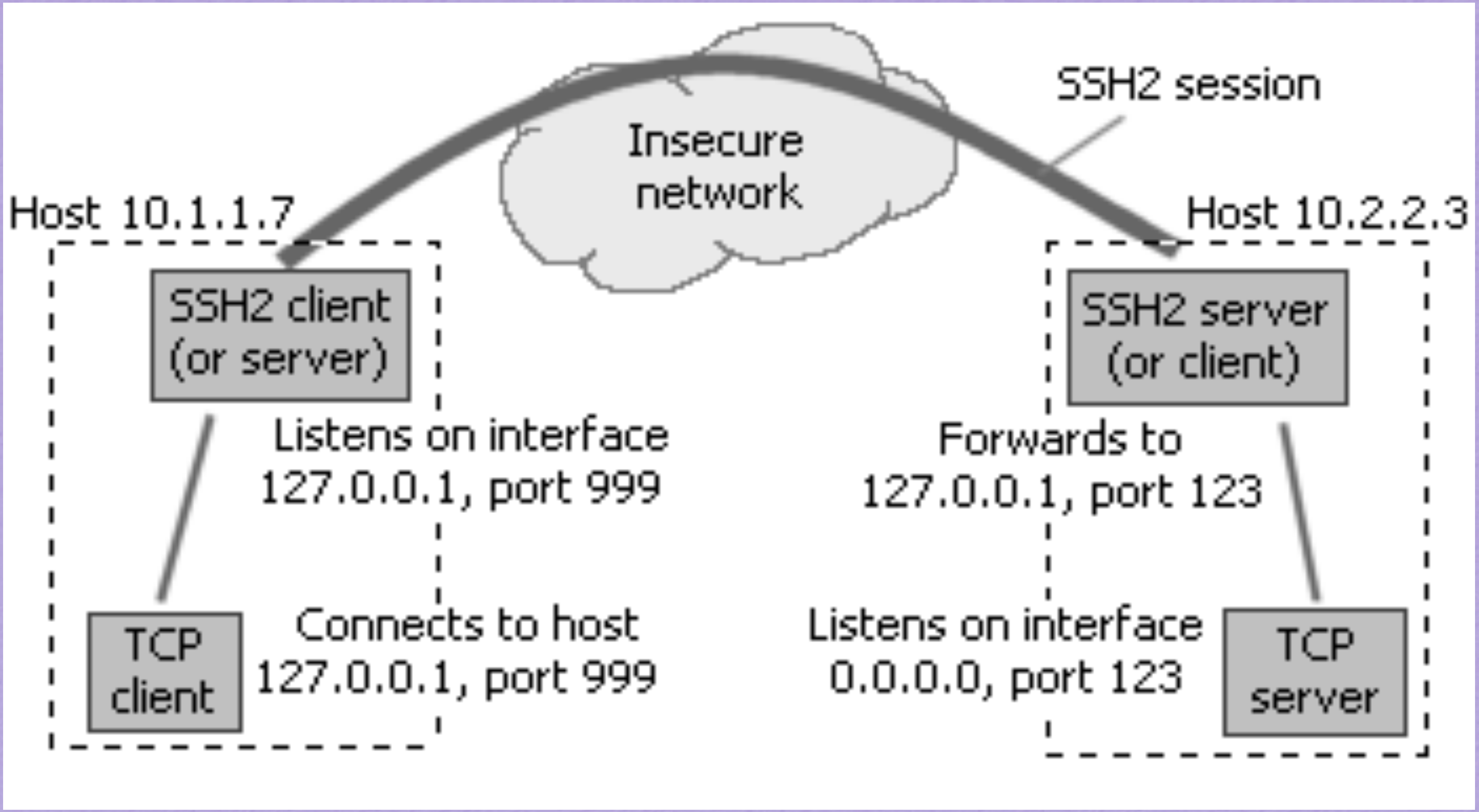
SSH Transport Layer Packet Exchanges



Port Forwarding



TCP/IP port forwarding details


SSH2 session
Insecure network
Host 10.1.1.7
Host 10.2.2.3
SSH2 client (or server)
SSH2 server (or client)
Listens on interface 127.0.0.1, port 999
Forwards to 127.0.0.1, port 123
TCP client
Connects to host 127.0.0.1, port 999
Listens on interface 0.0.0.0, port 123
TCP server

Picture copied from http://www.bitvise.com/port-forwarding.html

Secure File Transfer

- Secure File Transfer Protocol (SFTP) is a subsystem of the Secure Shell protocol.
- Separate protocol layered over the Secure Shell protocol to handle file transfers.

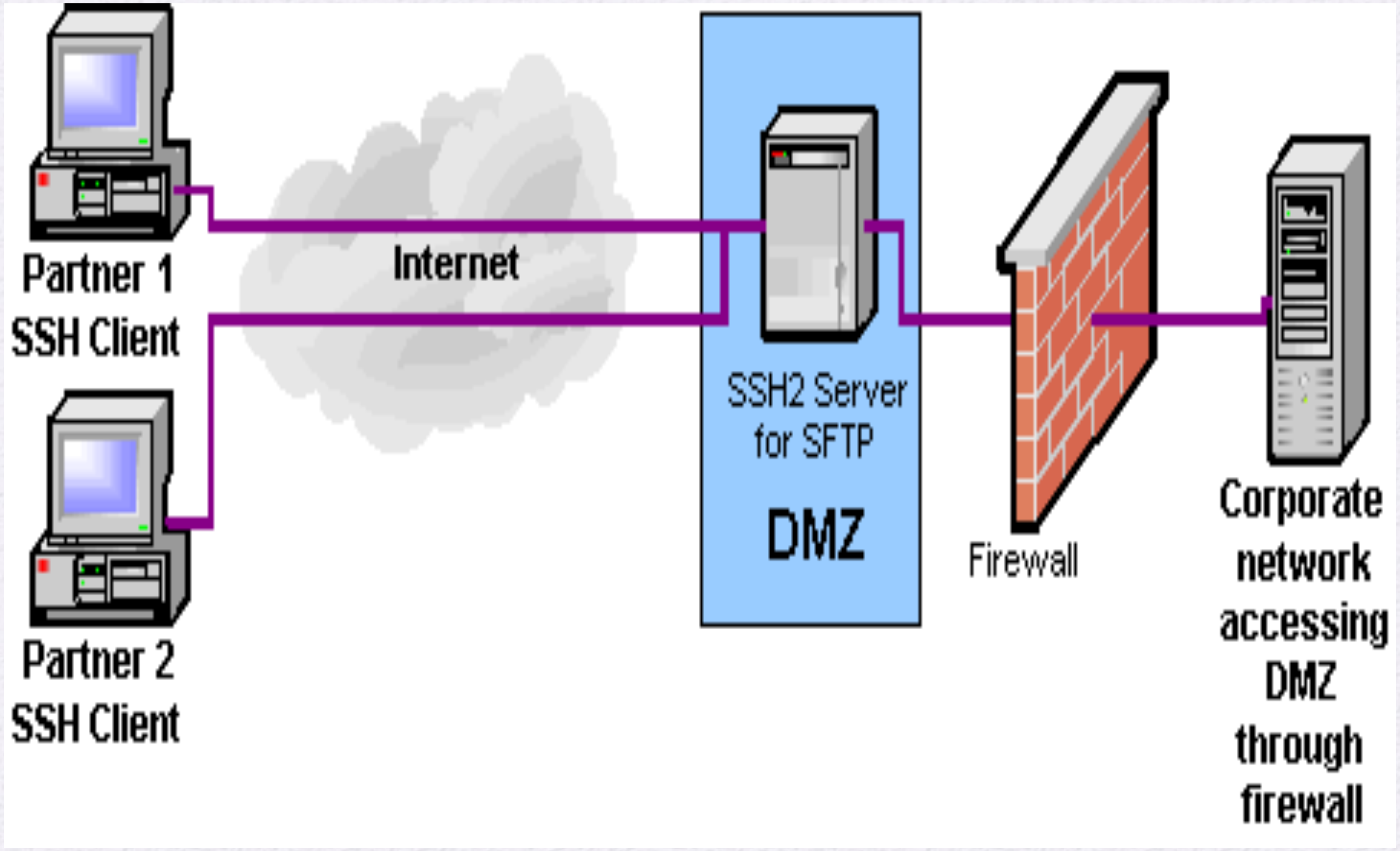
SFTP

- SFTP encrypts both the username/password and the data being transferred.
- Uses the same port as the Secure Shell server, eliminating the need to open another port on the firewall or router.
- Using SFTP also avoids the network address translation (NAT) issues that can often be a problem with regular FTP.

SFTP

- An ideal use of SFTP is to fortify a server or servers outside the firewall or router accessible by remote users and/or partners (sometimes referred to as a secure extranet or DMZ).

Fortified DMZ file server


Partner 1
SSH Client
Internet
Partner 2
SSH Client
SSH2 Server
for SFTP
DMZ
Firewall
Corporate
network
accessing
DMZ
through
firewall