Secure Sockets Layer (SSL) and Man-in-the-Middle Vulnerability

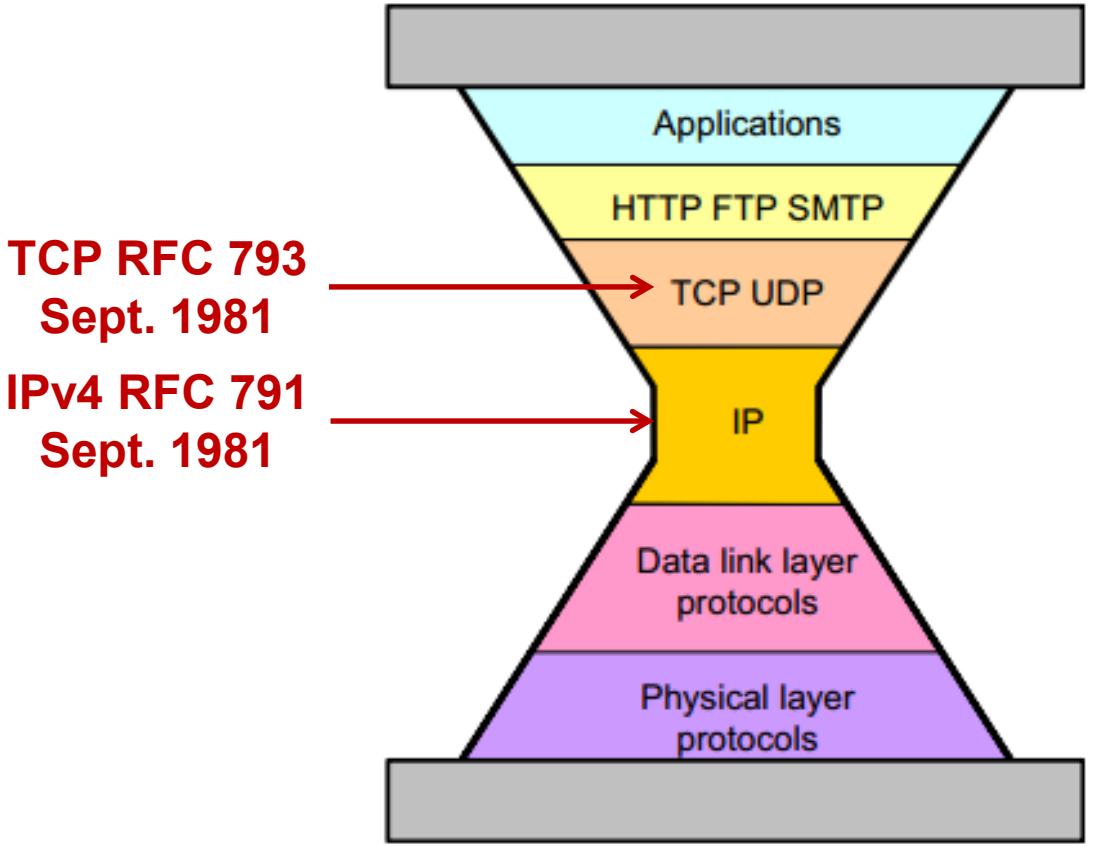
Prof. Ravi Sandhu
Executive Director and Endowed Chair

Lecture 5

ravi.utsa@gmail.com
www.profsandhu.com

Internet Security Protocols

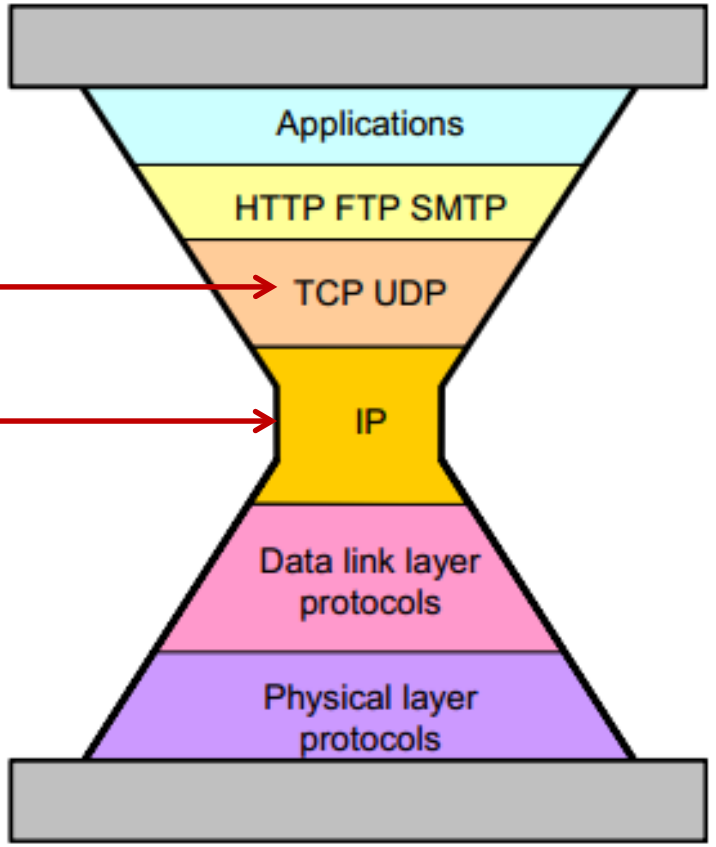
Internet Hourglass Model TCP/IP



Internet Security Protocols

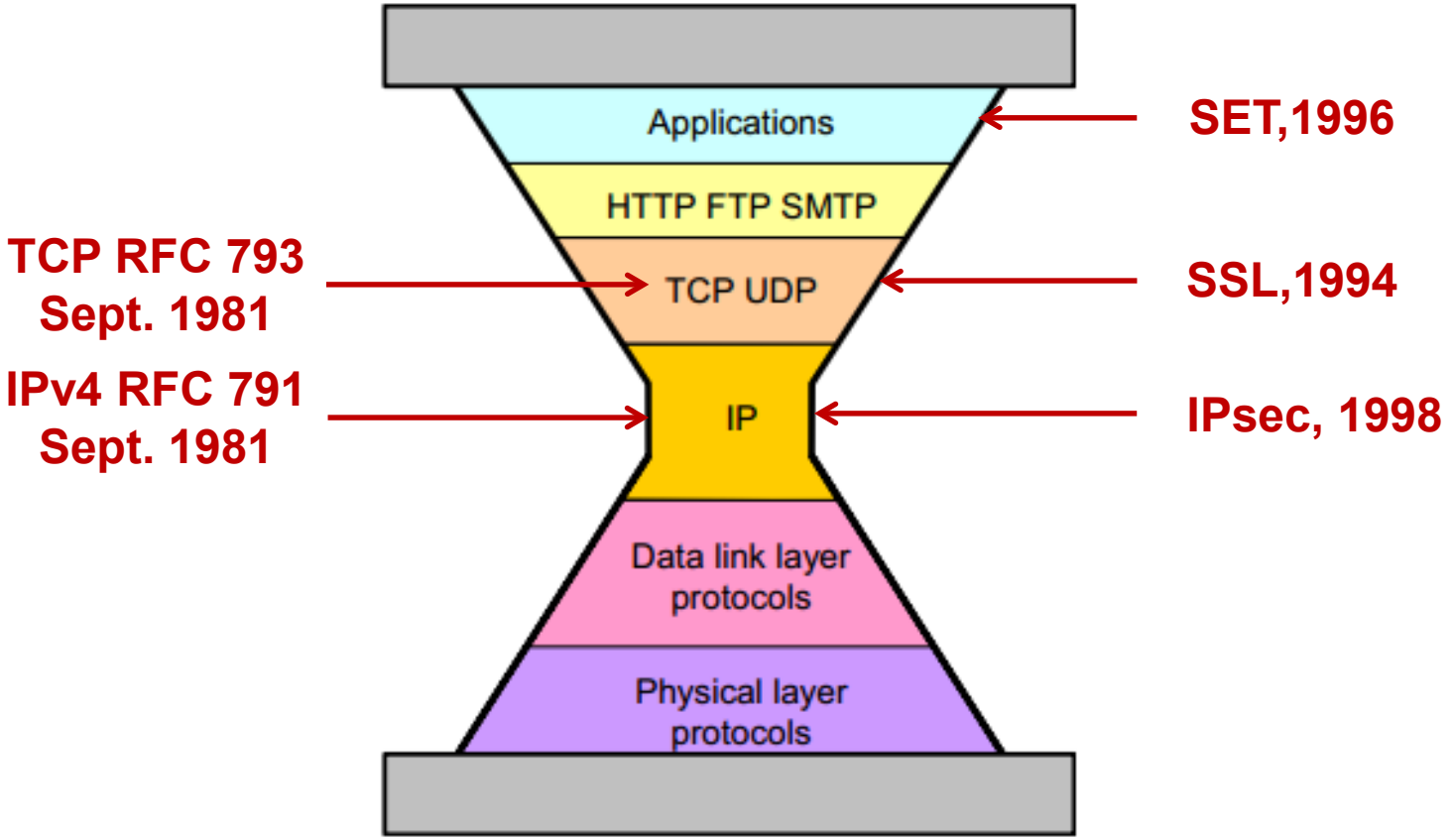
TCP RFC 793
Sept. 1981

IPv4 RFC 791
Sept. 1981



Where to inject security?

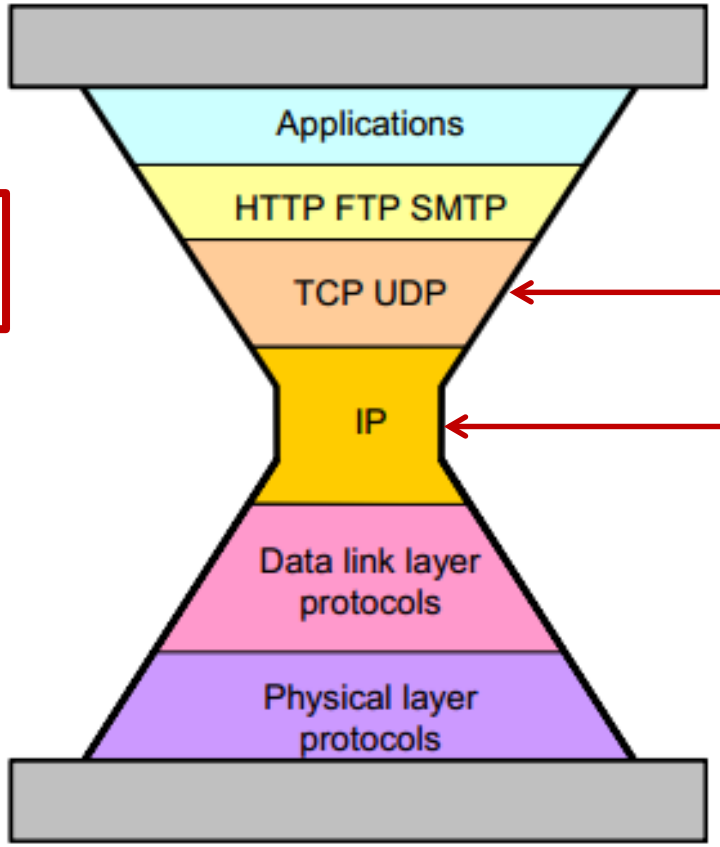
Internet Security Protocols



Internet Security Protocols

Dozens of other security protocols

Some successes
Many failures



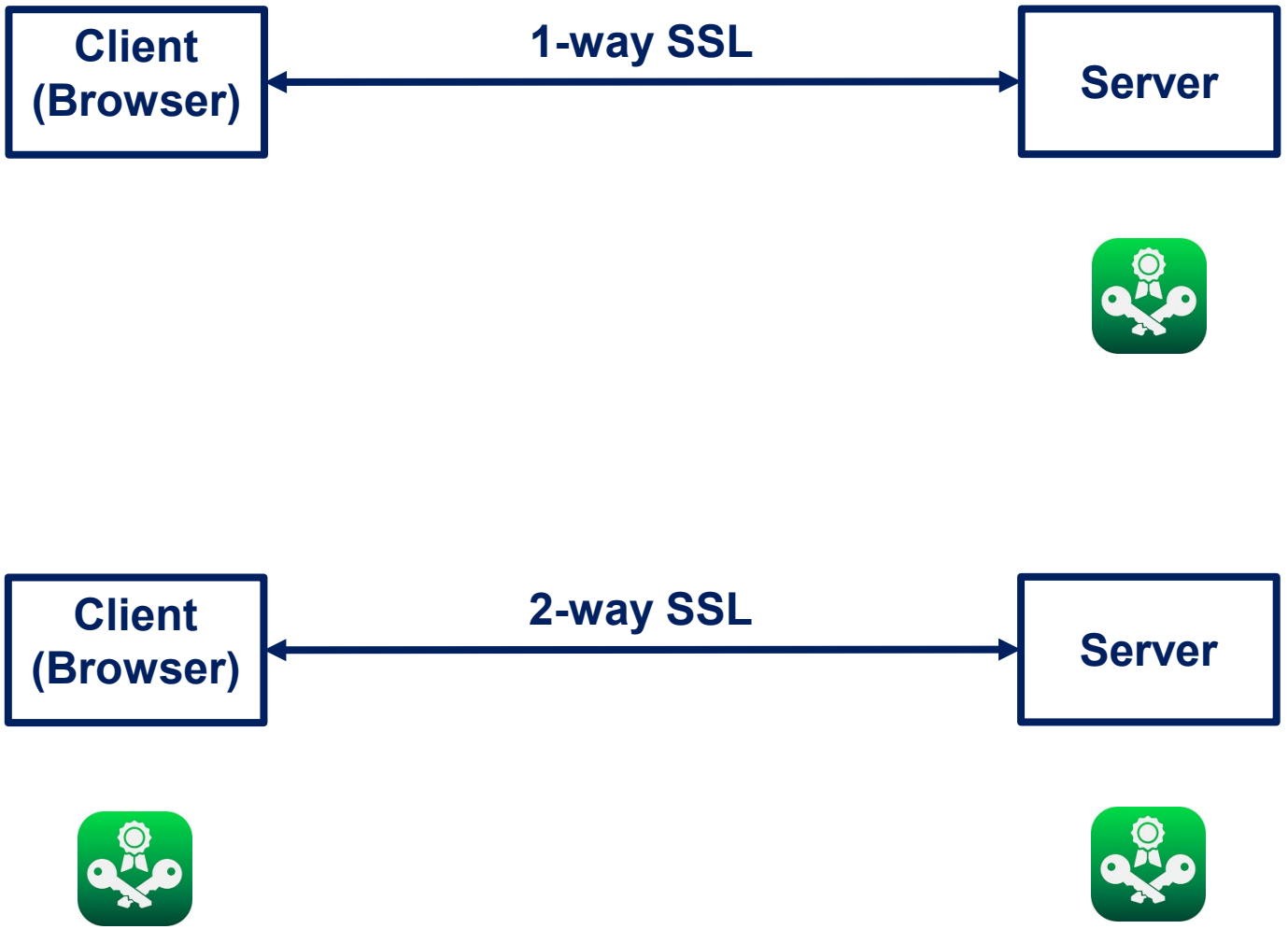
Half successful

SSL,1994

IPsec, 1998

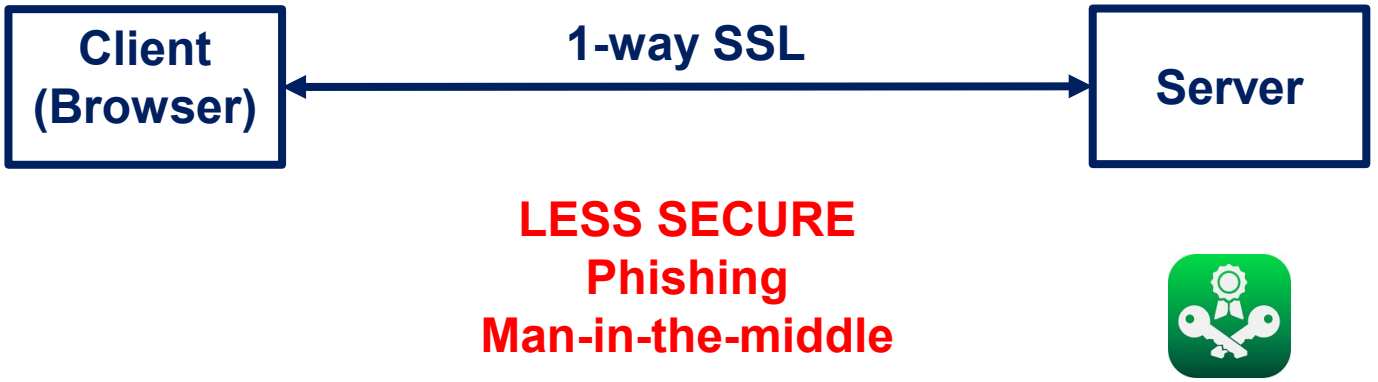
Largely failed

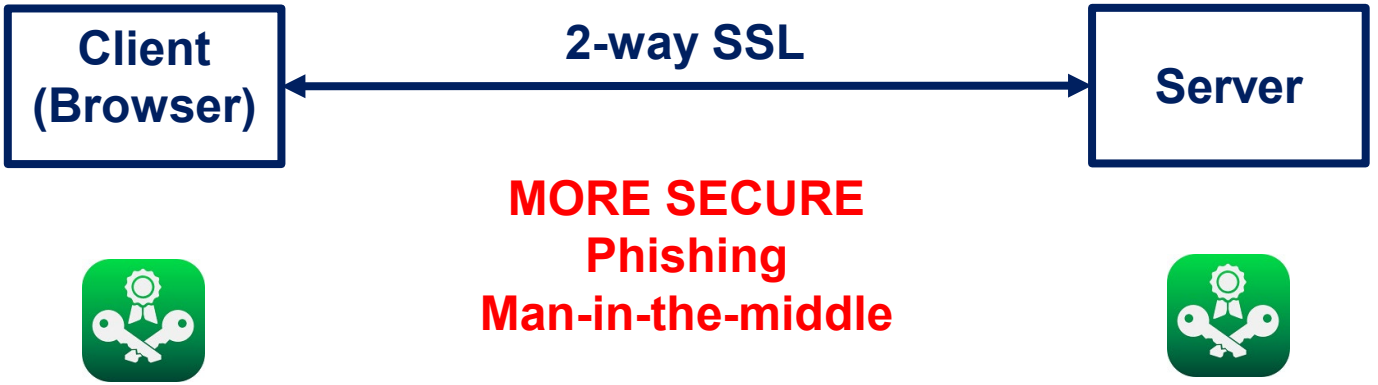
1-way vs 2-way SSL



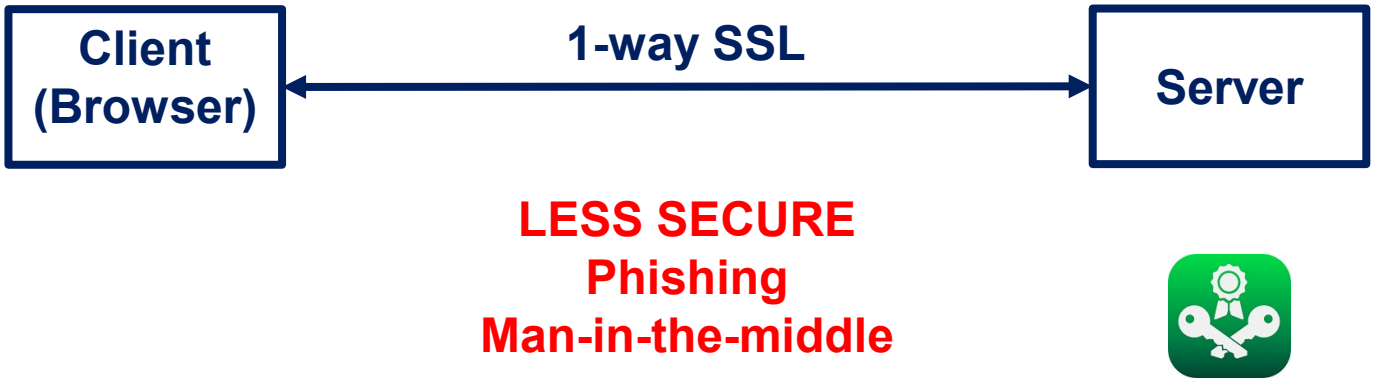
1-way vs 2-way SSL

1-way vs 2-way SSL



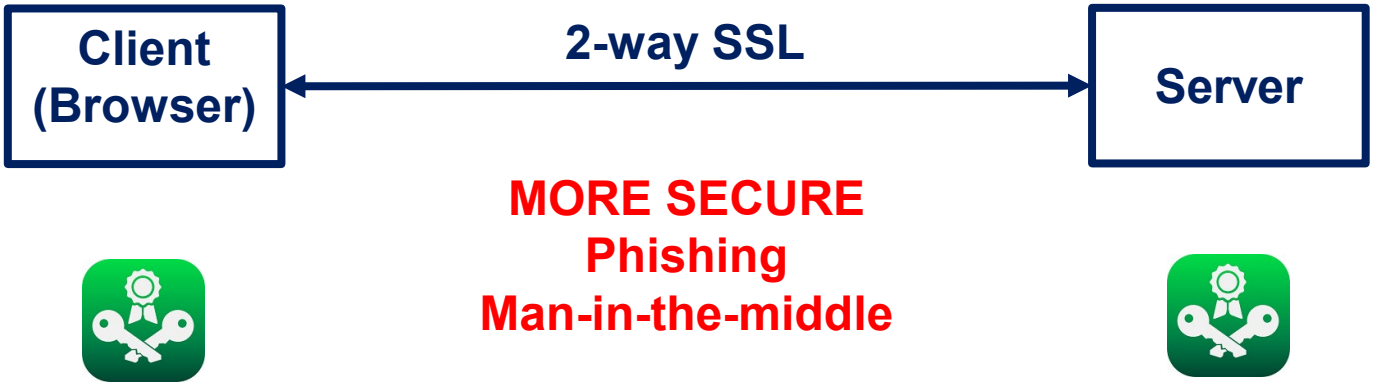


1-way vs 2-way SSL



LESS SECURE
Phishing
Man-in-the-middle

MASS DEPLOYMENT



MORE SECURE
Phishing
Man-in-the-middle

MINIMAL DEPLOYMENT

The SSL Lesson

- Client-less trumps client-full
- Start-ups (SSL) trump committees (IPSEC)

SSL Details

SSL

- layered on top of TCP
- SSL versions 1.0, 2.0, 3.0, 3.1
- Netscape protocol
- later refitted as IETF standard TLS (Transport Layer Security)
- TLS 1.0 very close to SSL 3.1

SSL

- application protocol independent
- does not specify how application protocols add security with SSL
  - how to initiate SSL handshaking
  - how to interpret certificates
- left to designers of upper layer protocols to figure out

SSL vs TCP Ports

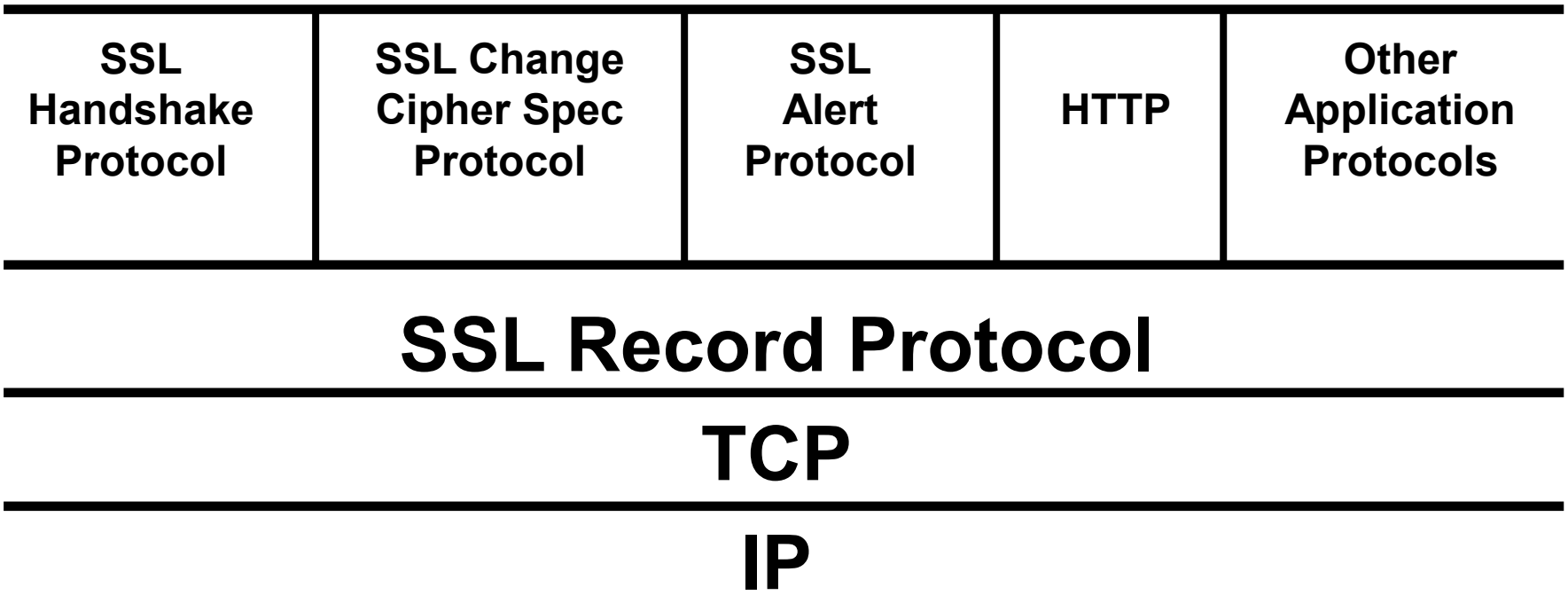
- https 443
- ssmtp 465
- snntp 563
- sldap 636
- spop3 995

- ftp-data 889
- ftps 990
- imaps 991
- telnets 992
- ircs 993

SSL Services

- peer entity authentication
- data confidentiality
- data authentication and integrity
- compression/decompression
- generation/distribution of session keys
  - integrated into protocol
- security parameter negotiation

SSL Architecture

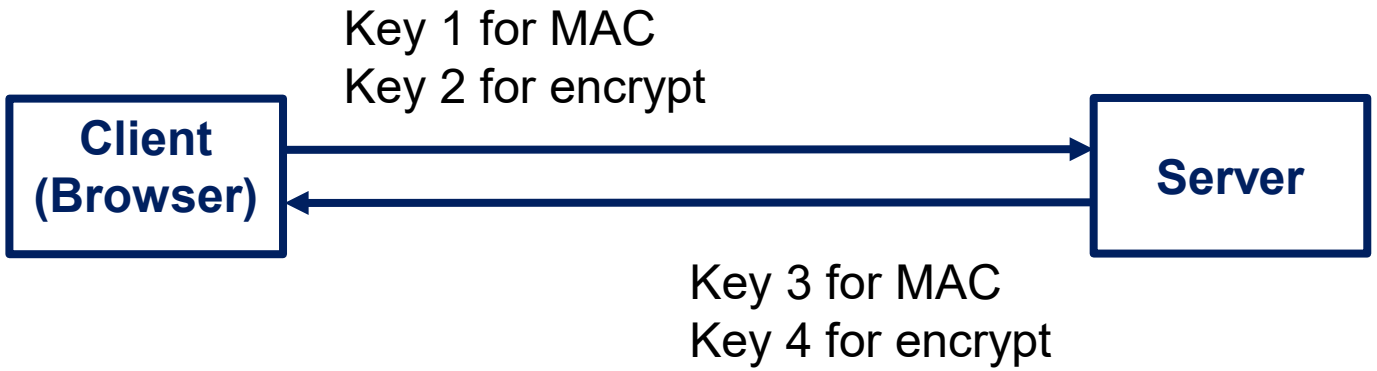


SSL Architecture

- Handshake protocol: complicated
  - embodies key exchange & authentication
  - runs in plaintext
  - 10 message types
- Change Cipher Spec protocol: straightforward
  - single 1 byte message with value 1
  - could be considered part of handshake protocol
  - transitions from plaintext to encrypted and mac'ed
- Record protocol: straightforward
  - fragment, compress, MAC, encrypt
  - uses 4 symmetric keys
- Alert protocol: straightforward
  - 2 byte messages
  - 1 byte alert level- fatal or warning; 1 byte alert code

SSL Record Protocol

- 4 symmetric keys



SSL Record Protocol

- 4 steps by sender (reversed by receiver)
  - Fragmentation
  - Compression
  - MAC
  - Encryption

SSL Record Protocol

- each SSL record contains
  - content type: 8 bits, only 4 defined
    - change_cipher_spec
    - alert
    - handshake
    - application_data
  - protocol version number: 8 bits major, 8 bits minor
  - length: max 16K bytes (actually 2^{14}+2048)
  - data payload: optionally compressed and encrypted
  - message authentication code (MAC)

SSL Handshake Protocol

- initially SSL session has null compression and cipher algorithms
- both are set by the handshake protocol at beginning of session
- handshake protocol may be repeated during the session

SSL Session

- SSL session negotiated by handshake protocol
  - session ID
    - chosen by server
  - X.509 public-key certificate of peer
    - possibly null
  - compression algorithm
  - cipher spec
    - encryption algorithm
    - message digest algorithm
  - master secret
    - 48 byte shared secret
  - is resumable flag
    - can be used to initiate new connections
    - each session is created with one connection, but additional connections within the session can be further created

SSL Connection State

- connection end: client or server
- client and server random: 32 bytes each
- keys generated from master secret, client/server random
  - client_write_MAC_secret server_write_MAC_secret
  - client_write_key server_write_key
  - client_write_IV server_write_IV
- compression state
- cipher state: initially IV, subsequently next feedback block
- sequence number: starts at 0, max $2^{64}-1$

SSL Connection State

- 4 parts to state
  - current read state
  - current write state
  - pending read state
  - pending write state
- handshake protocol
  - initially current state is empty
  - either pending state can be made current and reinitialized to empty

SSL Handshake Protocol

- Type: 1 byte
  - 10 message types defined
- length: 3 bytes
- content

SSL Handshake Protocol

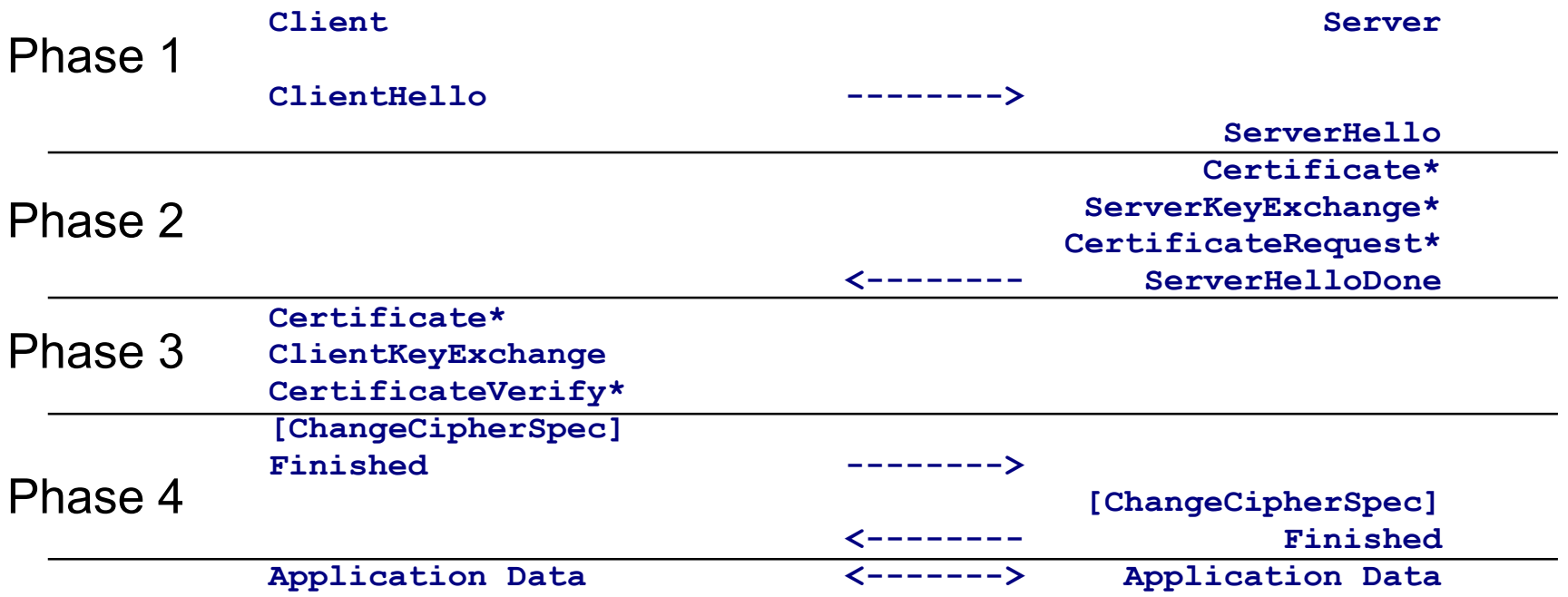


Fig. 1 - Message flow for a full handshake

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

SSL Handshake Protocol

- Phase 1:
  - Establish security capabilities
- Phase 2:
  - Server authentication and key exchange
- Phase 3:
  - Client authentication and key exchange
- Phase 4:
  - Finish

SSL Handshake Protocol

- these handshake messages must occur in order
- optional messages can be eliminated
- 10th message
  - hello_request
  - can be sent anytime from server to client to request client to start handshake protocol to renegotiate session
- change_cipher_spec is a separate 1 message protocol
  - functionally just like a message in the handshake protocol

SSL 1-Way Handshake with RSA

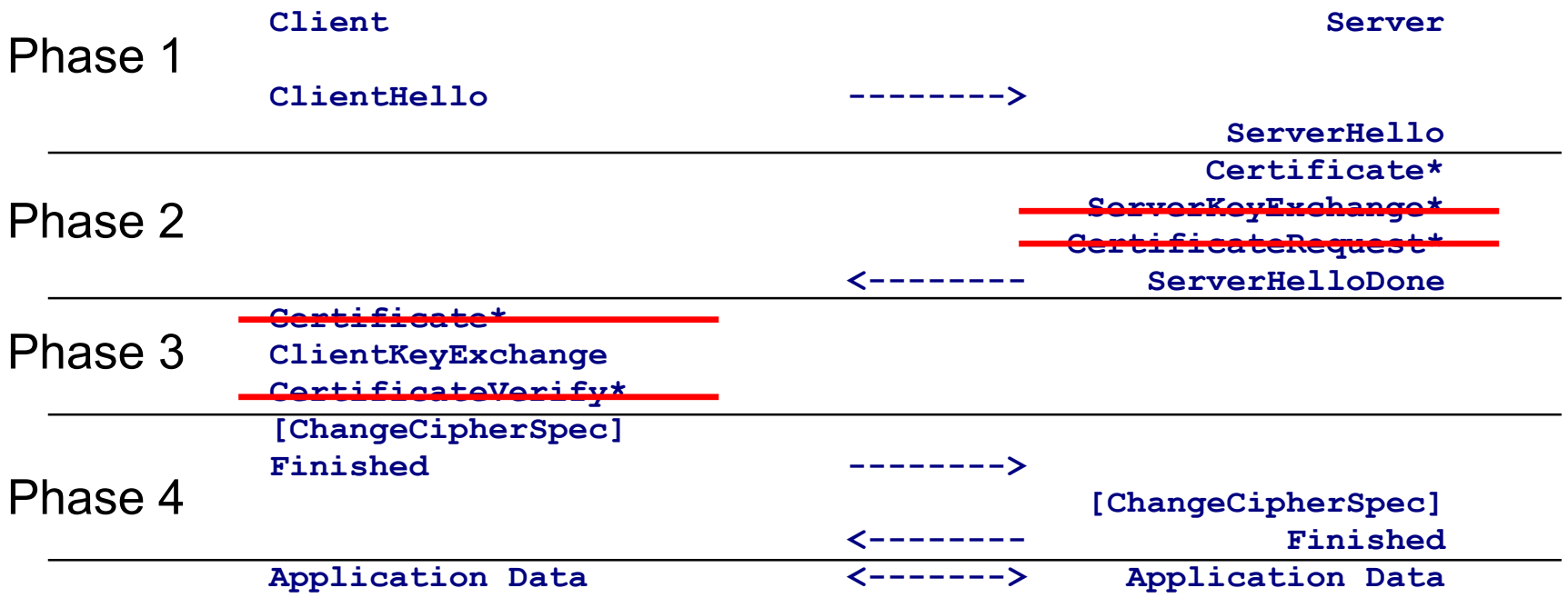


Fig. 1 - Message flow for a full handshake

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

SSL Handshake Phase 1

- Establish security capabilities
- client hello message
  - 4 byte timestamp, 28 byte random value
  - session ID:
    - non-zero for new connection on existing session
    - zero for new connection on new session
  - client version: highest version
  - cipher_suite list: ordered list
    - key exchange method, encryption method, MAC method
  - compression list: ordered list
- server hello message
  - 32 byte random value
  - session ID:
    - new or reuse
  - version
    - lower of client suggested and highest supported
  - cipher_suite list: single choice
  - compression list: single choice

SSL 1-Way Handshake with RSA

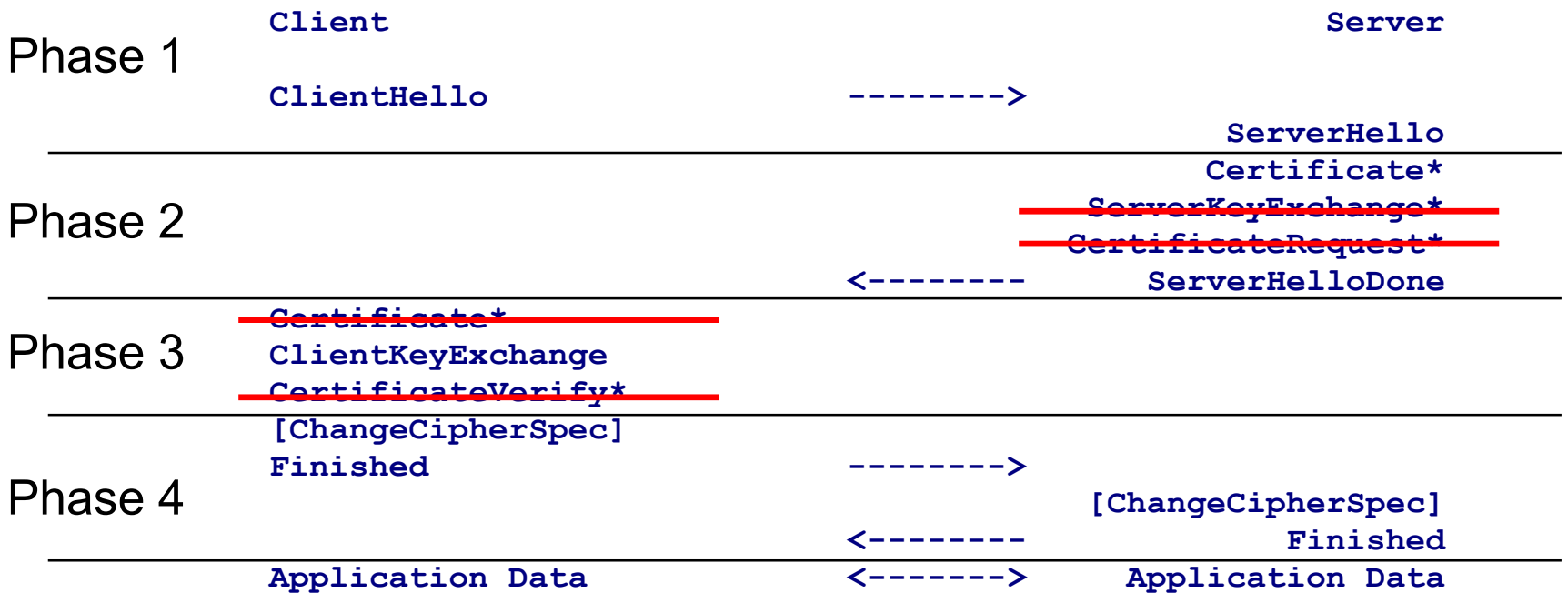


Fig. 1 - Message flow for a full handshake

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

SSL RSA 1-way Handshake Phase 2

- Server authentication and key exchange
- certificate message
  - server's X.509v3 certificate followed by optional chain of certificates
  - required for RSA
- server done message
  - ends phase 2, always required

SSL 1-Way Handshake with RSA

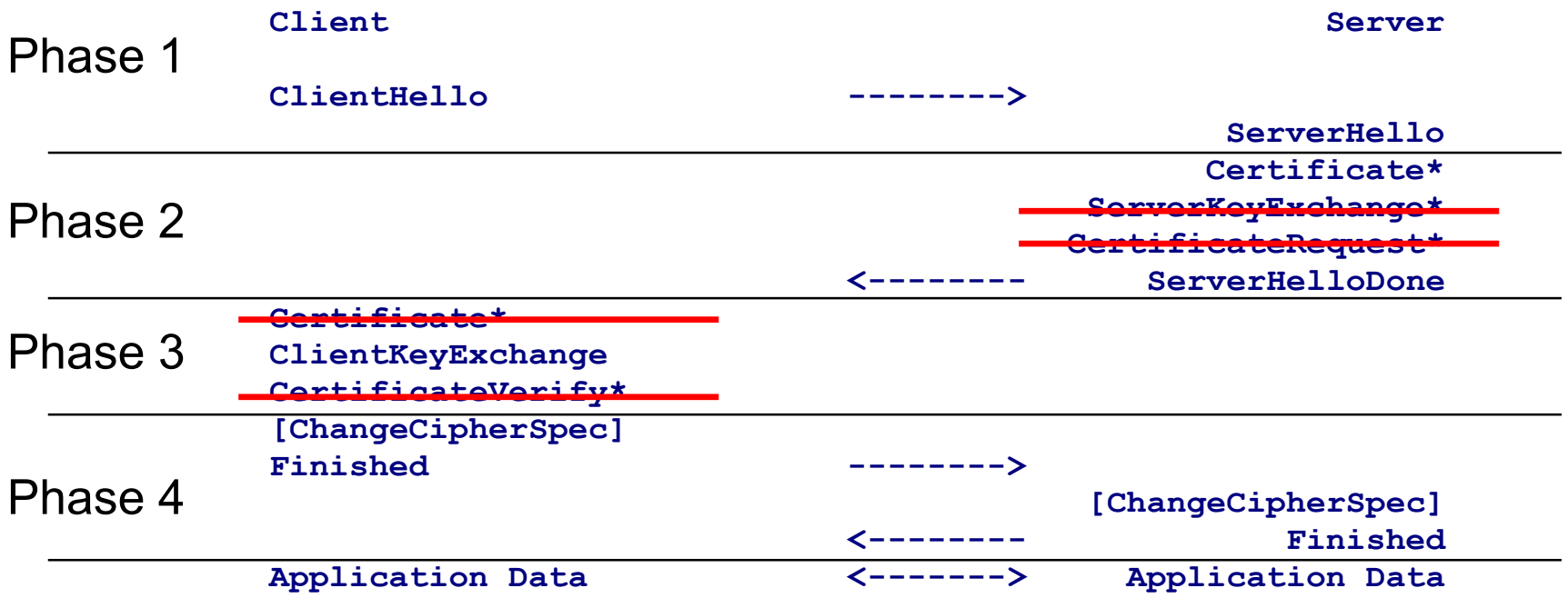
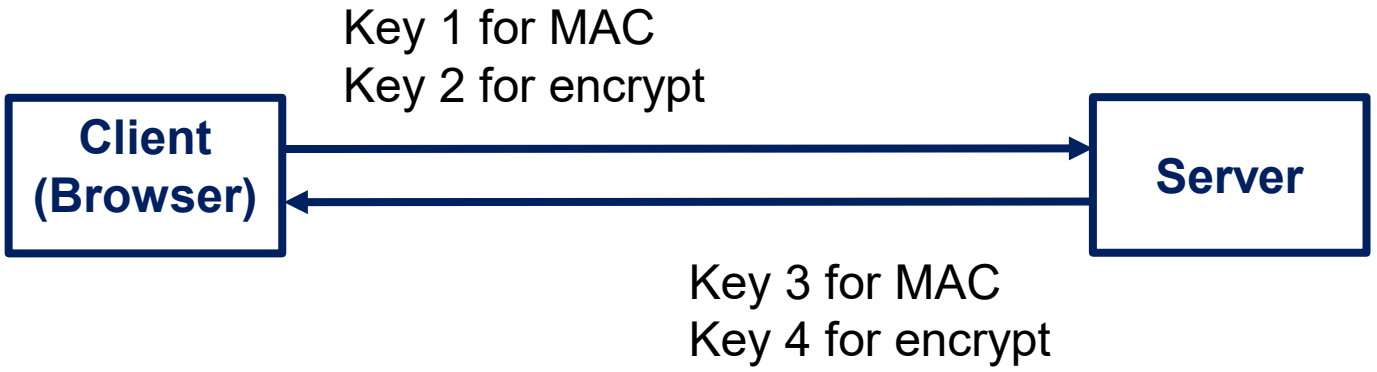


Fig. 1 - Message flow for a full handshake

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

SSL 1-way Handshake Phase 3

- Client authentication and key exchange
- client key exchange message
  - client generates 48-byte pre-master secret, encrypts with server's RSA public key
- client and server compute 48 byte master secret
  - using 48-byte pre-master secret, ClientHello.random, ServerHello.random
- client and server compute 4 symmetric keys from master secret



SSL 1-Way Handshake with RSA

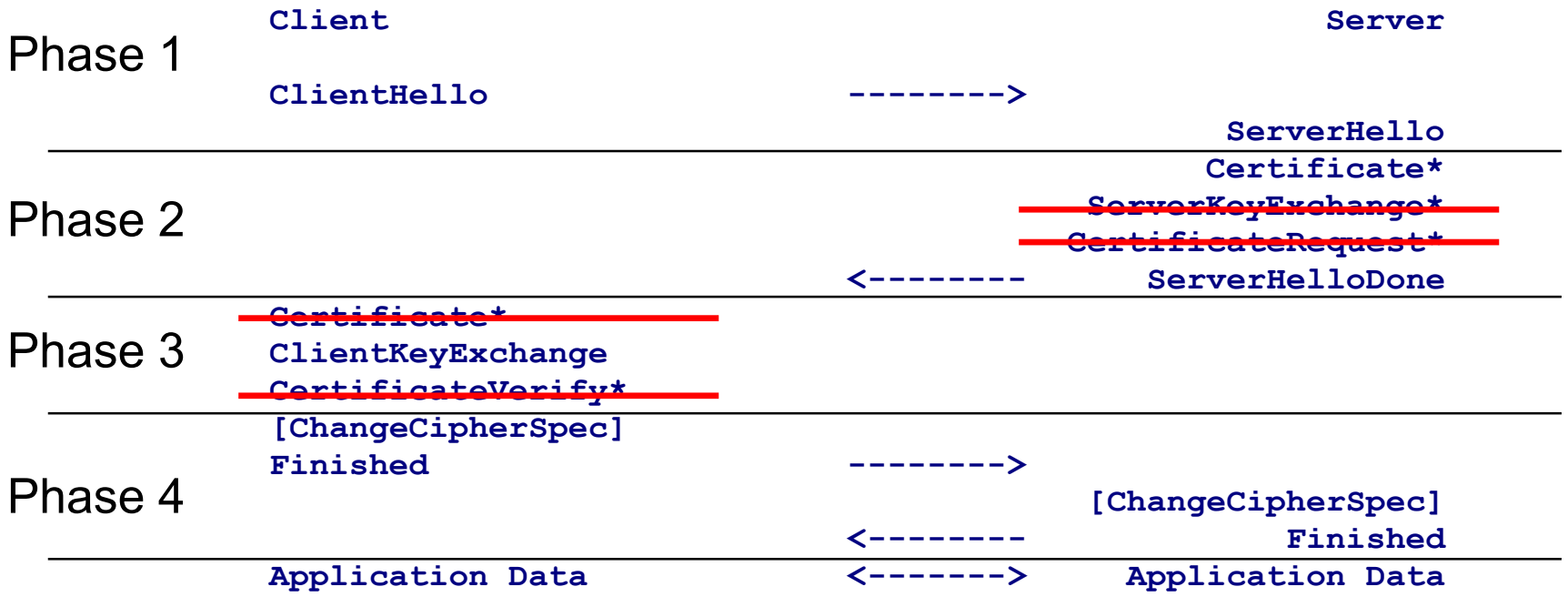


Fig. 1 - Message flow for a full handshake

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

SSL 1-way RSA Handshake Phase 4

- Finish and move to record protocol
- change cipher spec message
  - not considered part of handshake protocol but in some sense is part of it
  - 1 byte message protected by current state
  - copies pending state to current state
- Finished message
  - sent under new algorithms and keys
  - content is MAC of all previous messages with master secret and constant “client finished” or “server finished”

SSL 1-Way Handshake with RSA

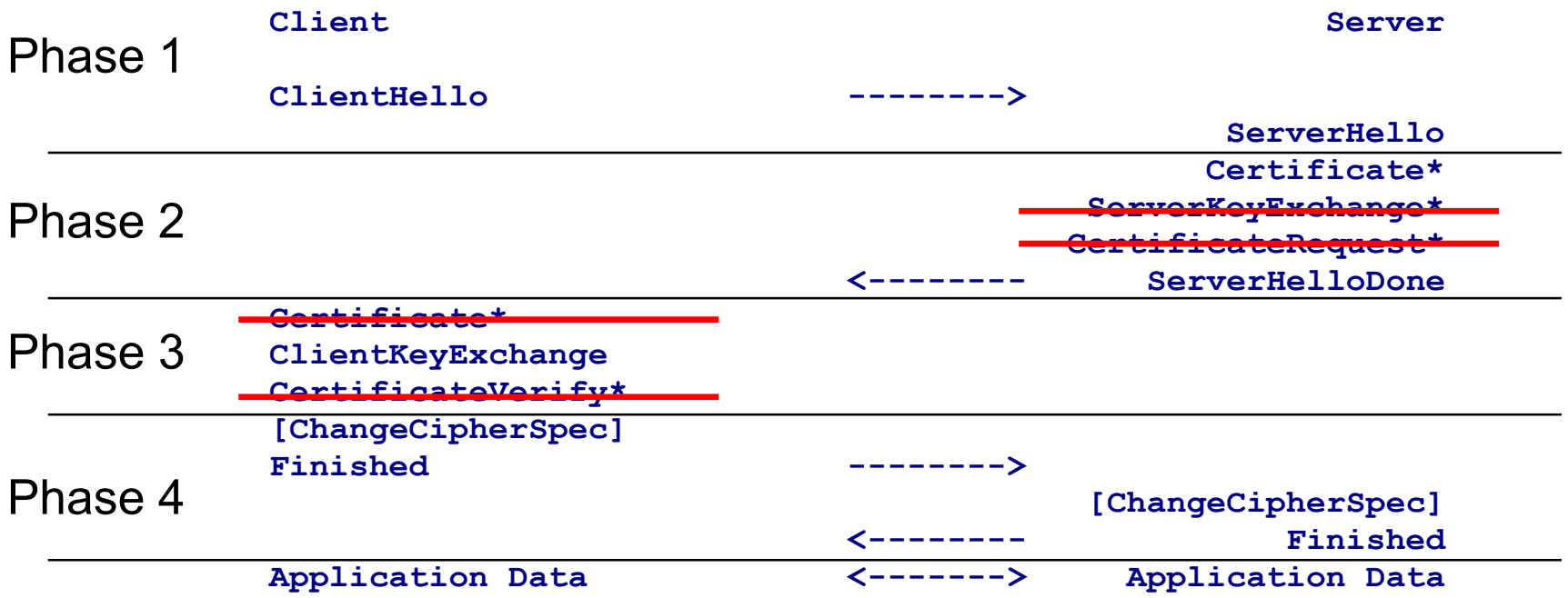


Fig. 1 - Message flow for a full handshake

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

SSL 2-Way Handshake with RSA

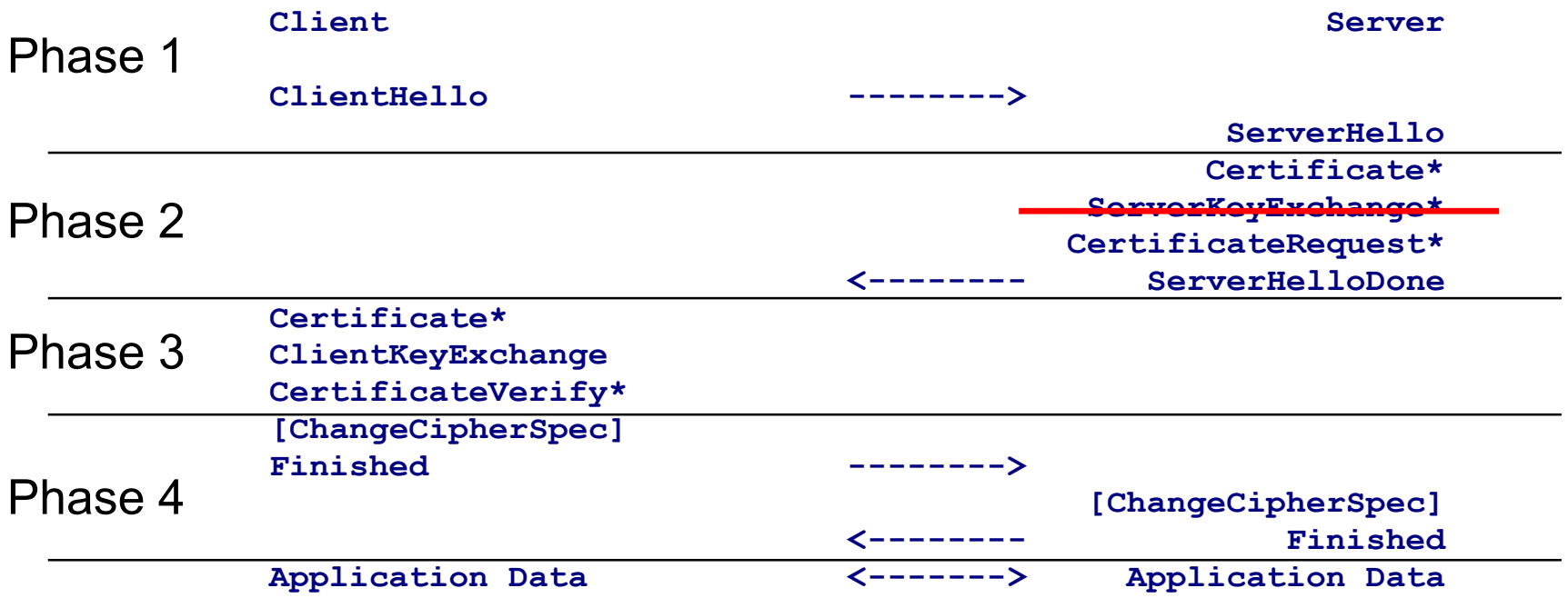


Fig. 1 - Message flow for a full handshake

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

SSL RSA 2-way Handshake Phase 2

- Server authentication and key exchange
- certificate message
  - server's X.509v3 certificate followed by optional chain of certificates
  - required for RSA
- certificate request message
  - request a certificate from client
  - specifies Certificate Type and Certificate Authorities
- server done message
  - ends phase 2, always required

SSL 2-way Handshake Phase 3

- Client authentication and key exchange
- certificate message
  - client's X.509v3 certificate followed by optional chain of certificates
- client key exchange message
  - client generates 48-byte pre-master secret, encrypts with server's RSA public key
- certificate verify message
  - signs hash of master secret (established by key exchange) and all handshake messages so far

- client and server compute 48 byte master secret
  - using 48-byte pre-master secret, ClientHello.random, ServerHello.random
- client and server compute 4 symmetric keys from master secret

SSL Alert Protocol

- 2 byte alert messages
  - 1 byte level
    - fatal or warning
  - 1 byte
    - alert code

SSL Alert Messages

Warning or fatal

```
close_notify(0),
unexpected_message(10),
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),
export_restriction(60),
protocol_version(70),
insufficient_security(71),
internal_error(80),
user_canceled(90),
no_renegotiation(100),
```

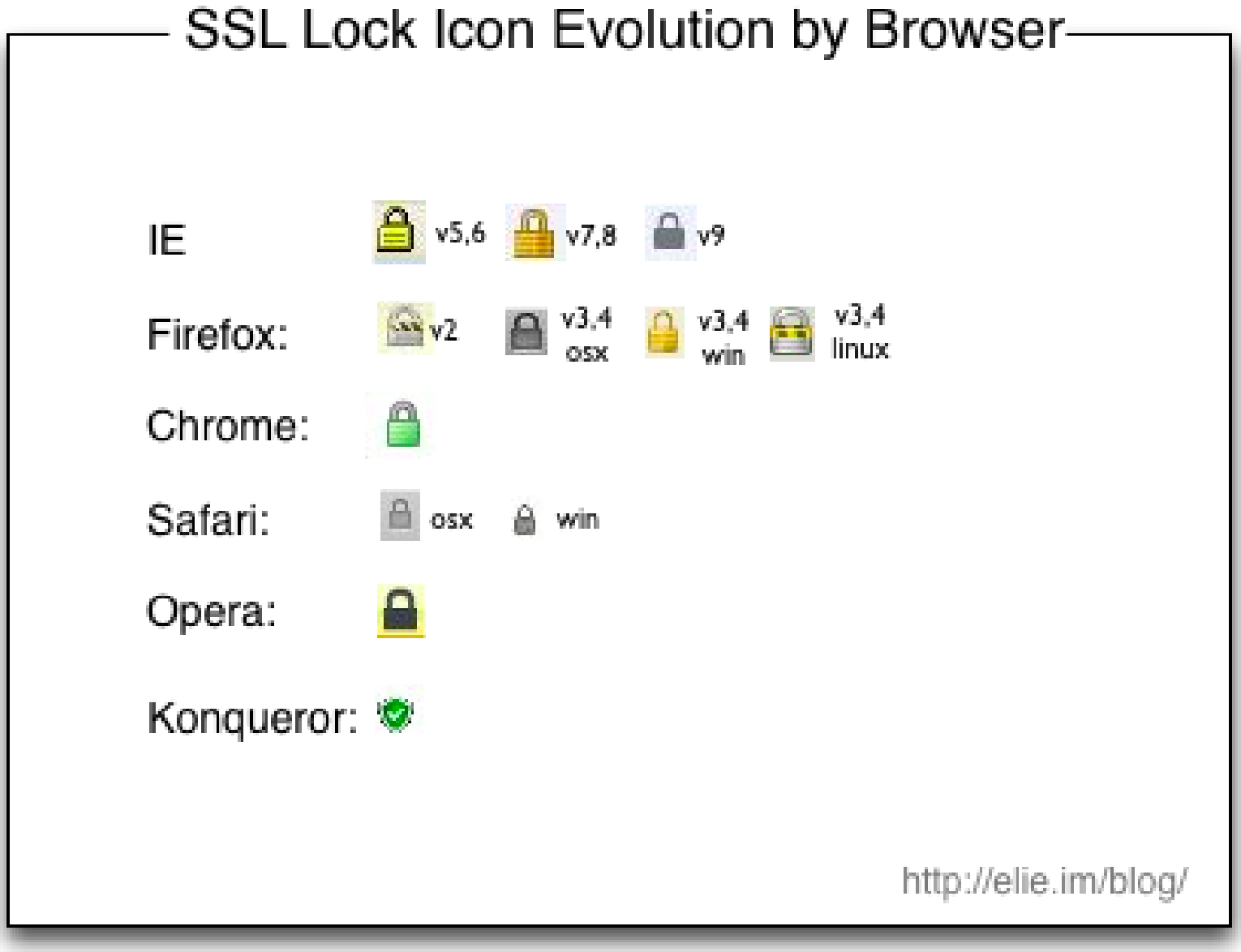
SSL Alert Messages

- always fatal
  - unexpected_message
  - bad_record_mac
  - decompression_failure
  - handshake_failure
  - illegal_parameter

SSL Man-in-the-Middle (MITM) Attack

1-way SSL MITM

SSL Lock Icon Evolution by Browser



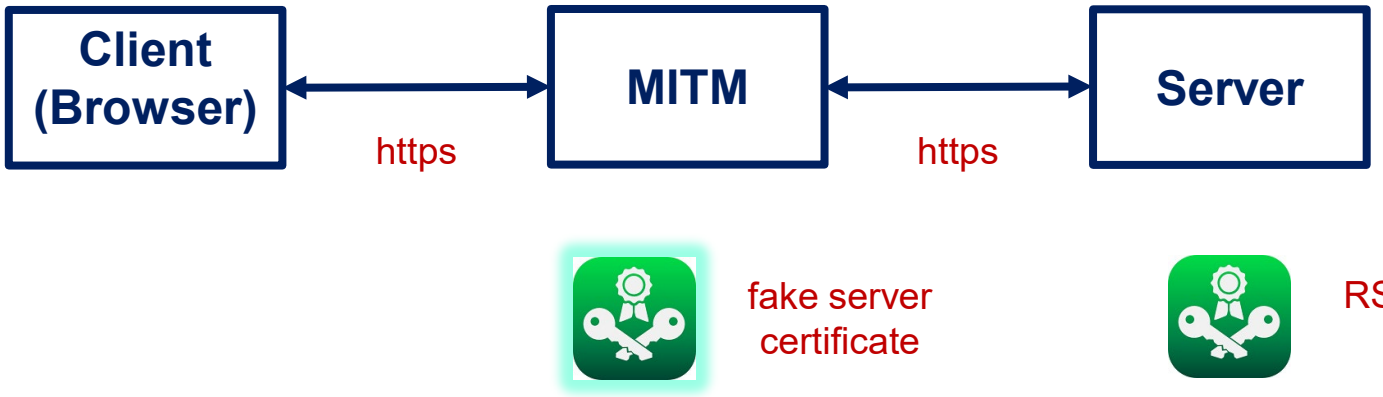
1-way SSL MITM

RSA encryption certificate

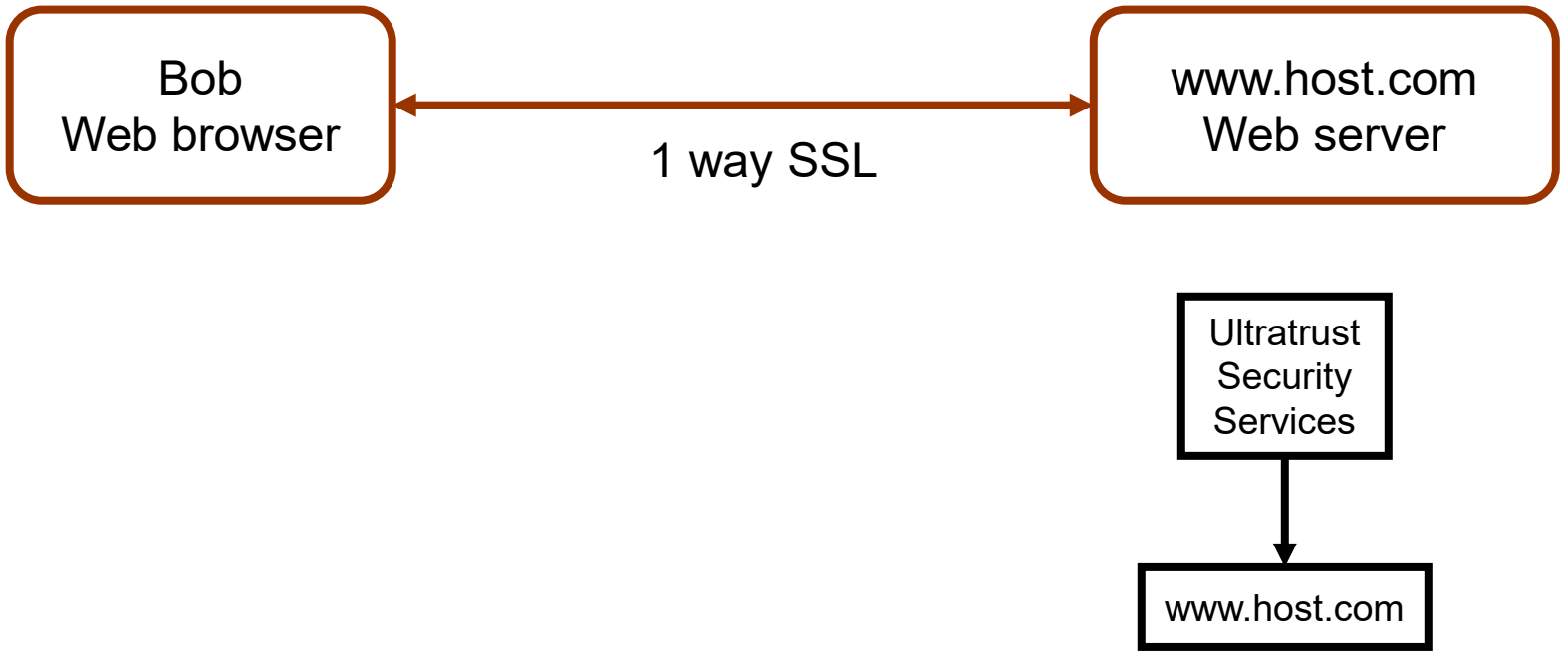
1-way SSL MITM

RSA encryption certificate

1-way SSL MITM



Server-Side Masquerading



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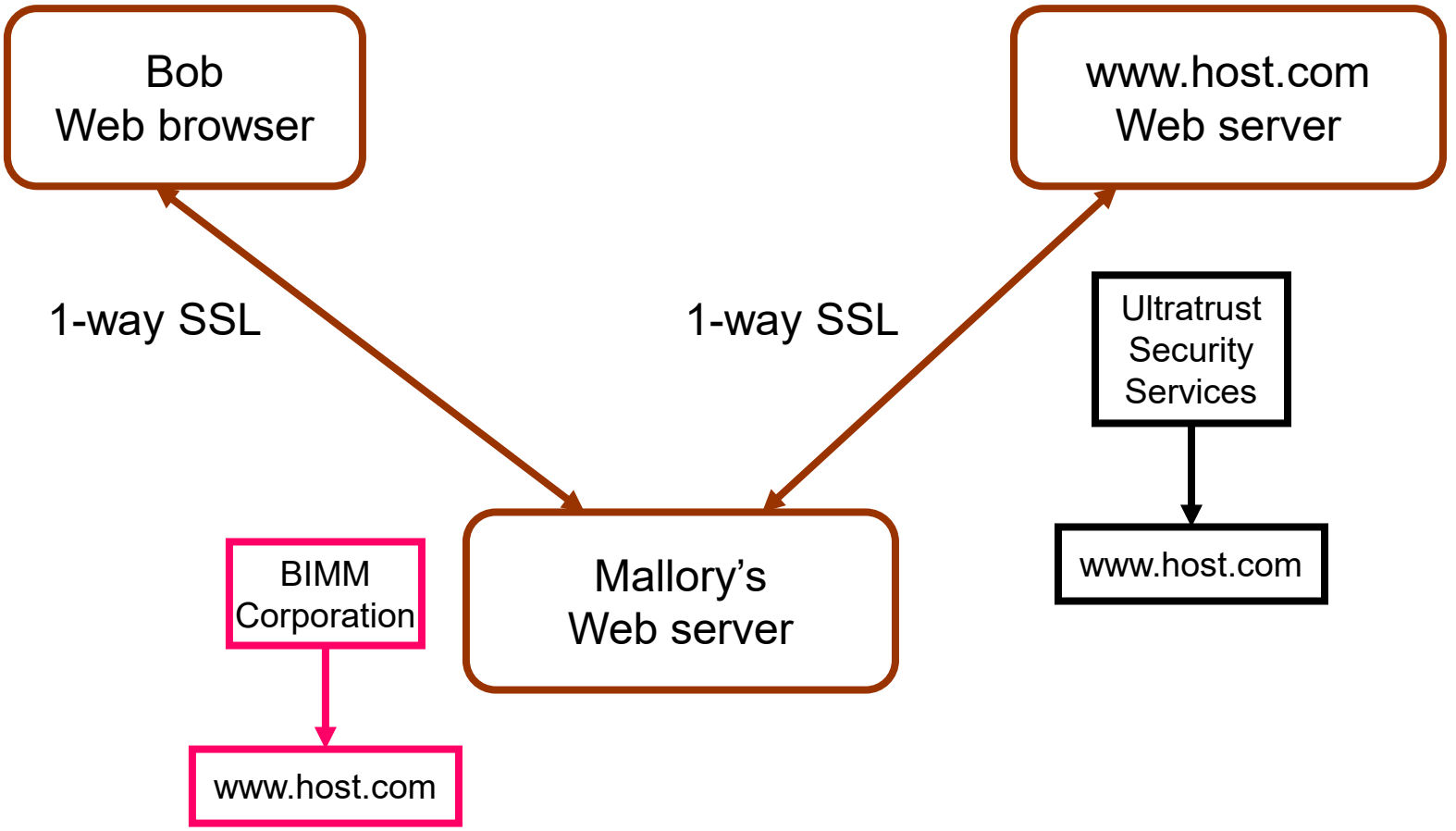

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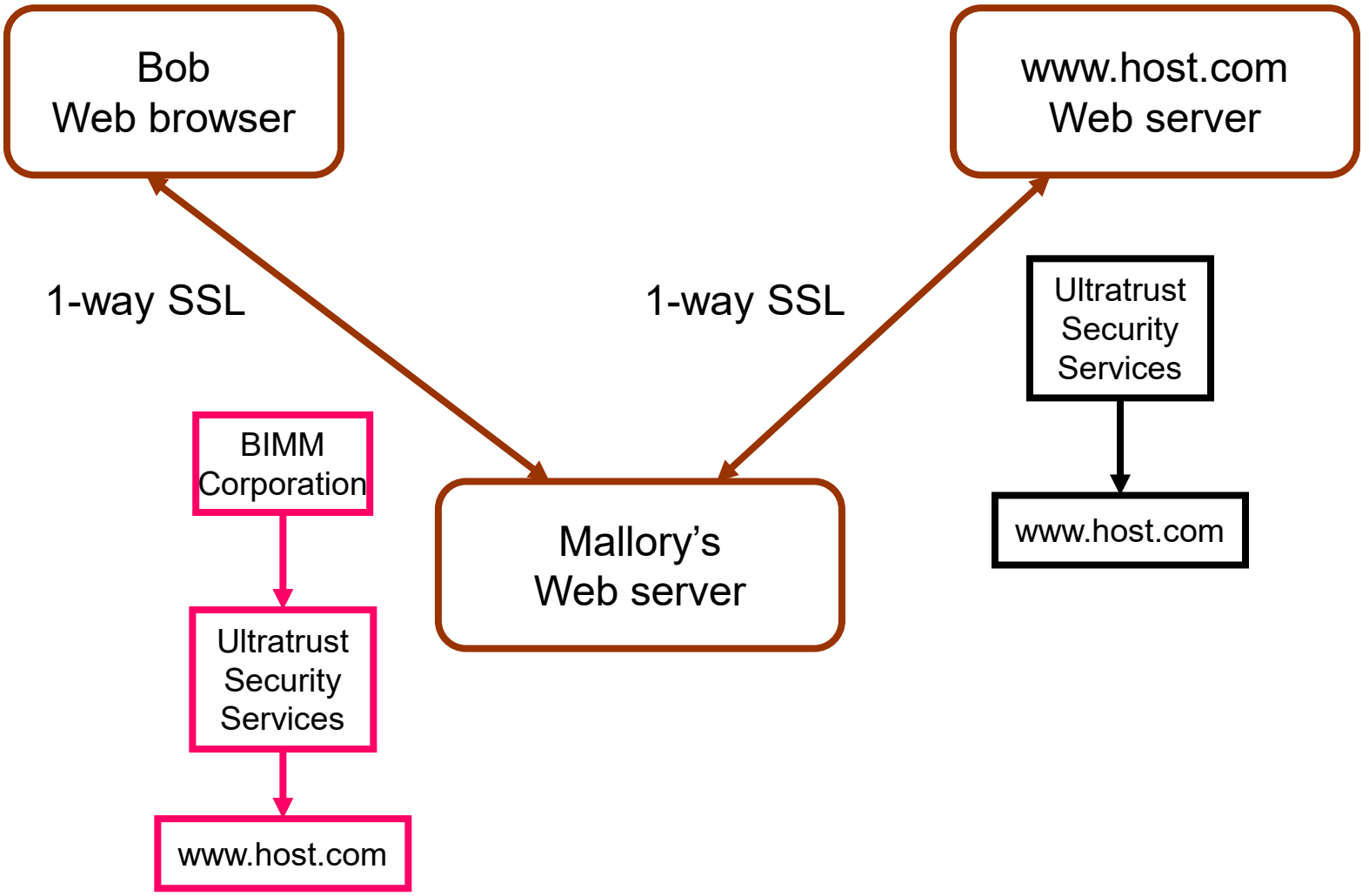
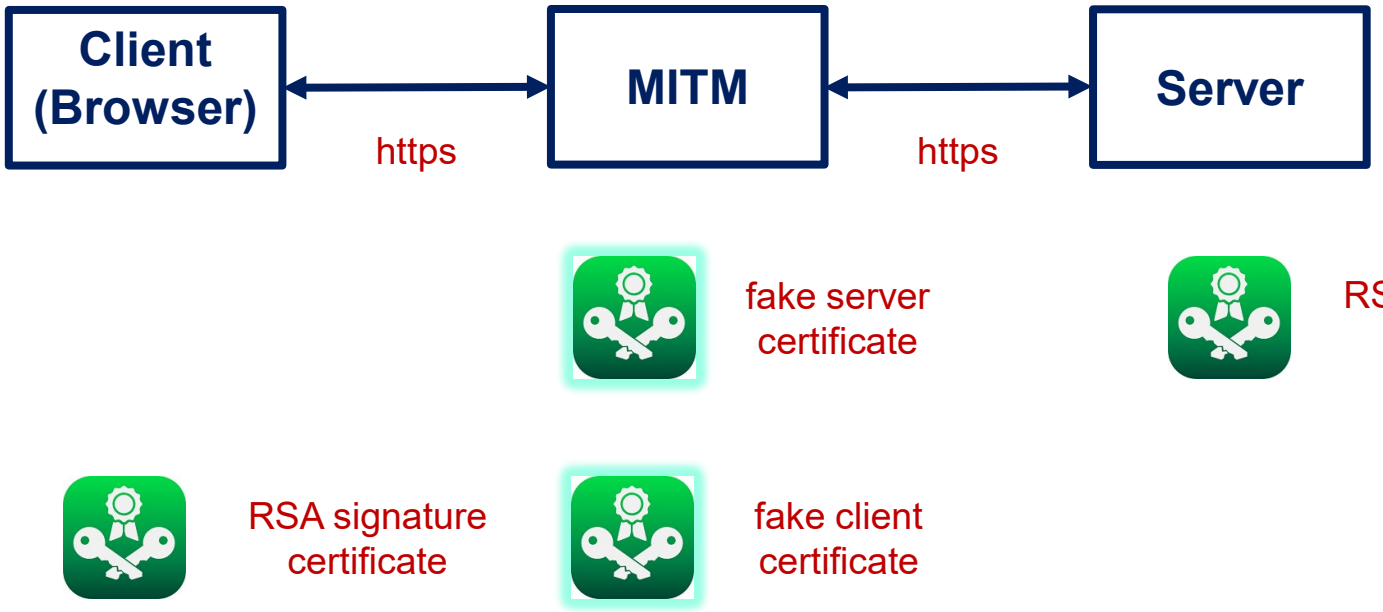


1-way SSL MITM



OpenSSL Heartbleed Attack

Heartbeat Protocol: RFC 6520, Feb. 2012