Lecture 13

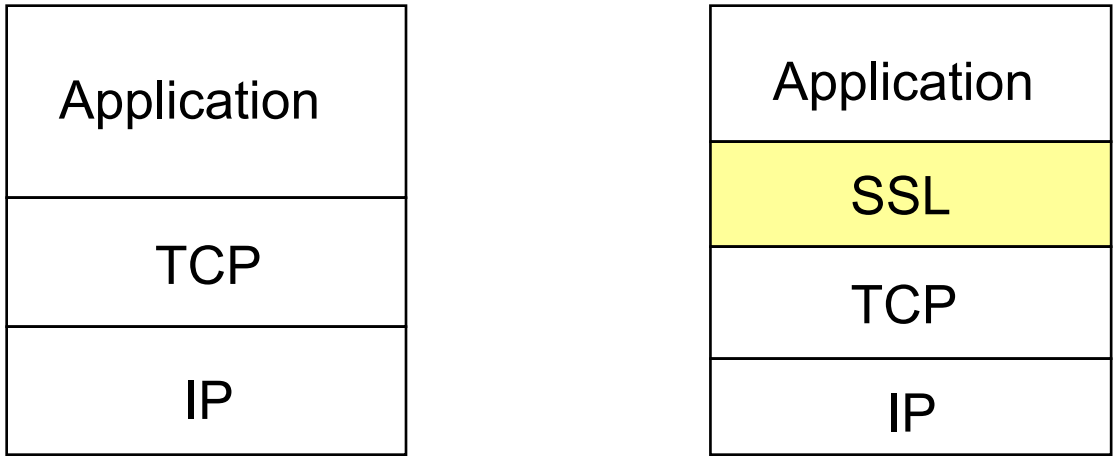
Transport Layer Security/ Secure Socket Layer (TLS/SSL)

(Chapter 9 in KPS)

SSL: Secure Sockets Layer

- widely deployed security protocol
  - supported by almost all browsers, web servers
  - the "s" in https
  - billions $/year over SSL
- mechanisms: [Woo 1994], implementation: Netscape
- variation -TLS: transport layer security, RFC 2246
- provides
  - *confidentiality*
  - *integrity*
  - *authentication*
- original goals:
  - Web e-commerce transactions
  - encryption (especially credit-card numbers)
  - Web-server authentication
  - optional client authentication
  - minimum hassle in doing business with new merchant
- available to all TCP applications
  - secure socket interface

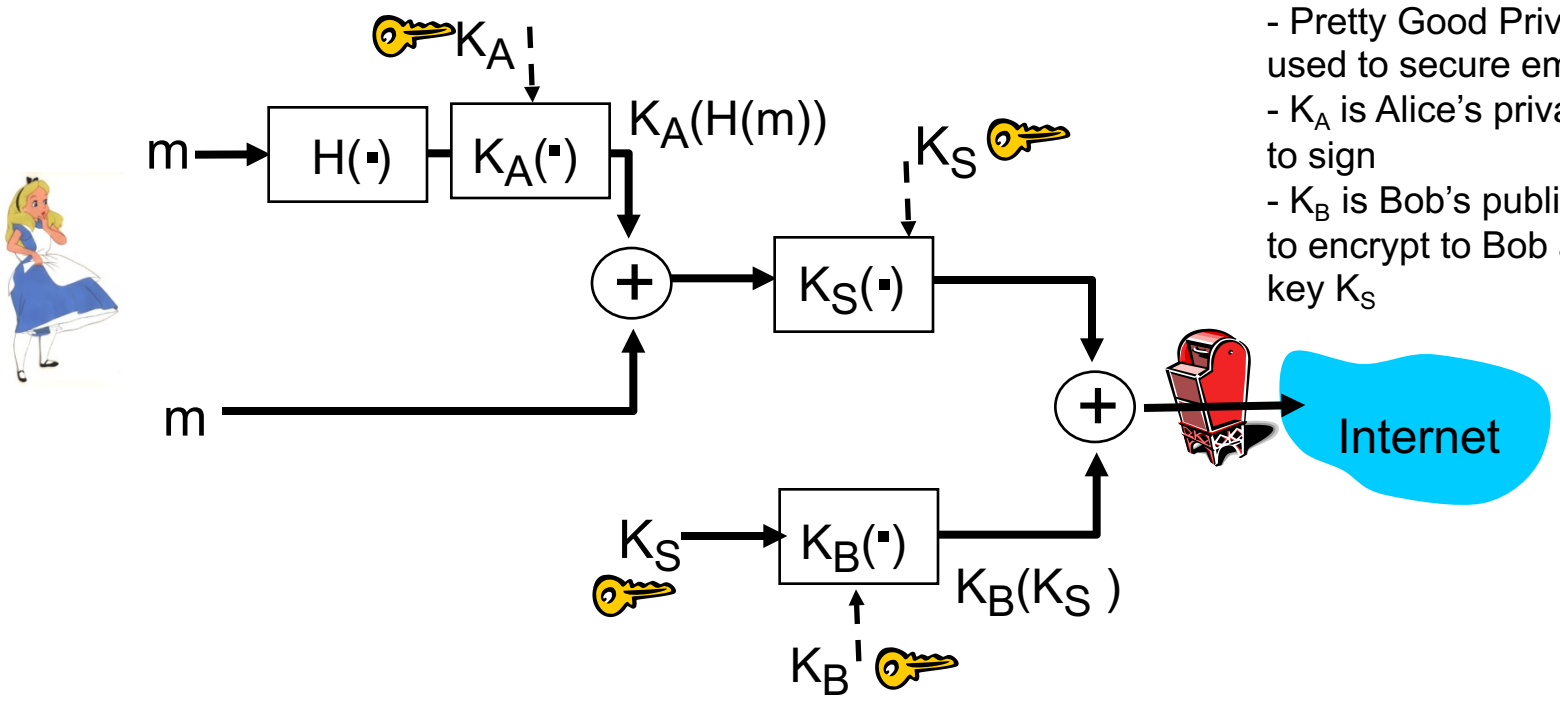
SSL and TCP/IP



normal application *application with SSL*

- SSL provides application programming interface (API) to applications
- C and Java SSL libraries/classes readily available

Could do something like PGP:



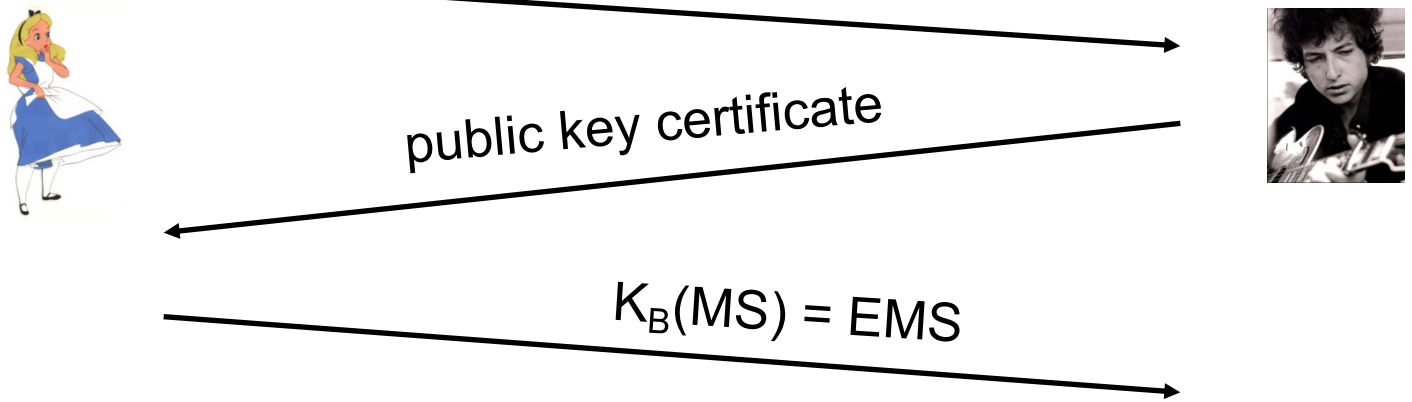
- Pretty Good Privacy (PGP) used to secure email
- K_A is Alice's private key used to sign
- K_B is Bob's public key used to encrypt to Bob a session key K_S

- but want to send byte streams & interactive data
- want set of secret keys for entire connection
- want certificate exchange as part of protocol: handshake phase

Toy SSL: a Simple Secure Channel

- *handshake:* Alice and Bob use their certificates, private keys to authenticate each other and exchange a shared secret
- *key derivation:* Alice and Bob use shared secret to derive set of keys
- *data transfer:* data to be transferred is broken up into series of records
- *connection closure:* special messages to securely close connection

Toy: a Simple Handshake



MS: master secret

EMS: encrypted master secret

Toy: Key Derivation

- considered bad to use same key for more than one cryptographic operation
  - use different keys for message authentication code (MAC) and encryption
- four keys:
  - K_c = encryption key for data sent from client to server
  - M_c = MAC key for data sent from client to server
  - K_s = encryption key for data sent from server to client
  - M_s = MAC key for data sent from server to client
- keys derived from key derivation function (KDF)
  - takes master secret and (possibly) some additional random data and creates the keys

Toy: Data Records

- why not encrypt data in constant stream as we write it to TCP?
  - where would we put the MAC? If at end, no message integrity until all data processed.
  - e.g., with instant messaging, how can we do integrity check over all bytes sent before displaying?
- instead, break stream in series of records
  - each record carries a MAC
  - receiver can act on each record as it arrives
- issue: in record, receiver needs to distinguish MAC from data
  - want to use variable-length records

Toy: Sequence Numbers

- *problem:* attacker can capture and replay record or re-order records
- *solution:* put sequence number into MAC:
  - MAC = MAC(M_x, sequence||data)
  - note: no sequence number field, M_x = MAC key

- *problem:* attacker could replay all records
- *solution:* use nonce

Toy: Control Information

- *problem:* truncation attack:
  - attacker forges TCP connection close segment
  - one or both sides thinks there is less data than there actually is
- *solution:* record types, with one type for closure
  - type 0 for data; type 1 for closure
- MAC = MAC(M_x, sequence||type||data)

Toy SSL: Summary

hello

certificate, nonce

$K_B(MS) = EMS$

type 0, seq 1, data

type 0, seq 2, data

type 0, seq 1, data

type 0, seq 3, data

type 1, seq 4, close

type 1, seq 2, close

encrypted

bob.com

Toy SSL isn't complete

- how long are fields?
- which encryption algorithms to use?
- want negotiation?
  - allow client and server to support different encryption algorithms
  - allow client and server to choose together specific algorithm before data transfer

SSL Cipher Suite

- cipher suite
  - public-key algorithm
  - symmetric encryption algorithm
  - MAC algorithm
- SSL supports several cipher suites
- negotiation: client, server agree on cipher suite
  - client offers choice
  - server picks one

common SSL symmetric ciphers

- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- RC2 – Rivest Cipher 2: block
- RC4 – Rivest Cipher 4: stream

SSL Public key encryption

- RSA

Real SSL: Handshake (1)

Purpose

1. server authentication
2. negotiation: agree on crypto algorithms
3. establish keys
4. client authentication (optional)

Real SSL: Handshake (2)

1. client sends list of algorithms it supports, along with client nonce
2. server chooses algorithms from list; sends back: choice + certificate + server nonce
3. client verifies certificate, extracts server's public key, generates pre_master_secret, encrypts with server's public key, sends to server
4. client and server independently compute encryption and MAC keys from pre_master_secret and nonces
5. client sends a MAC of all the handshake messages
6. server sends a MAC of all the handshake messages

Real SSL: Handshake (3)

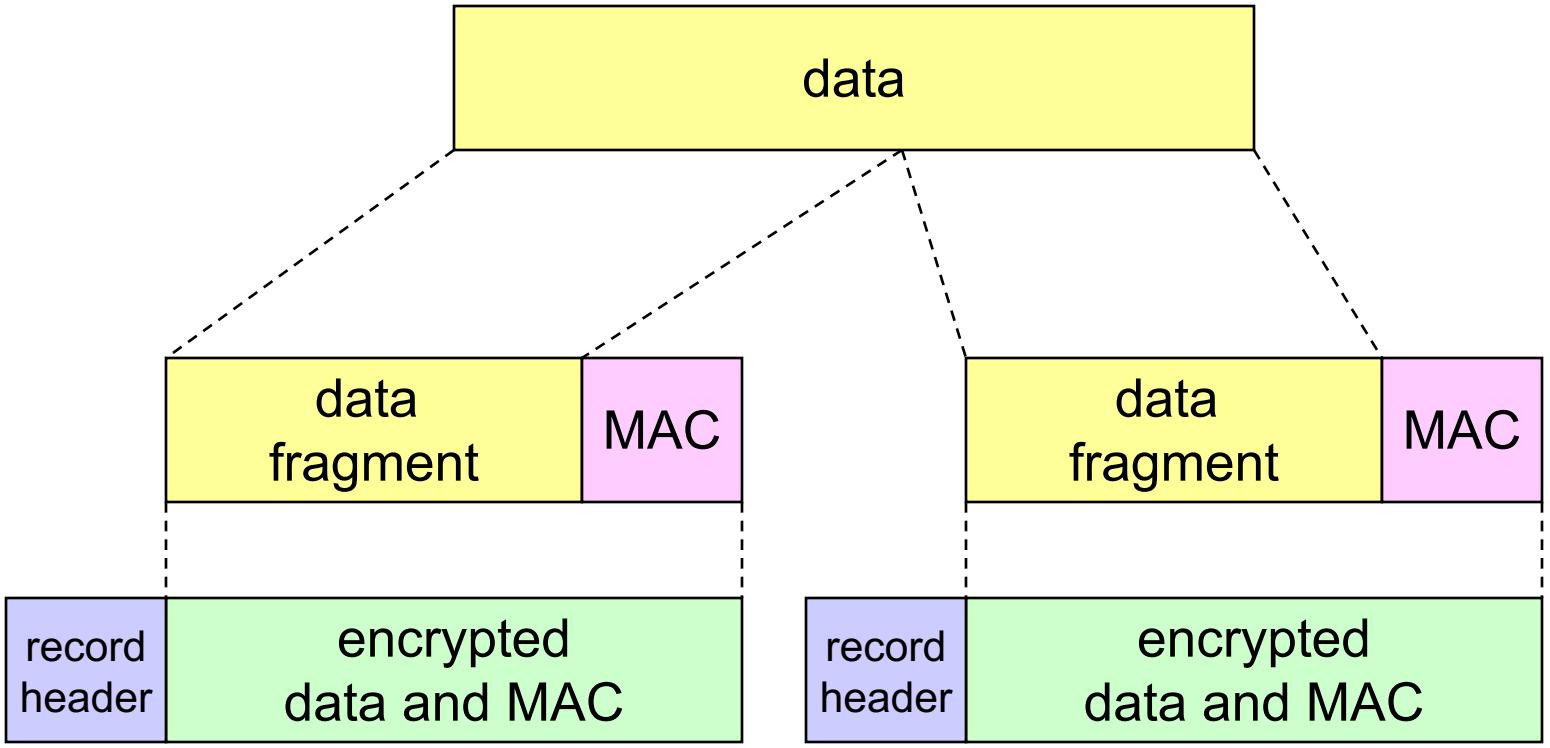
last 2 steps protect handshake from tampering

- client typically offers range of algorithms, some strong, some weak
- man-in-the middle could delete stronger algorithms from list
- last 2 steps prevent this
  - last two messages are encrypted

Real SSL: Handshake (4)

- why two random nonces?
- suppose Trudy sniffs all messages between Alice & Bob
- next day, Trudy sets up TCP connection with Bob, sends exact same sequence of records
  - Bob (Amazon) thinks Alice made two separate orders for the same thing
  - solution: Bob sends different random nonce for each connection. This causes encryption keys to be different on the two days
  - Trudy's messages will fail Bob's integrity check

SSL Record Protocol

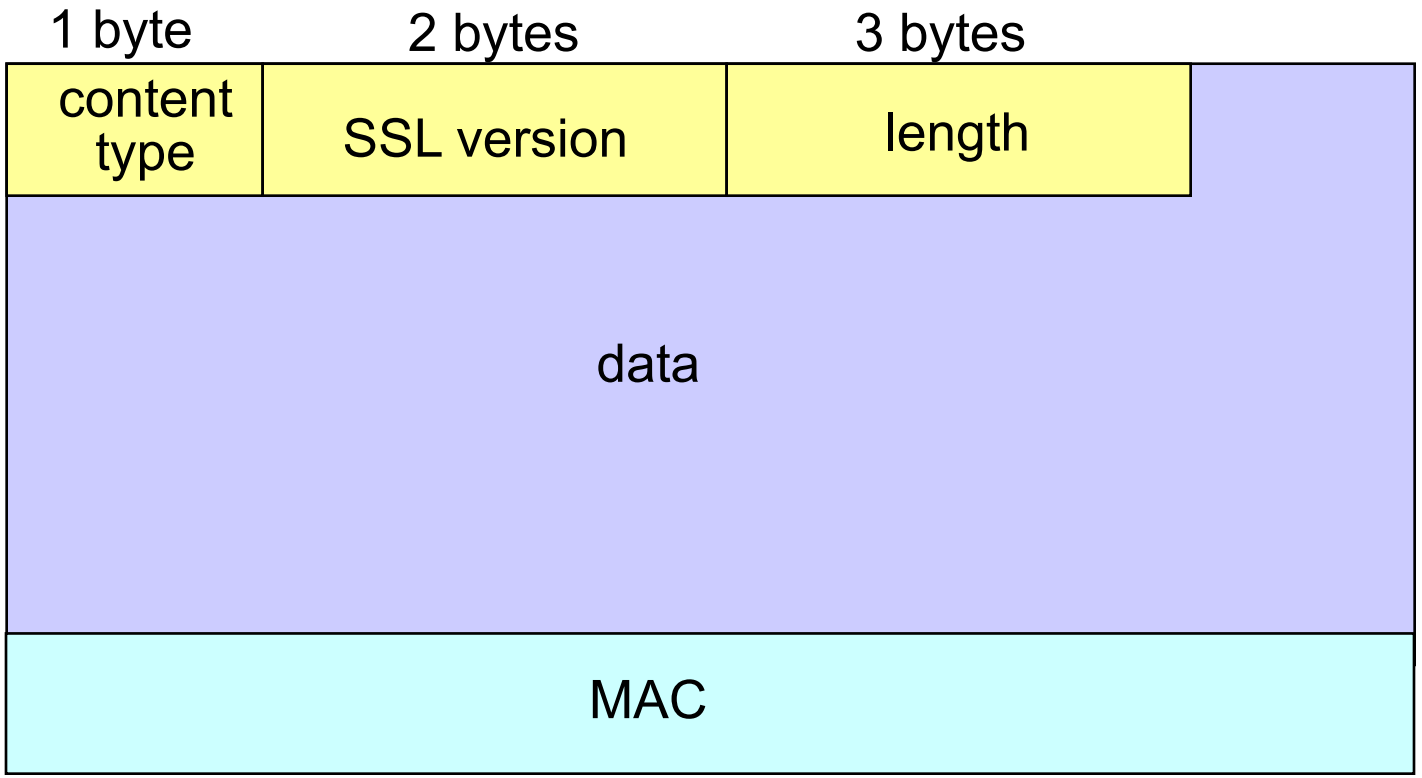


record header: content type; version; length

MAC: includes sequence number, MAC key M_x

fragment: each SSL fragment 2^{14} bytes (~16 Kbytes)

SSL Record Format



data and MAC encrypted (symmetric algorithm)

Real SSL Connection

handshake: ClientHello

handshake: ServerHello

handshake: Certificate

handshake: ServerHelloDone

handshake: ClientKeyExchange

ChangeCipherSpec

handshake: Finished

everything henceforth is encrypted

ChangeCipherSpec

handshake: Finished

application_data

application_data

Alert: warning, close_notify

TCP FIN message follows

Key Derivation

- client nonce, server nonce, and pre-master secret input into pseudo random-number generator (PRG).
  - produces master secret
- master secret and new nonces input into another random-number generator: "key block"

- key block sliced and diced:
  - client MAC key
  - server MAC key
  - client encryption key
  - server encryption key
  - client initialization vector (IV)
  - server initialization vector (IV)