Security at the Transport Layer

CS 352, Lecture 21

http://www.cs.rutgers.edu/~sn624/352-S19

Srinivas Narayana

(heavily adapted from slides by Prof. Badri Nath and the textbook authors)

RUTGERS
UNIVERSITY | NEW BRUNSWICK

Transport Layer Security

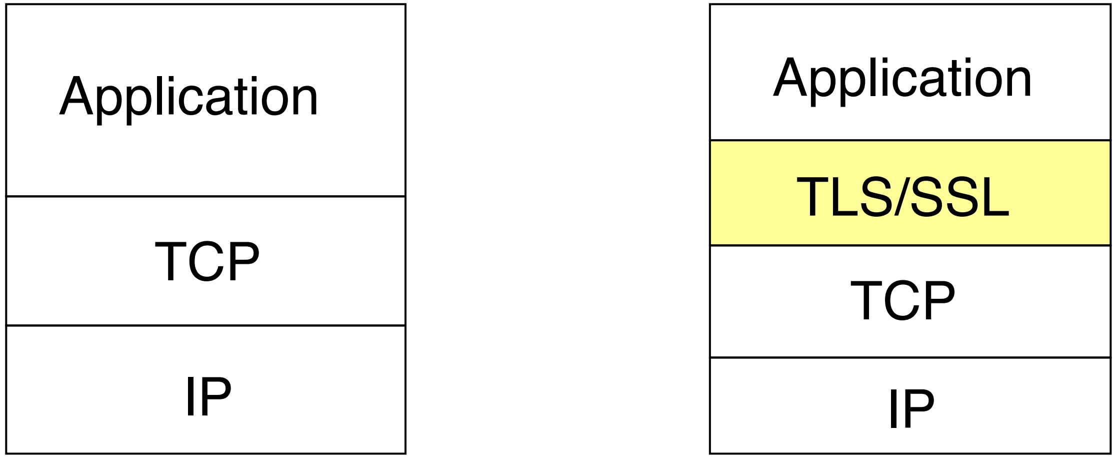
TLS/SSL

TLS/SSL: A Secure Sockets Layer

- widely deployed security protocol
  - supported by almost all browsers, web servers
  - https
  - billions $/year over TLS/SSL
- Origins: [Woo 1994] implementation by Netscape
- 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

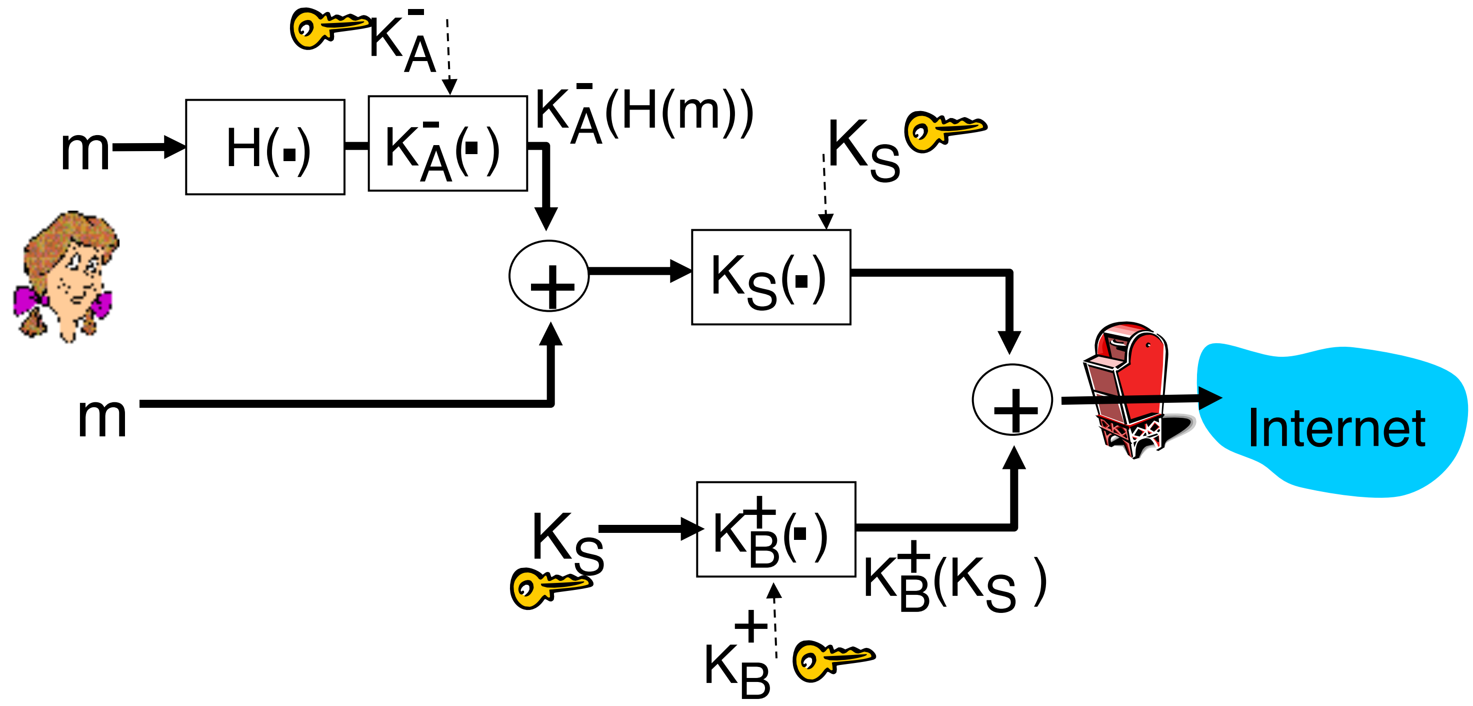
TLS/SSL and the rest of the protocol stack



normal application   *application with TLS/SSL*

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

Could do something like PGP

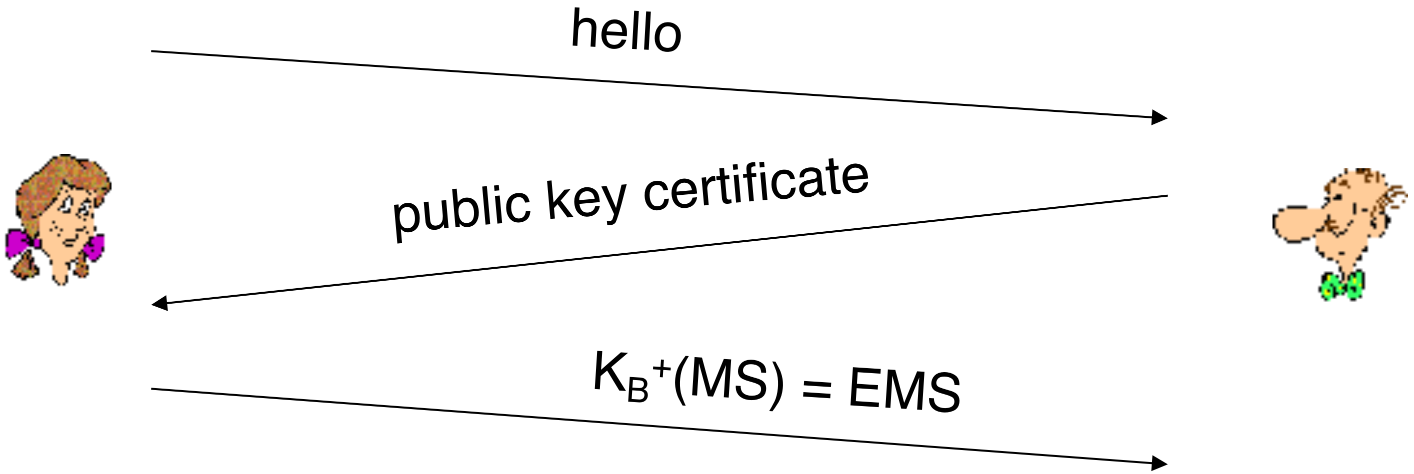


- but want to send byte streams & interactive data
- want set of secret keys for entire connection
- want certificate exchange as part of protocol: handshake phase

TLS/SSL protocol: Constituents

- *handshake:* Alice and Bob use their certificates, private keys to authenticate each other and exchange 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

Step (1): a simple handshake



MS: master secret

EMS: encrypted master secret

Q: What all might the “master secret” be used for?

Step (2): 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

Step (3): 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
- How does receiver distinguish MAC from data within a record?
  - want to use variable-length records

Defending against replay attacks?

- Problem: What if attacker could record and replay all or some records?

- Solution:
- Use nonce (ex: cipher block chaining)
- Handles both record replay and *connection* replay

Defending against reordering?

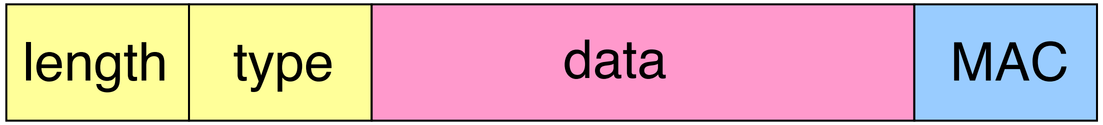
- Problem: What if attacker re-orders the records?
  - Issue: per-record MAC provides only record-level integrity
  - But record-level integrity is not the same as *stream-level* integrity

- Solution:
- Put sequence number in MAC:
  - MAC = MAC(M_x, sequence-number II data)

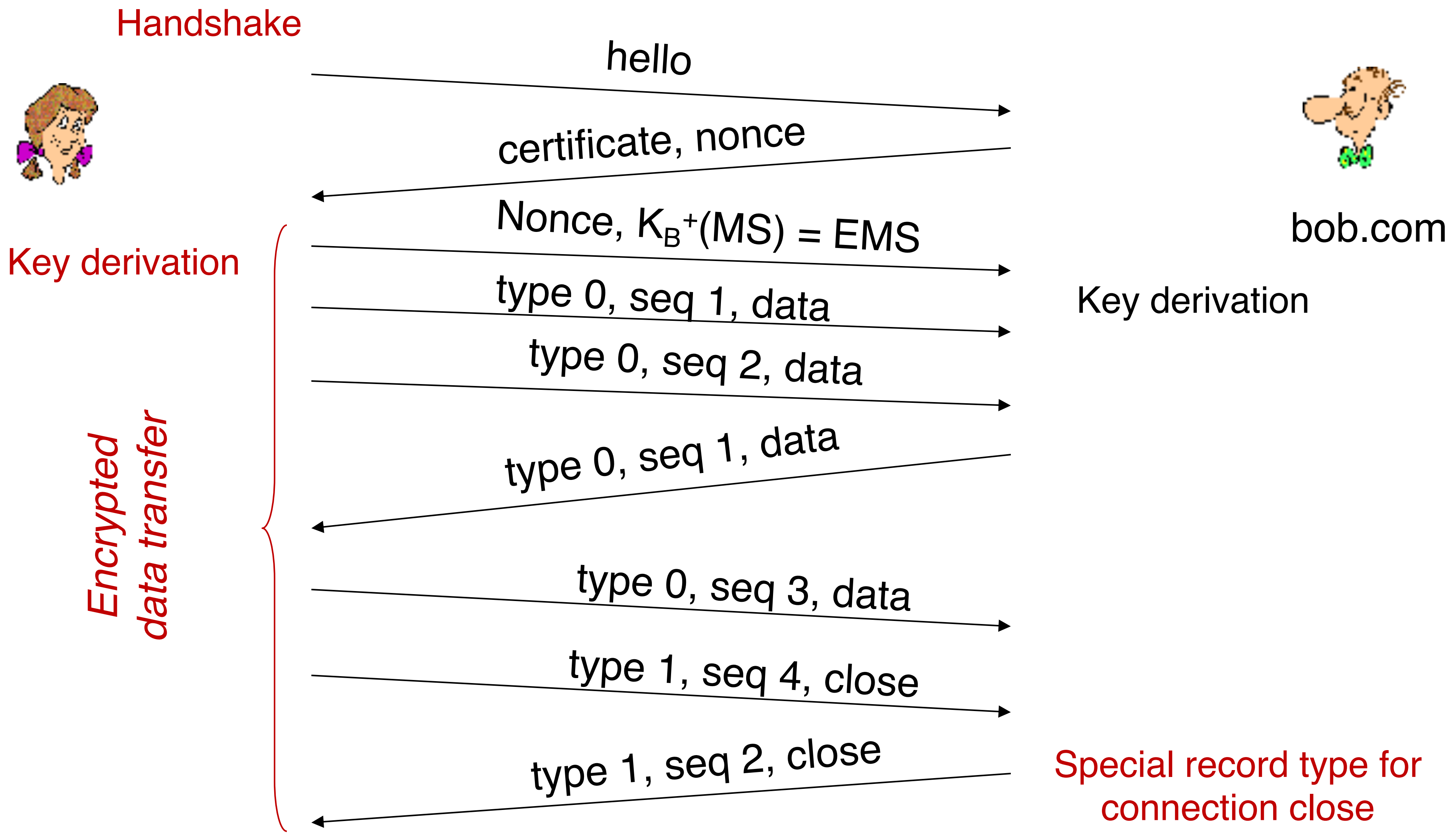
- Note: no sequence number field on record
  - Instead, sender and receiver implicitly keep seq numbers on records

Defending against truncation?

- *problem:* truncation attack
  - attacker forges TCP connection close segment
  - one or both sides thinks there is less data than there actually is
  - A stream of records in order so far != stream being *complete*
- *solution:* record types, with one type for closure
  - type 0 for data; type 1 for closure
- MAC = MAC(M_x, sequence || type || data)



TLS/SSL: summary so far



But our TLS/SSL description isn't complete yet

- how long are fields?
- which encryption protocols?
- Could we implement *negotiation*?
  - allow client and server to support different encryption algorithms
  - allow client and server to choose together specific algorithm before data transfer

TLS/SSL “Cipher Suite”

- Cipher suite
  - public-key algorithm
  - symmetric encryption algorithm
  - MAC algorithm
- TLS/SSL supports several cipher suites

- Negotiation: client, server agree on cipher suite
  - client offers choices
  - server picks one

Common symmetric ciphers

- AES – Advanced Encryption Standard
- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- ChaCha: stream
- RC4 – Rivest Cipher 4: stream

SSL Public key encryption

- RSA with DH

Message authentication code

- HMAC-MD5 and others

Improved Handshake with Negotiation (1/5)

Purpose

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

Improved Handshake with Negotiation (2/5)

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

Improved Handshake with Negotiation (3/5)

Why steps (5) and (6)?

(MAC of all handshake messages)

- 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
  - Note that the last two messages are encrypted

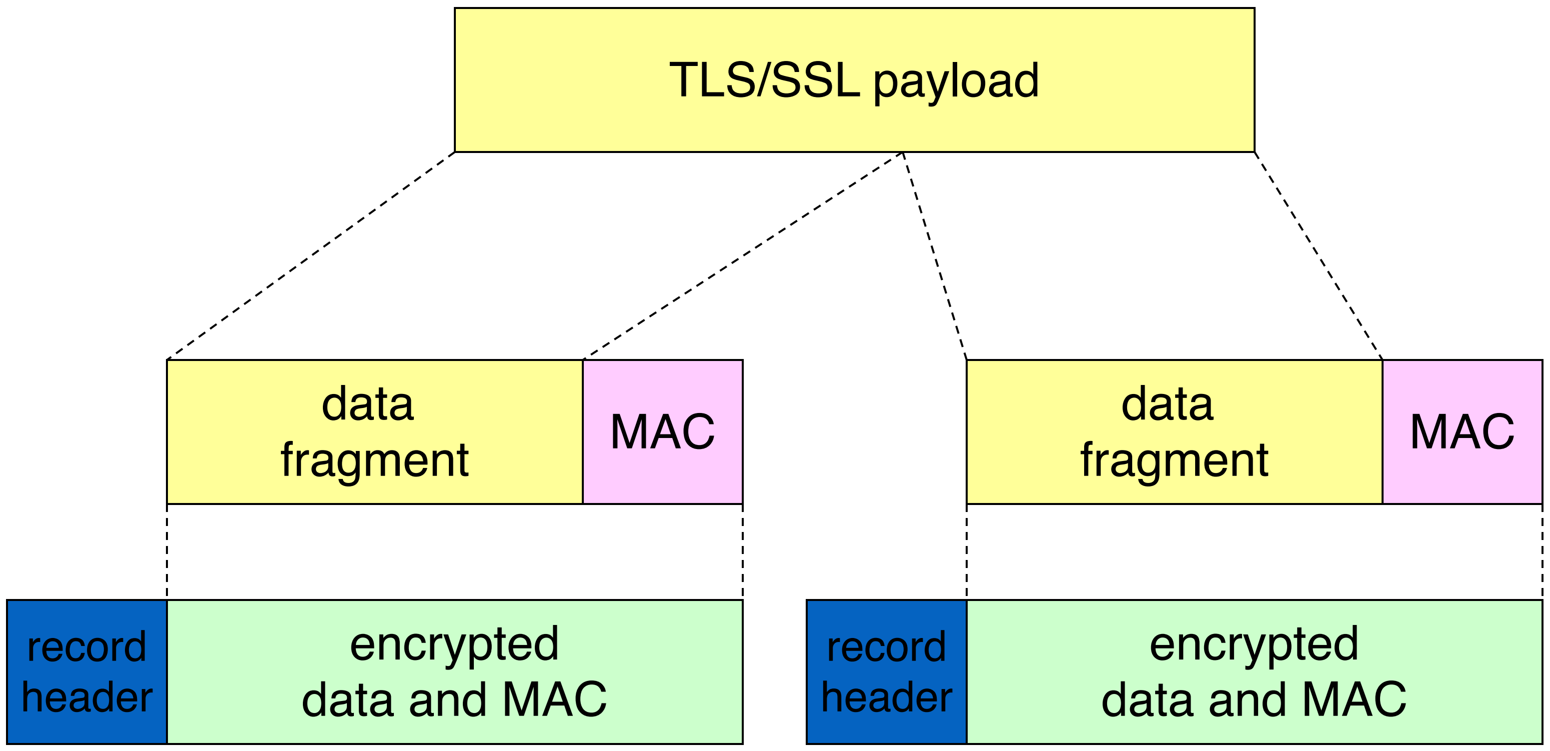
Improved Handshake with Negotiation (4/5)

- Why two 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 for each connection.
  - Trudy’s messages will fail Bob’s integrity check

Key derivation as part of handshake (5/5)

- client nonce, server nonce, and pre-master secret are fed into a pseudo random-number generator
  - produces master secret
- master secret and nonces are fed into another random-number generator to get a key block
- key block sliced and diced:
  - client MAC key
  - server MAC key
  - client encryption key
  - server encryption key
  - client initialization vector (for CBC)
  - server initialization vector (for CBC)

TLS/SSL protocol messages

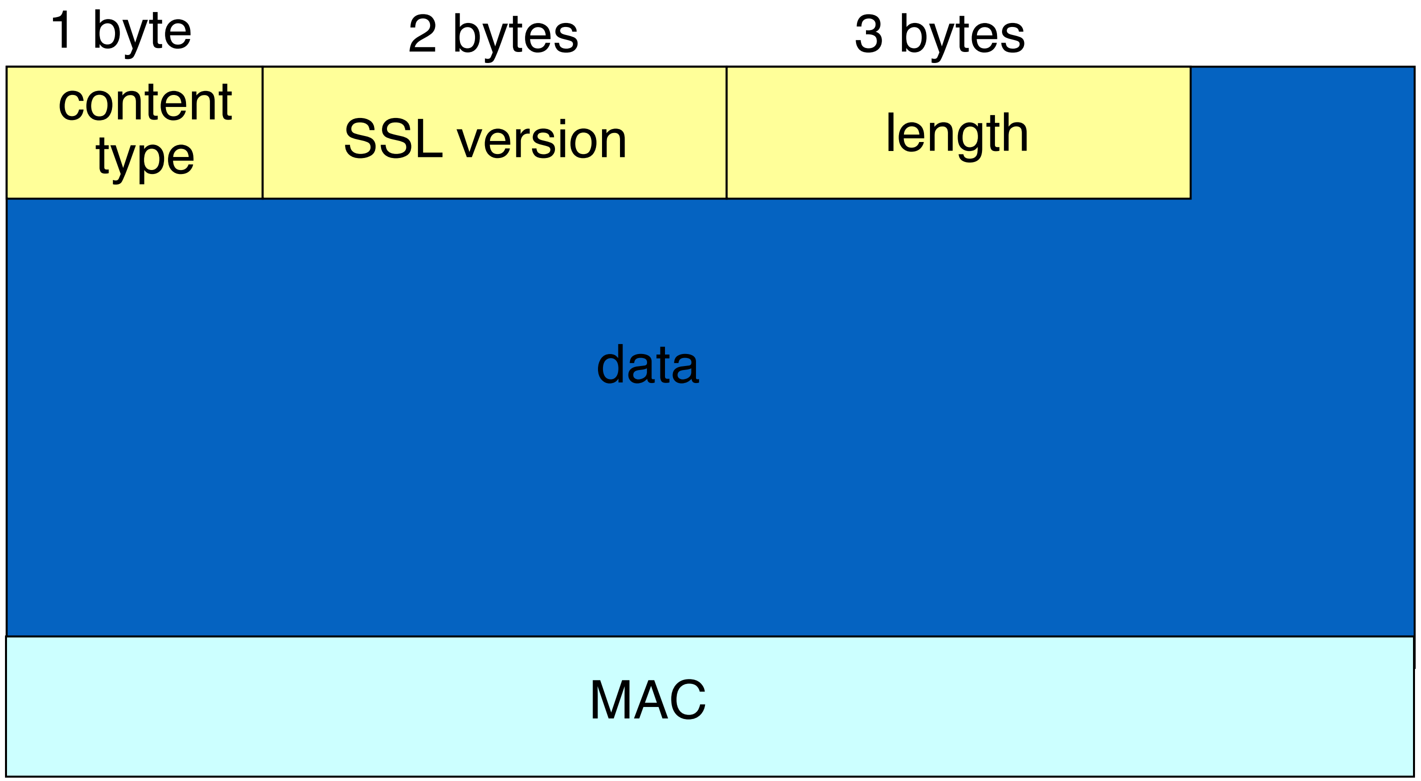


record header: content type; version; length

MAC: includes sequence number, MAC key M_x

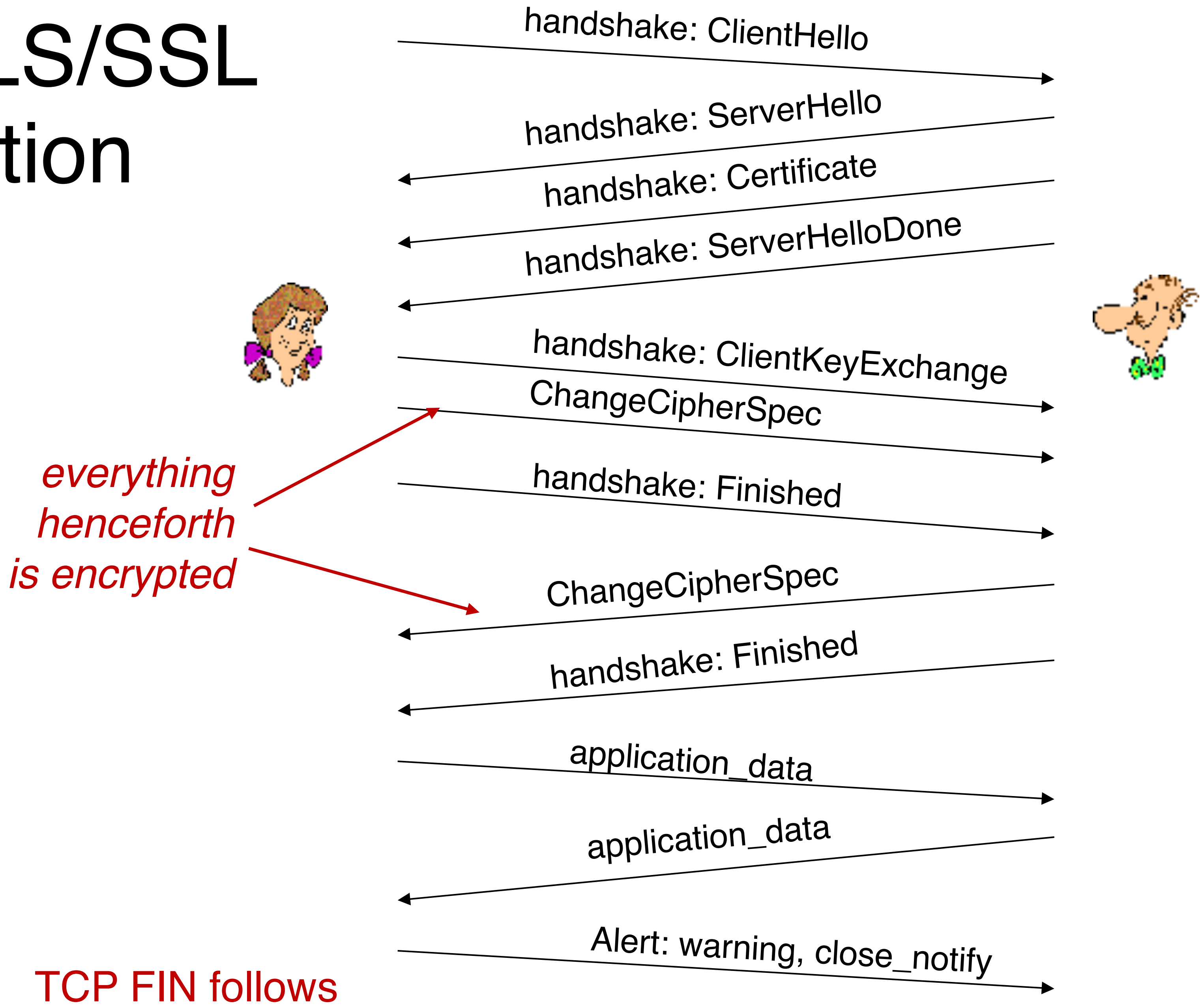
fragment: each SSL fragment 2^{14} bytes (~16 Kbytes)

TLS/SSL record format



data and MAC encrypted (symmetric key algorithm)

Real TLS/SSL connection



TLS/SSL: the big picture

- A protocol to agree on a set of ciphers for security properties
  - Not a cipher itself
- Can be used by any application at the app layer
- Customized for security properties at the record-level and stream-level, to work with real applications
- Latest standard: TLS v1.3 (Aug 2018)

Activity

- Look at the certificate for a website on your browser
- badssl.com
- https://www.selfsignedcertificate.com
- `openssl x509 -in test-self-signed-cert-cert.cert -text -noout`

Security: The Big Picture

- Cryptography: building block for security on the Internet today
    - Symmetric key (ex: AES) and public key (ex: RSA)
    - Provide confidentiality, but need more work for other properties
- Message integrity through MAC
- Digital signatures: authenticity, integrity, non-repudiation
- Certificate authorities
- Real applications and protocols: PGP and TLS/SSL
- Many real benefits from the tools and techniques in this field
- Many real problems remain