COMP9121: Design of Networks and Distributed Systems

Week 12: Network Security 2

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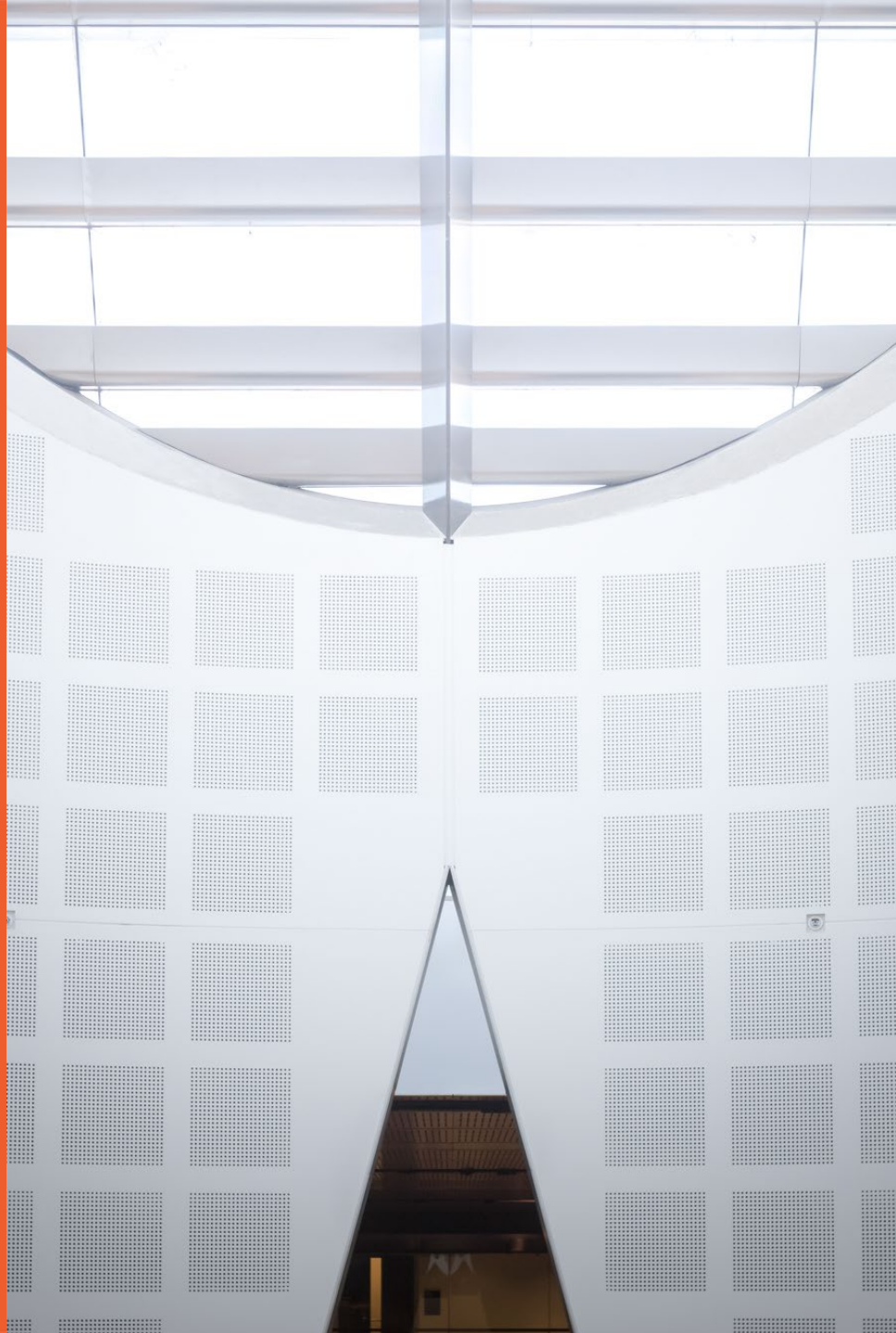
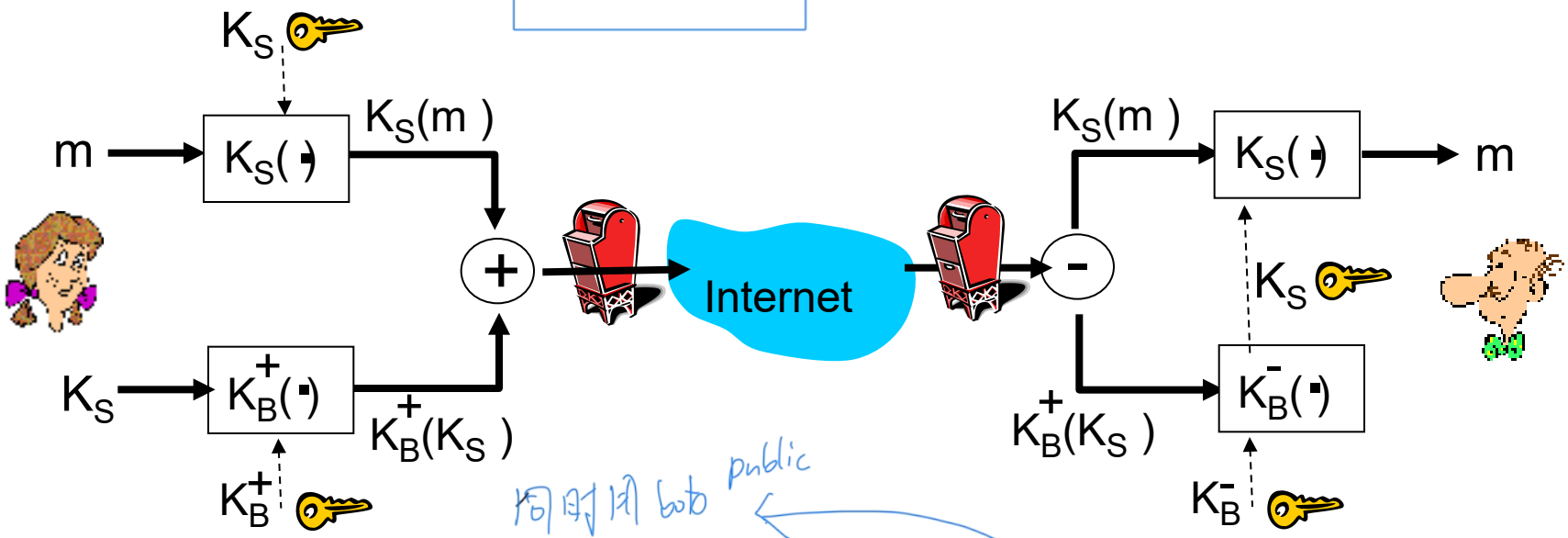


Securing e-mail

Secure e-mail, Pretty Good Privacy (PGP)

Alice wants to send confidential e-mail, m, to Bob.

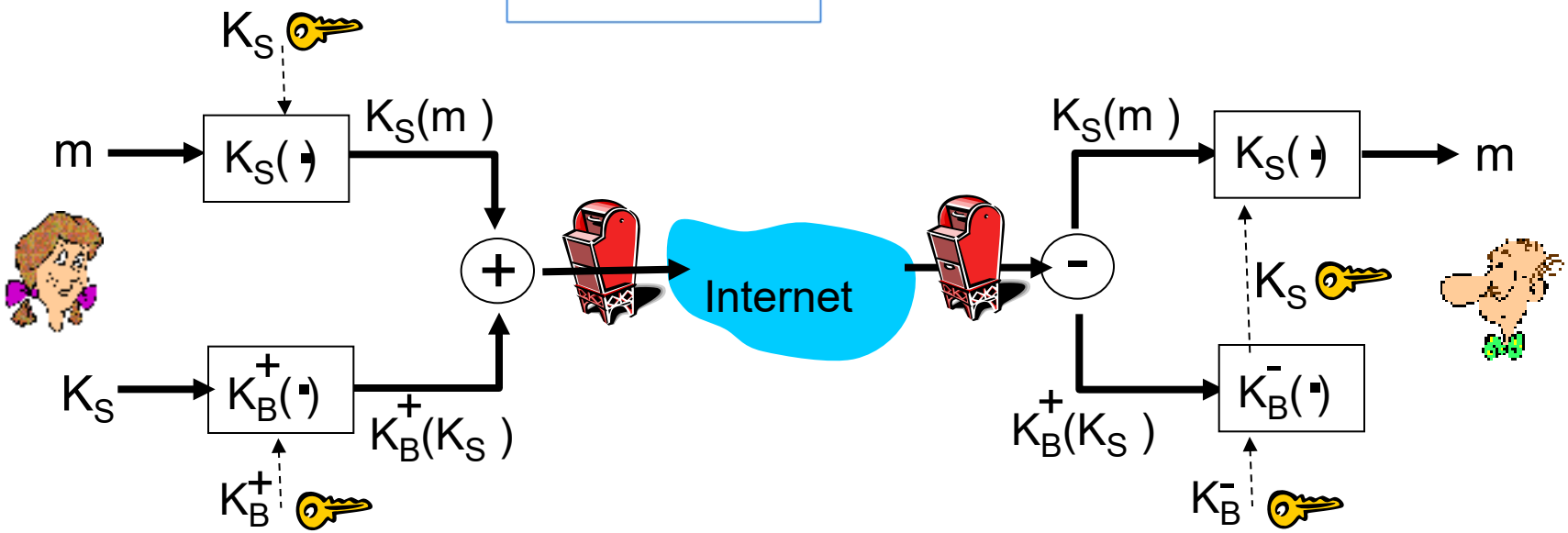


Alice:

- generates random *symmetric* private key, K_S
- encrypts message with K_S (for efficiency)
- also encrypts K_S with Bob's public key
- sends both $K_S(m)$ and $K_B(K_S)$ to Bob

Secure e-mail

Alice wants to send confidential e-mail, m, to Bob.

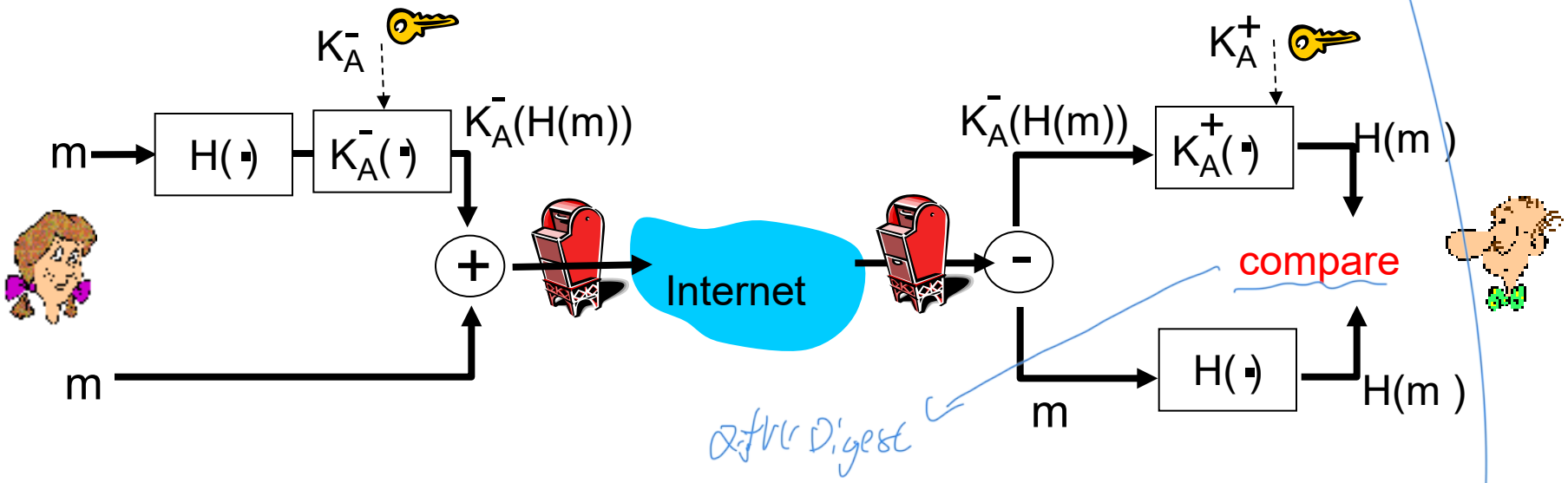


Bob:

- uses his private key to decrypt and recover K_S
- uses K_S to decrypt $K_S(m)$ to recover m

Secure e-mail (continued)

Alice wants to provide sender authentication message integrity



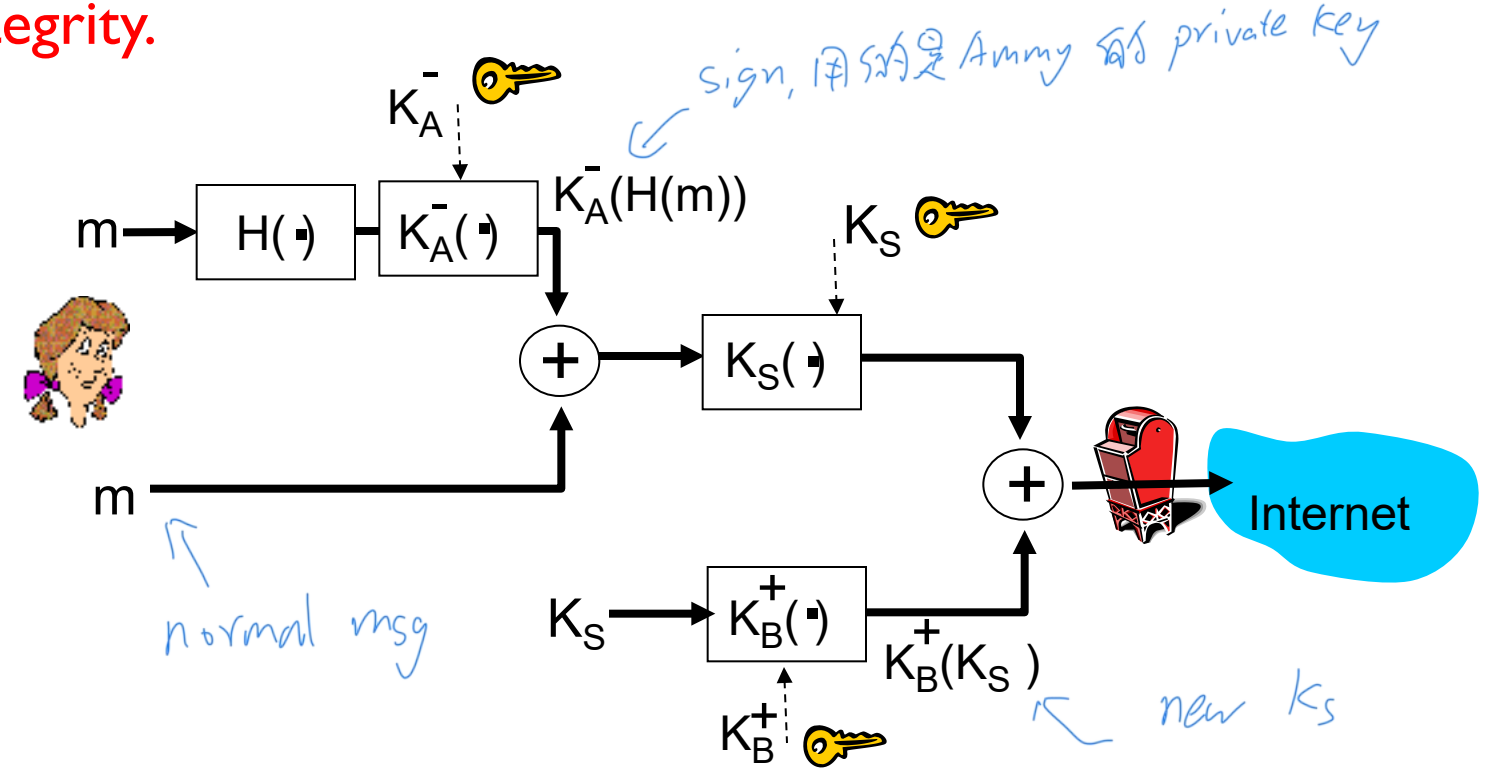
- Alice digitally signs message
- sends both message (in the clear) and digital signature

Not best way: very slow

Both Alice and Bob's public key need to be certificated by Government CA

Secure e-mail (continued)

Alice wants to provide secrecy, sender authentication, message integrity.



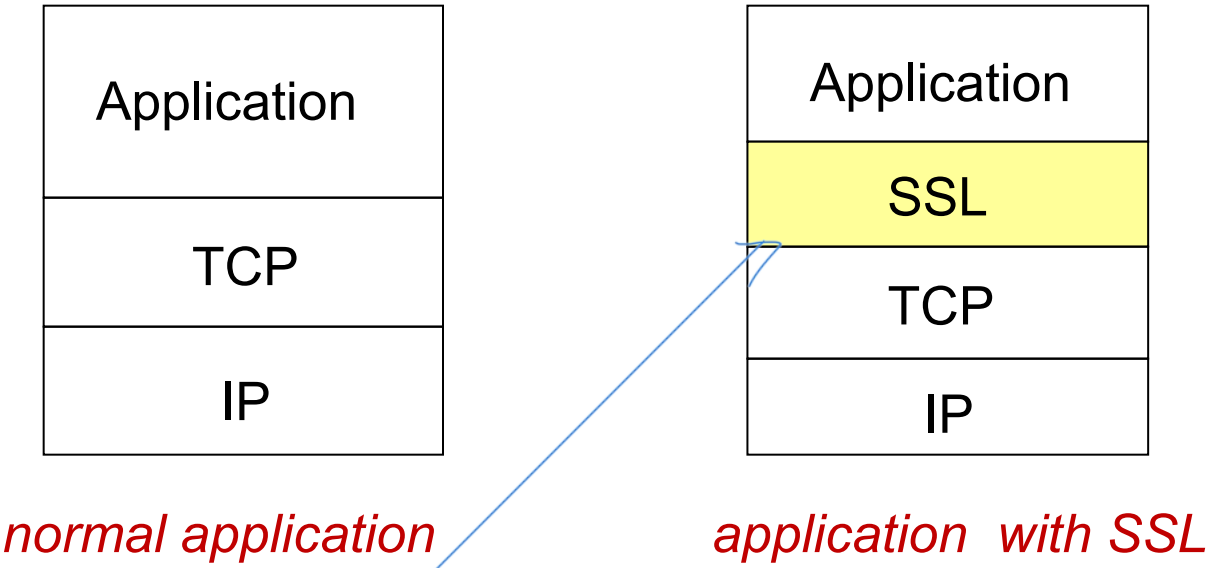
Alice uses three keys: her private key, Bob's public key, newly created symmetric key

Securing TCP connections: SSL

SSL: Secure Sockets Layer

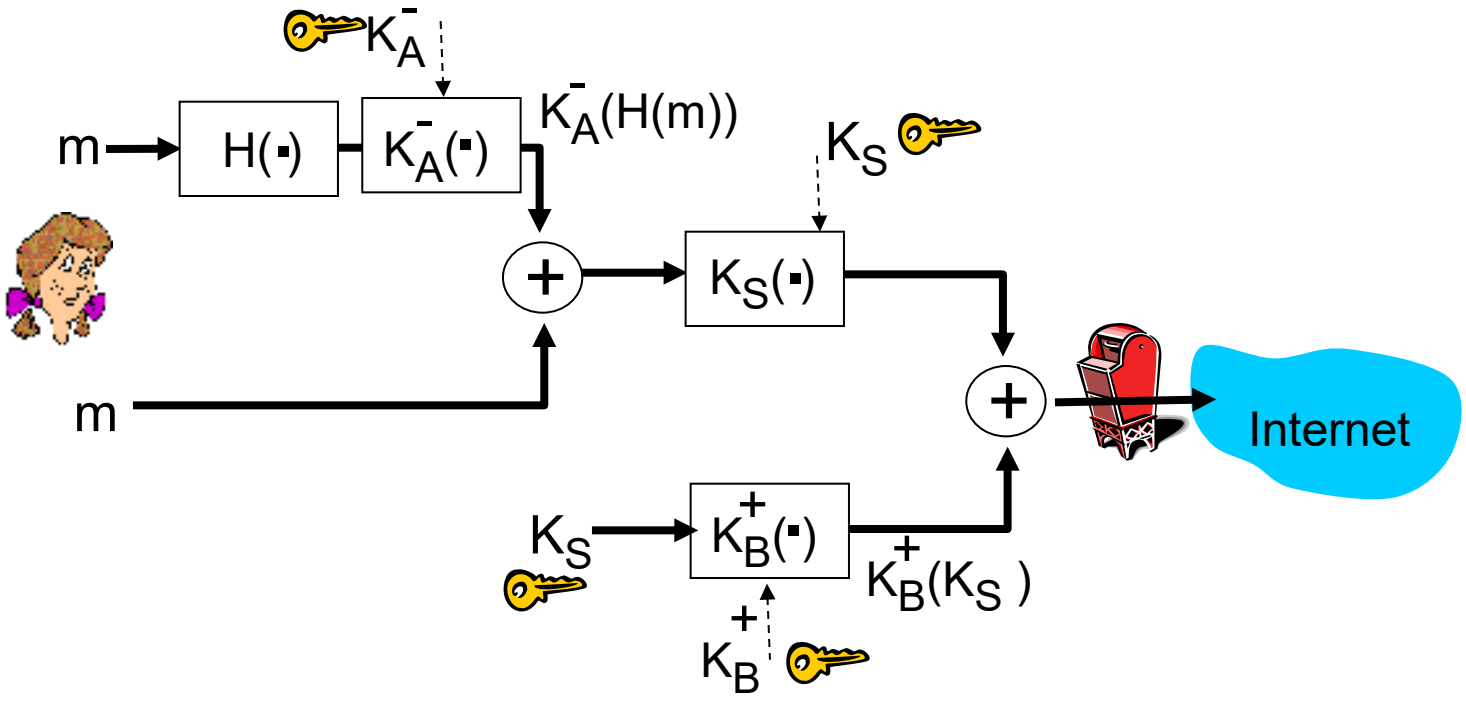
- widely deployed security protocol
  - supported by almost all browsers, web servers
  - https
  - billions $/year over SSL
- mechanisms: [Woo 1994], implementation: Netscape
- New name -TLS: transport layer security, RFC 2246
- provides
  - *confidentiality*
  - *integrity*
  - *authentication*
- original 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



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

Could do something like PGP:



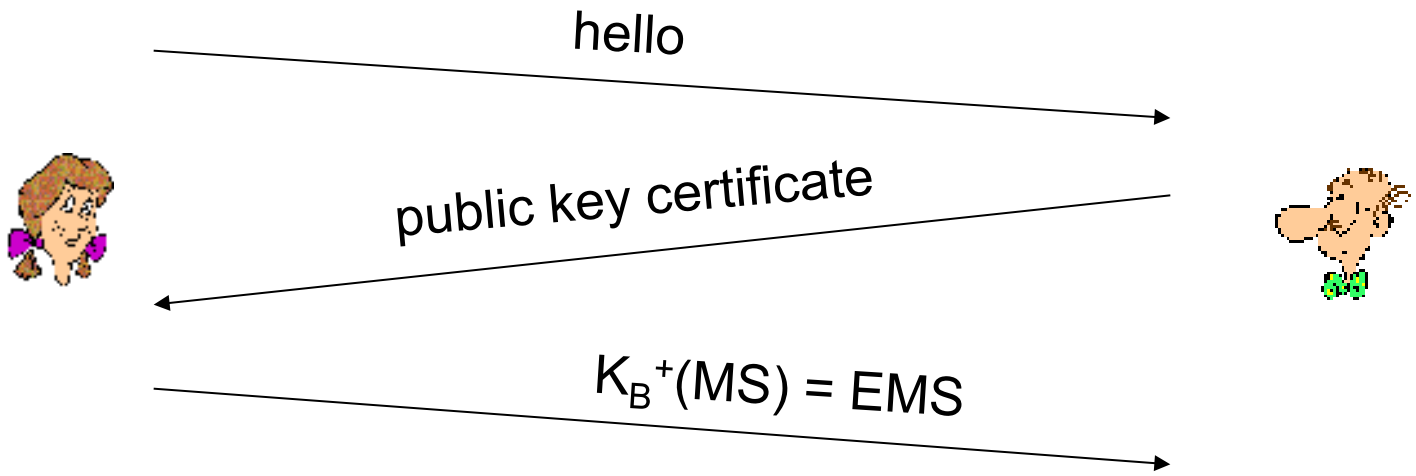
- but want to send byte streams & interactive data
- want set of secret keys for entire connection
- want certificate exchange as part of protocol: handshake phase

Toy SSL: a simple secure channel

简易 SSL

- *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

Toy: a simple handshake



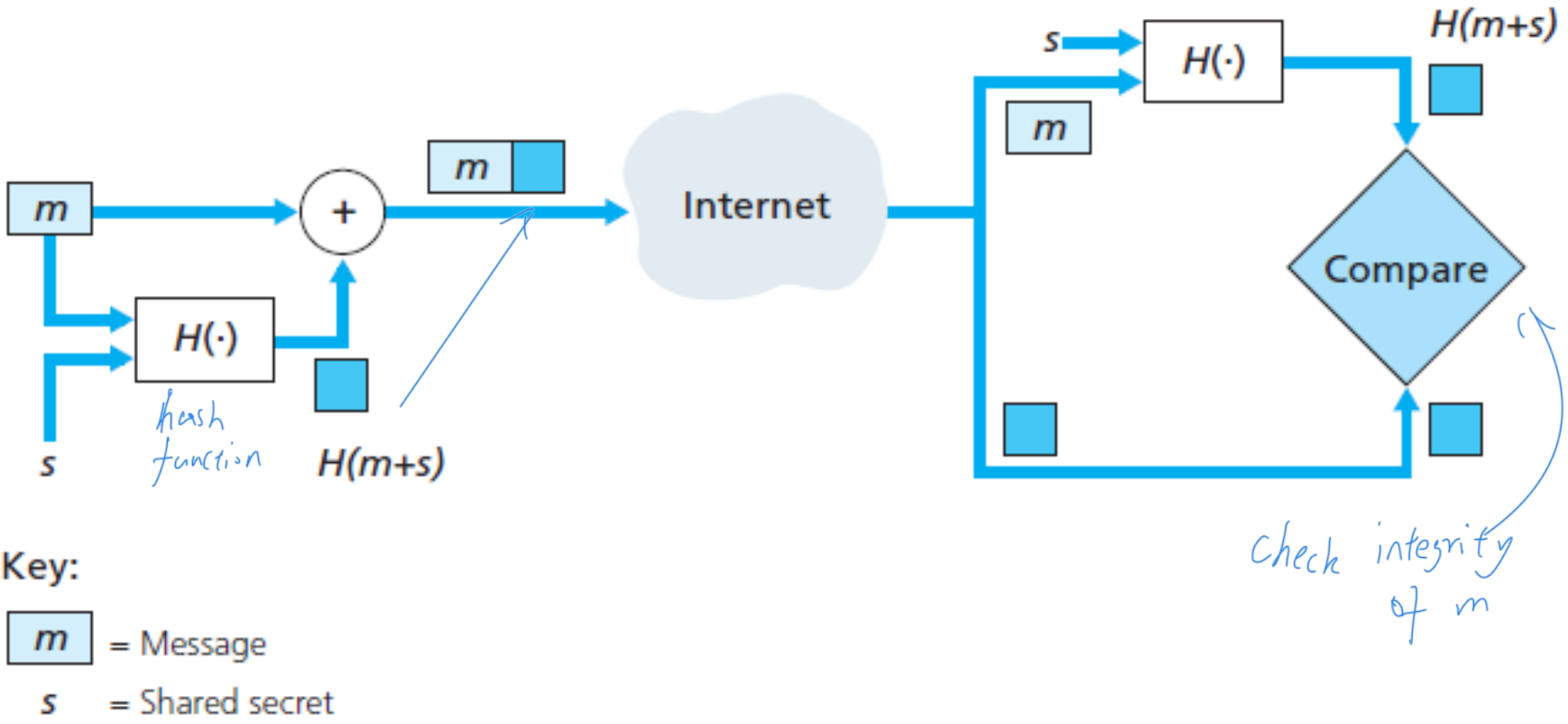
MS: master secret

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 = session MAC key for data sent from client to server
  - K_s = encryption key for data sent from server to client
  - M_s = session 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

Message authentication code (MAC)



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)

Sequence # of records are protected by MAC

- *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)

type of record,
关闭 record 有别于常的 type

Toy SSL: summary

certificated public key of Bob

hello

certificate, nonce

MS = KDF(nonce, PMS)

Alice create MS and send to Bob

$K_B^+(PMS) = EPMS$

Bob get MS

MS = KDF(nonce, PMS)

bob.com

PMS pre master secret

MS=[K_c, M_c, K_s, M_s]

K_c

Encrypted by K_c

type 0, seq 1, data, MAC(M_c)

type 0, seq 2, data, MAC (M_c)

type 0, seq 1, data, MAC (M_s)

type 0, seq 3, data, MAC (M_c)

type 1, seq 4, close, MAC (M_c)

type 1, seq 2, close, MAC (M_s)

K_s

Encrypted by K_s

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)

- client need to make sure server is correct
- server does not need to make sure client is correct

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

→ 确保前面没有被 MAC 保护的 MSG 是正确的

Real SSL: handshaking (3)

last 2 steps protect handshake from tampering

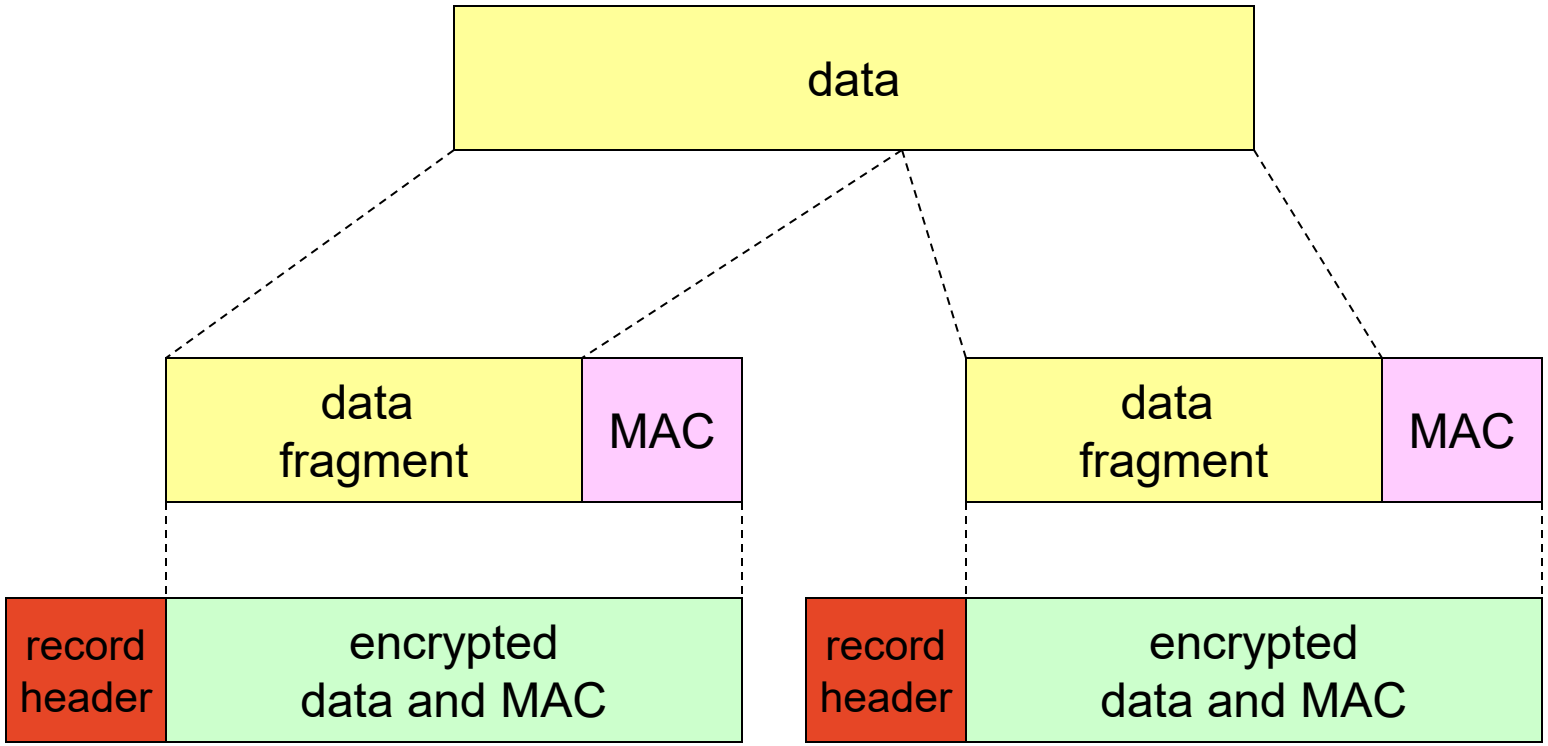
- client typically offers range of algorithms, some strong, some weak
- man-in-the middle could delete stronger algorithms from list
- last 2 steps prevent this
  - last two messages are encrypted

↓这样就使用 weak 会导致 easy 工夫

Real SSL: handshaking (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

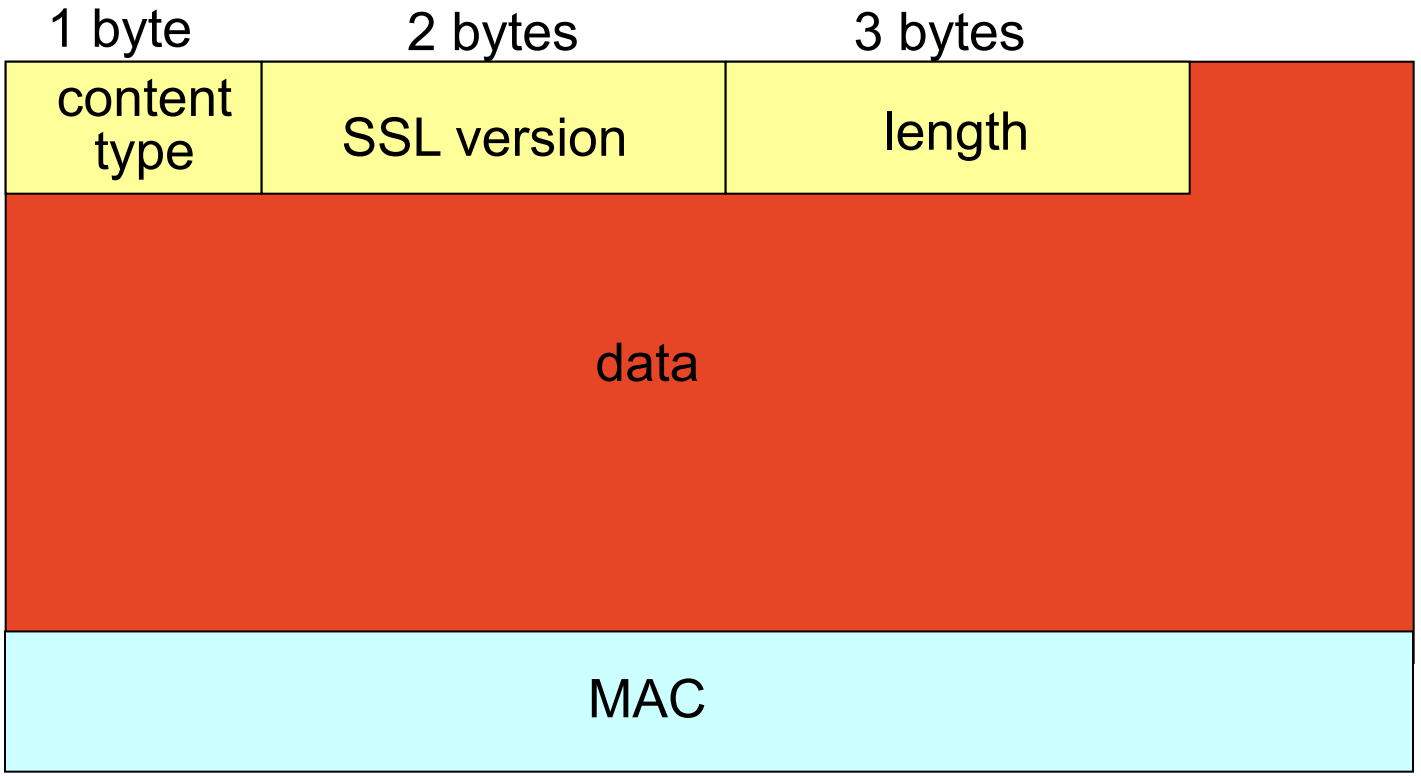


record header: content type; version; length

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)

Nonce 1, Available cipher suite

N_1

handshake: ClientHello

handshake: ServerHello

Nonce 2, Choose cipher suite

N_2

handshake: Certificate K_B^+

handshake: ServerHelloDone

Attacker never know N_3 因为不用MAC发过

Pre-master secret (Random number)

N_3

$K_B^+(N_3)$

$K_B^+(N_3)$ server does not need to verify client

K_A^+ handshake: ClientKeyExchange

ChangeCipherSpec

Master secret=KDF(N_1, N_2, N_3)

May or may not check client's certificate

handshake: Finished

Master secret=KDF(N_1, N_2, N_3)

Session key and MAC key are generated from master secret

ChangeCipherSpec

handshake: Finished

application_data

application_data

Alert: warning, close_notify

TCP FIN follows

Network layer security: IPsec

What is network-layer confidentiality ?

between two network entities:

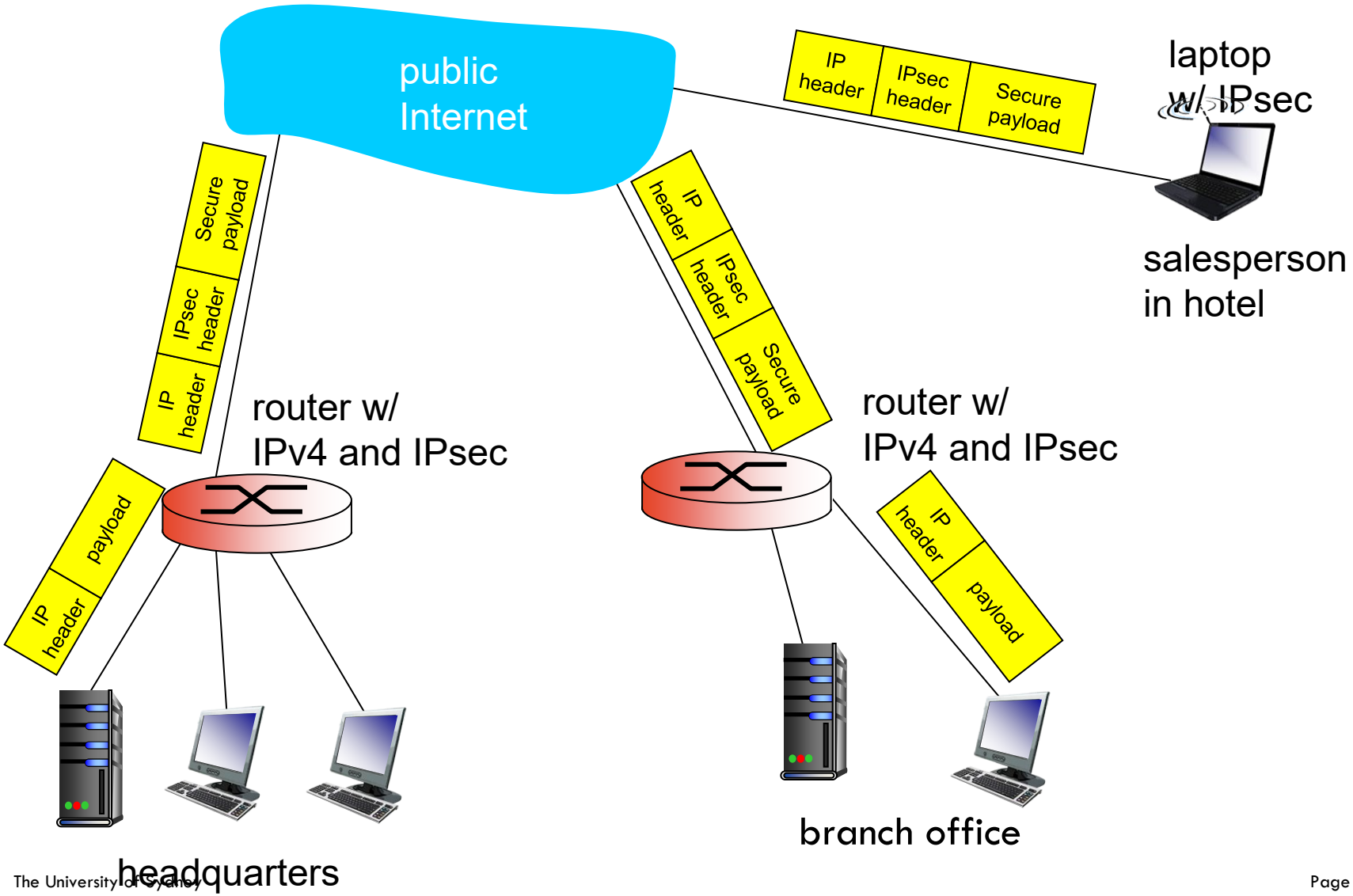
- sending entity encrypts datagram payload, payload could be:
  - TCP or UDP segment, ICMP message, OSPF message ….
- all data sent from one entity to other would be hidden:
  - web pages, e-mail, P2P file transfers, TCP SYN packets …
- "blanket coverage"

Virtual Private Networks (VPNs)

motivation:

- institutions often want private networks for security.
  - costly: separate routers, links, DNS infrastructure.
- VPN: institution's inter-office traffic is sent over public Internet instead
  - encrypted before entering public Internet

Virtual Private Networks (VPNs)

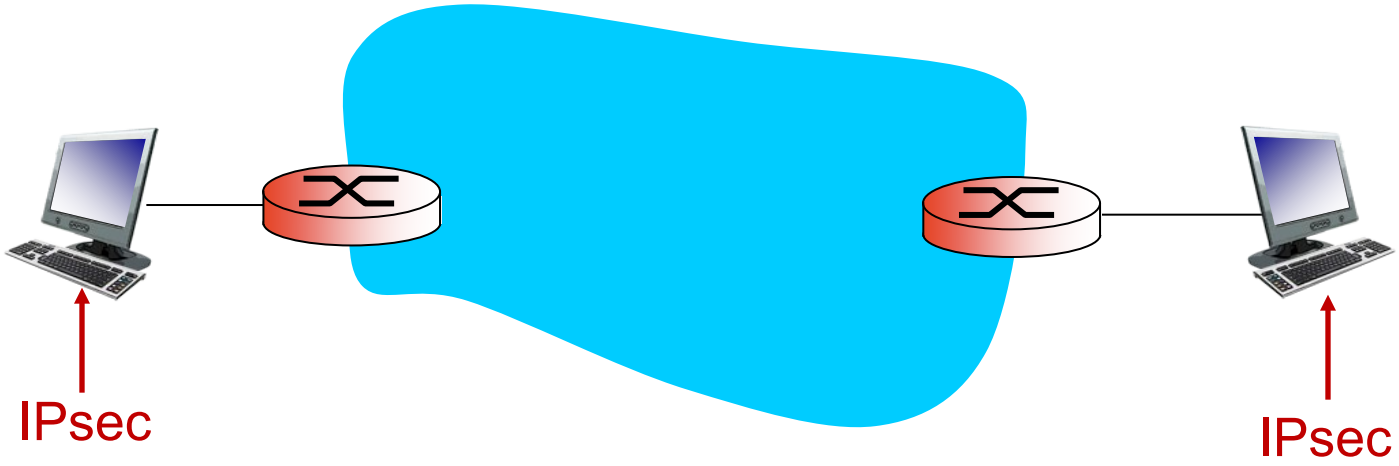


IPsec services

- data integrity
- origin authentication
- replay attack prevention
- confidentiality

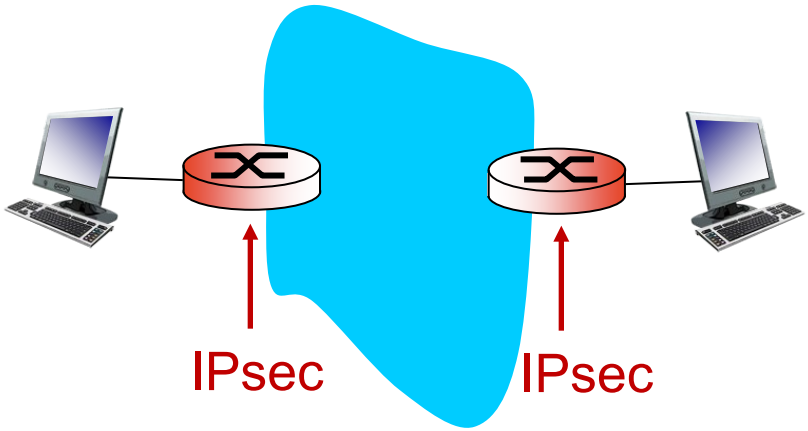
- two protocols providing different service models:
  - AH: Authentication Header
  - ESP: Encapsulation Security Protocol

IPsec transport mode

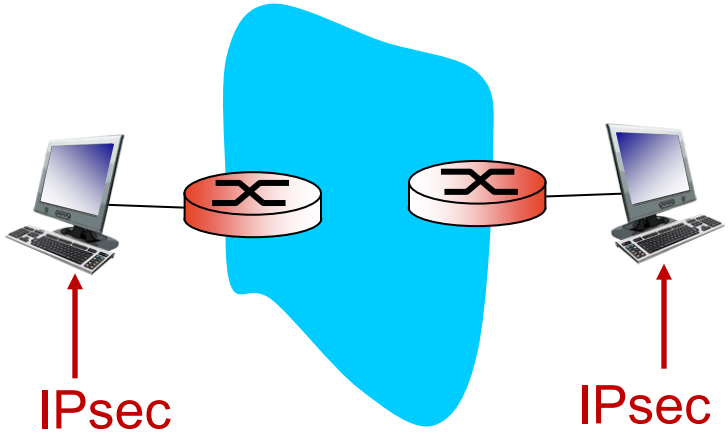


- IPsec datagram emitted and received by end-system
- protects upper level protocols

IPsec – tunneling mode



– edge routers IPsec-aware



- hosts IPsec-aware

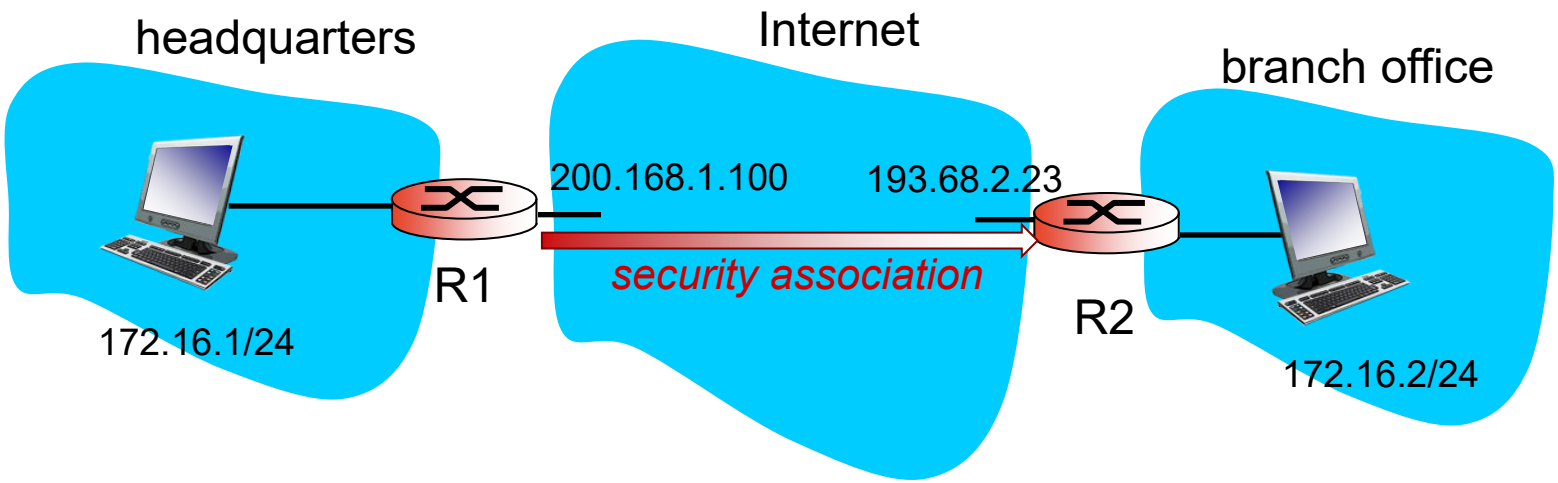
Two IPsec protocols

1. Authentication Header (AH) protocol
   - provides source authentication & data integrity but *not* confidentiality
2. Encapsulation Security Protocol (ESP) mostly used
   - provides source authentication, data integrity, *and confidentiality*
   - more widely used than AH

Security associations (SAs)

- before sending data, "security association (SA)" established from sending to receiving entity
  - SAs are simplex: for only one direction

Example SA from R1 to R2



R1 stores for SA:

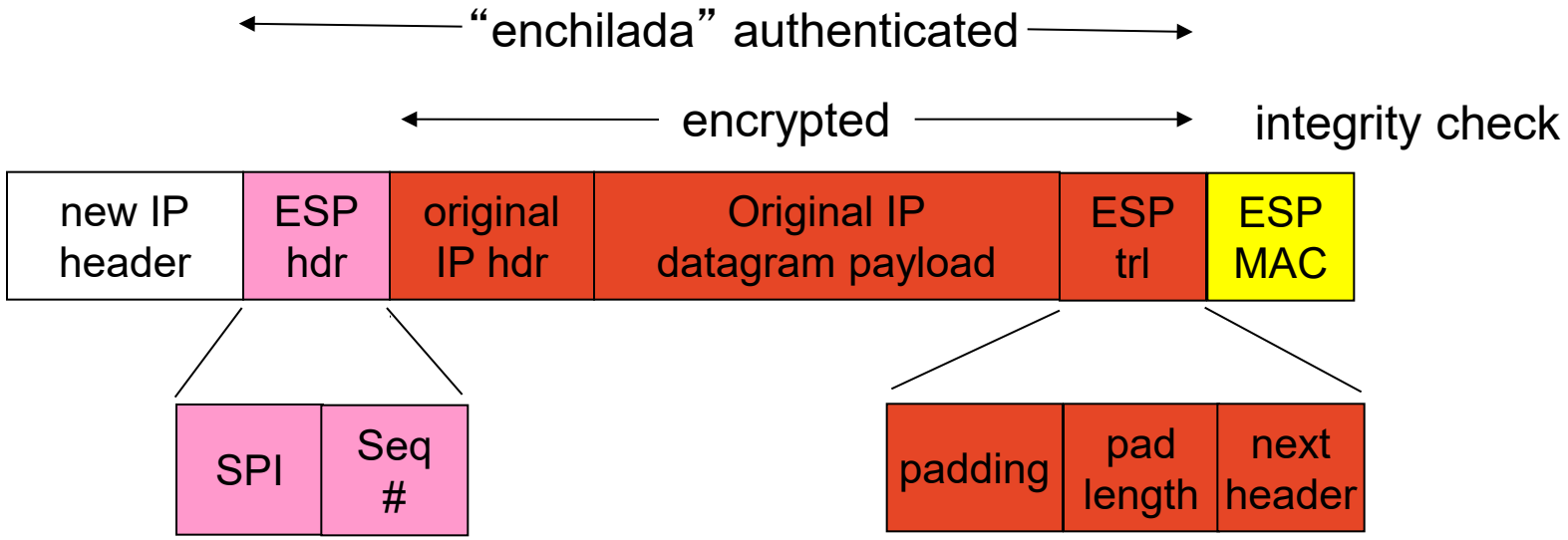
- 32-bit SA identifier: *Security Parameter Index (SPI)*
- origin SA interface (200.168.1.100)
- destination SA interface (193.68.2.23)
- type of encryption used
- encryption key
- type of integrity check used
- authentication key

Security Association Database (SAD)

- endpoint holds SA state in *security association database (SAD)*, where it can locate them during processing.
- when sending IPsec datagram, R1 accesses SAD to determine how to process datagram.
- when IPsec datagram arrives to R2, R2 examines SPI in IPsec datagram, indexes SAD with SPI, and processes datagram accordingly.

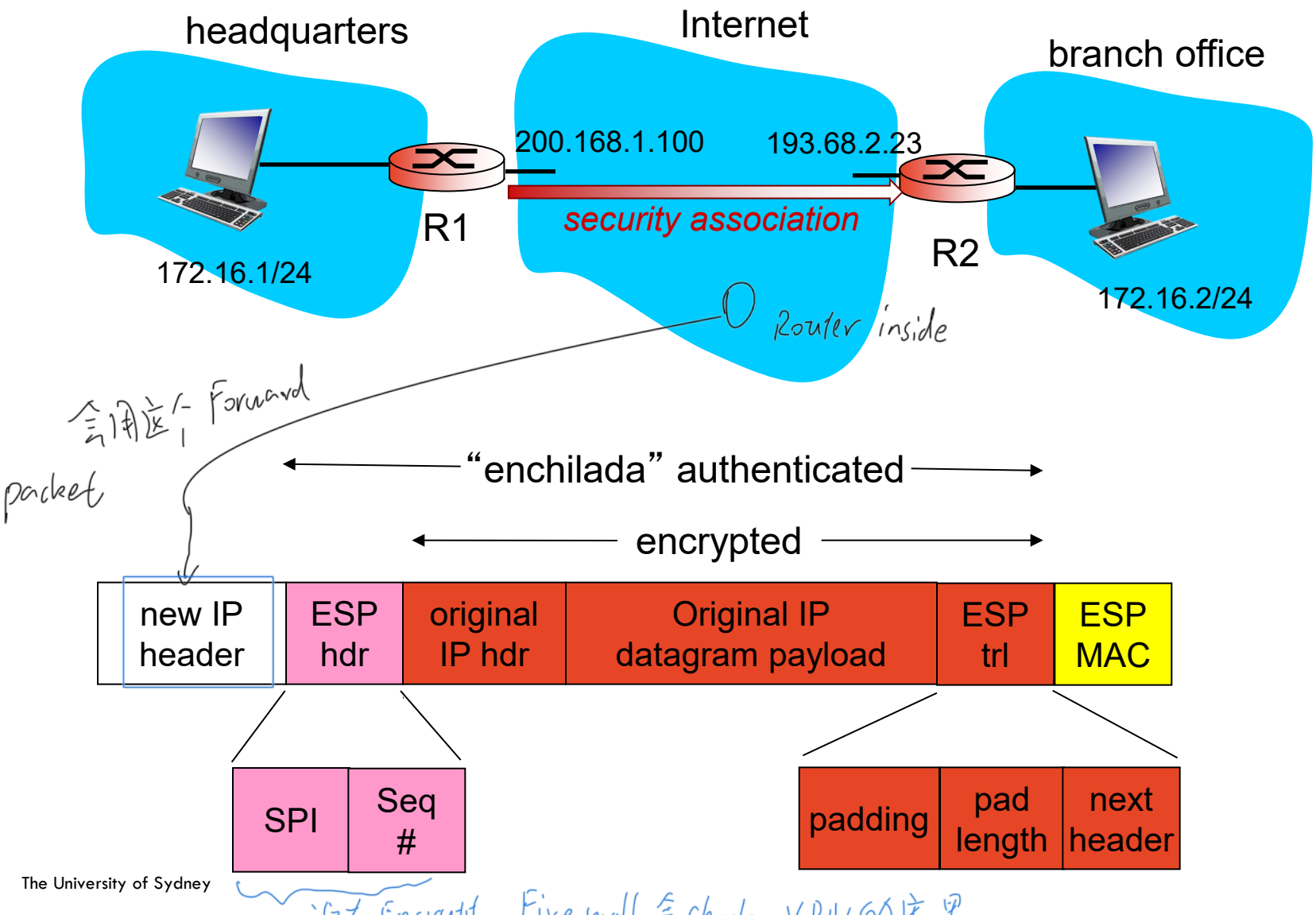
IPsec datagram

focus for now on tunnel mode with ESP



Type of payload: TCP/UDP

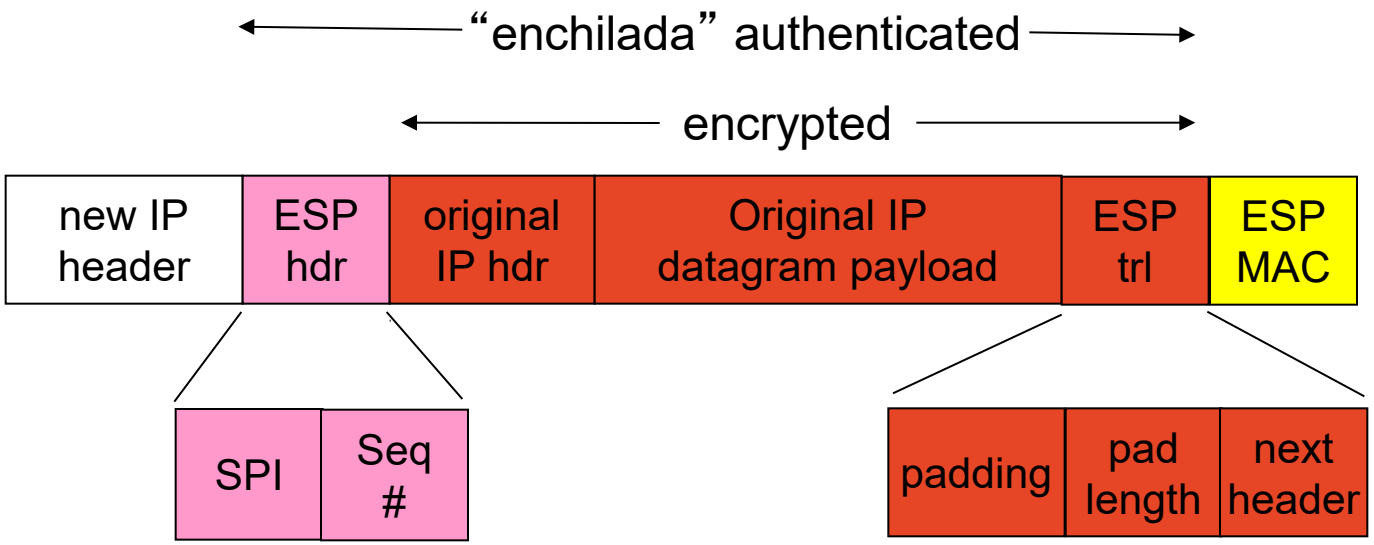
What happens?



R1: convert original datagram to IPsec datagram

- appends to back of original datagram (which includes original header fields!) an "ESP trailer" field.
- encrypts result using algorithm & key specified by SA.
- appends to front of this encrypted quantity the "ESP header, creating "enchilada".
- creates authentication MAC over the *whole enchilada*, using algorithm and key specified in SA;
- appends MAC to back of enchilada, forming *payload*;
- creates brand new IP header, with all the classic IPv4 header fields, which it appends before payload

Inside the enchilada:



- ESP trailer: Padding for block ciphers
- ESP header:
  - SPI, so receiving entity knows what to do
  - Sequence number, to thwart replay attacks
- MAC in ESP field is created with shared secret key

IKE: Internet Key Exchange

- *previous examples:* manual establishment of IPsec SAs in IPsec endpoints:

  Example SA

  SPI: 12345
  Source IP: 200.168.1.100
  Dest IP: 193.68.2.23
  Protocol: ESP
  Encryption algorithm: 3DES-cbc
  HMAC algorithm: MD5
  Encryption key: 0x7aeaca…
  HMAC key:0xc0291f…

- manual keying is impractical for VPN with ~100 endpoints

- instead use *IPsec IKE (Internet Key Exchange)*

IKE phases

user → 2 → 3 → 4 → ... → n
establish security conversation

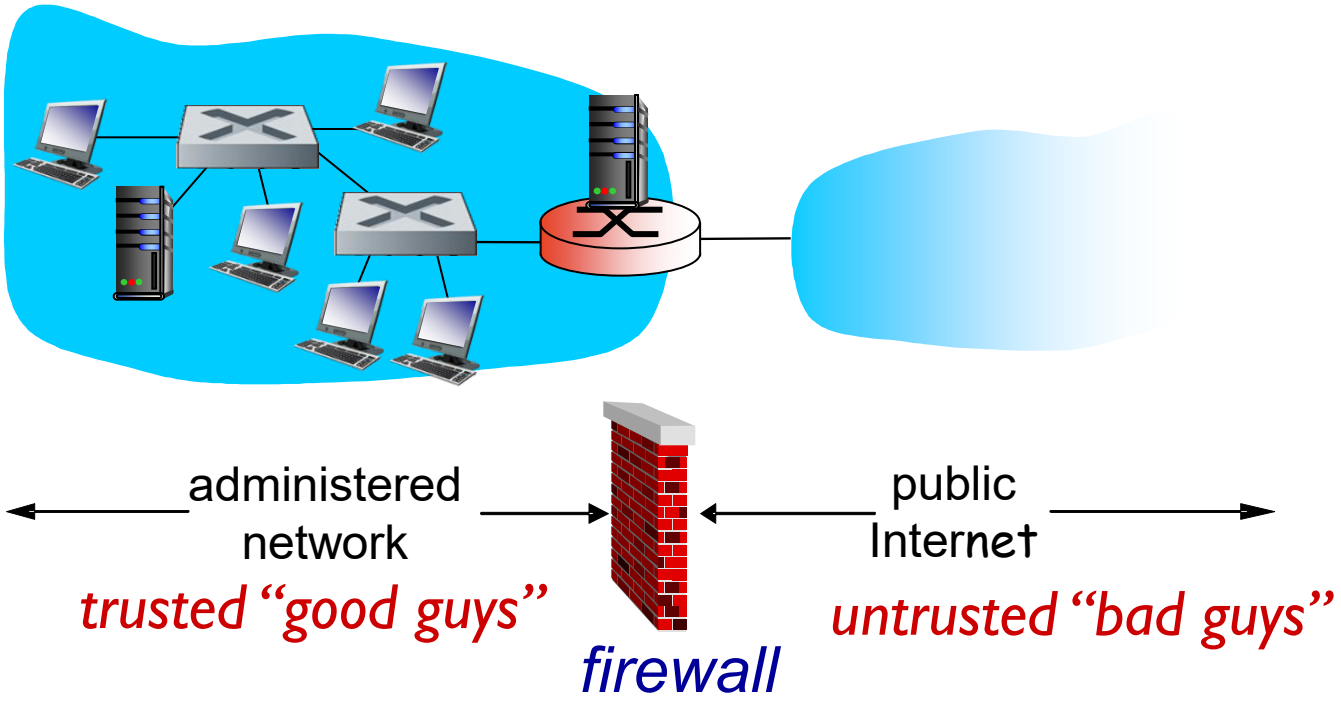
- IKE has two phases
  - *phase 1:* establish bi-directional IKE SA
    - note: IKE SA different from IPsec SA
  - *phase 2:* ISAKMP (Internet Security Association and Key Management Protocol) is used to securely negotiate IPsec pair of SAs

Firewalls and Intrusion Detection Systems (IDS)

Firewalls

firewall

isolates organization's intranet from larger Internet, allowing some packets to pass, blocking others



Firewalls: why

prevent denial of service attacks:

让server误认为有很多User

- SYN flooding: attacker establishes many bogus TCP connections, no resources left for "real" connections

prevent illegal modification/access of internal data

- e.g., attacker replaces Amazon's homepage with something else

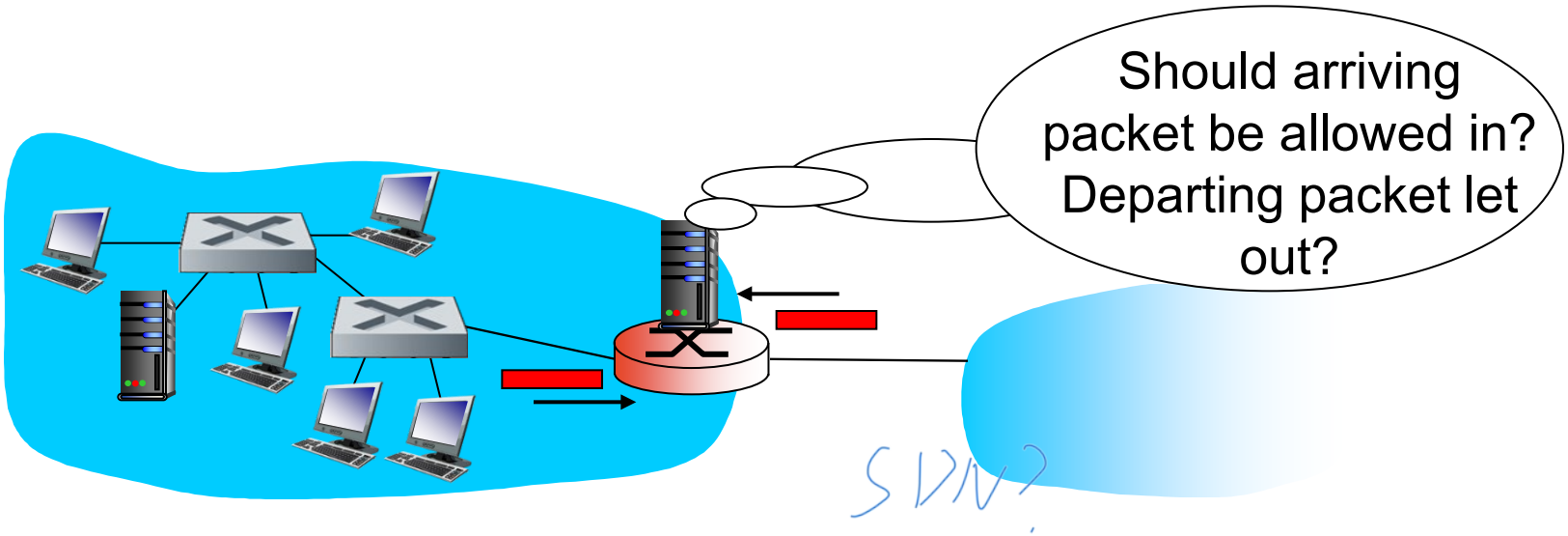
allow only authorized access to inside network

- set of authenticated users/hosts

three types of firewalls:

- stateless packet filters
- stateful packet filters
- application gateways

Stateless packet filtering



- internal network connected to Internet via *router firewall*
- router *filters packet-by-packet,* decision to forward/drop packet based on:
  - source IP address, destination IP address
  - TCP/UDP source and destination port numbers
  - ICMP message type
  - TCP SYN and ACK bits

Stateless packet filtering: example

- *example 1:* block incoming and outgoing datagrams with IP protocol field = 17 and with either source or dest port = 23
  - *result:* all incoming, outgoing UDP flows and telnet connections are blocked port # correspond to specific App
- *example 2:* block inbound TCP segments with ACK=0.
  - *result:* prevents external clients from making TCP connections with internal clients, but allows internal clients to connect to outside.

Stateless packet filtering: more examples

Policy	*Firewall Setting*
No outside Web access.	Drop all outgoing packets to any IP address, port 80 or 443
No incoming TCP connections, except those for institution's public Web server only.	Drop all incoming TCP SYN packets to any IP except 130.207.244.203, port 80 or 443
Prevent Web-radios from eating up the available bandwidth.	Drop all incoming UDP packets - except DNS and router broadcasts.
Prevent your network from being used for a smurf DoS attack.	Drop all ICMP packets going to a "broadcast" address (e.g. 130.207.255.255).
Prevent your network from being tracerouted	Drop all outgoing ICMP TTL expired traffic

Access Control Lists

ACL: table of rules, applied top to bottom to incoming packets: (action, condition) pairs: looks like OpenFlow forwarding!

80: Web 53: DNS

action	source address	dest address	protocol	source port	dest port	flag bit
allow	222.22/16	outside of 222.22/16	TCP	> 1023	80	any
allow	outside of 222.22/16	222.22/16	TCP	80	> 1023	ACK
allow	222.22/16	outside of 222.22/16	UDP	> 1023	53	---
allow	outside of 222.22/16	222.22/16	UDP	53	> 1023	----
deny	all	all	all	all	all	all

Stateful packet filtering

- *stateless packet filter:* heavy handed tool
  - admits packets that "make no sense," e.g., dest port = 80, ACK bit set, even though no TCP connection established:

action	source address	dest address	protocol	source port	dest port	flag bit
allow	outside of 222.22/16	222.22/16	TCP	80	> 1023	ACK

- *stateful packet filter:* track status of every TCP connection
  - track connection setup (SYN), teardown (FIN): determine whether incoming, outgoing packets "makes sense"
  - timeout inactive connections at firewall: no longer admit packets

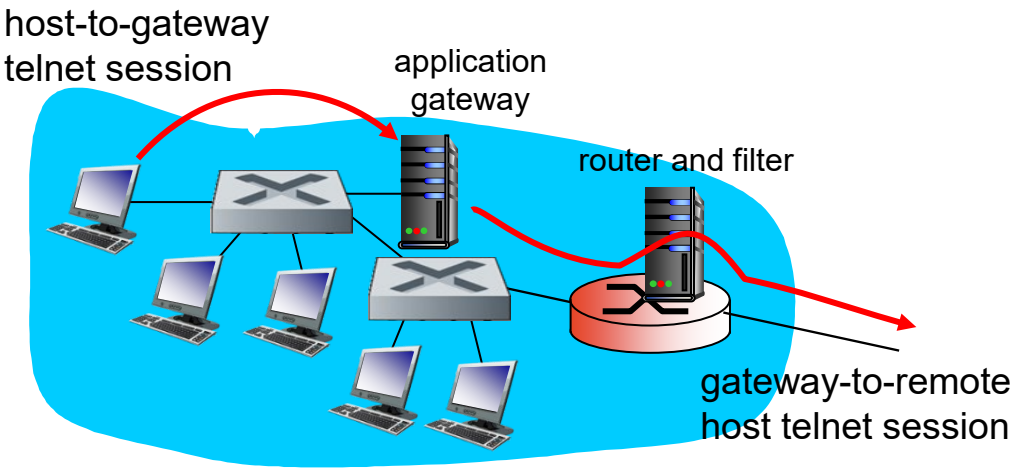
Stateful packet filtering

ACL augmented to indicate need to check connection state table before admitting packet

action	source address	dest address	proto	source port	dest port	flag bit	check conxion
allow	222.22/16	outside of 222.22/16	TCP	> 1023	80	any	
allow	outside of 222.22/16	222.22/16	TCP	80	> 1023	ACK	check
allow	222.22/16	outside of 222.22/16	UDP	> 1023	53	---	
allow	outside of 222.22/16	222.22/16	UDP	53	> 1023	----	check
deny	all	all	all	all	all	all	

Application gateways

- filter packets on application data as well as on IP/TCP/UDP fields.
- *example:* allow select internal users to telnet outside



1. require all telnet users to telnet through gateway.
2. for authorized users, gateway sets up telnet connection to dest host. Gateway relays data between 2 connections
3. router filter blocks all telnet connections not originating from gateway.

Limitations of firewalls, gateways

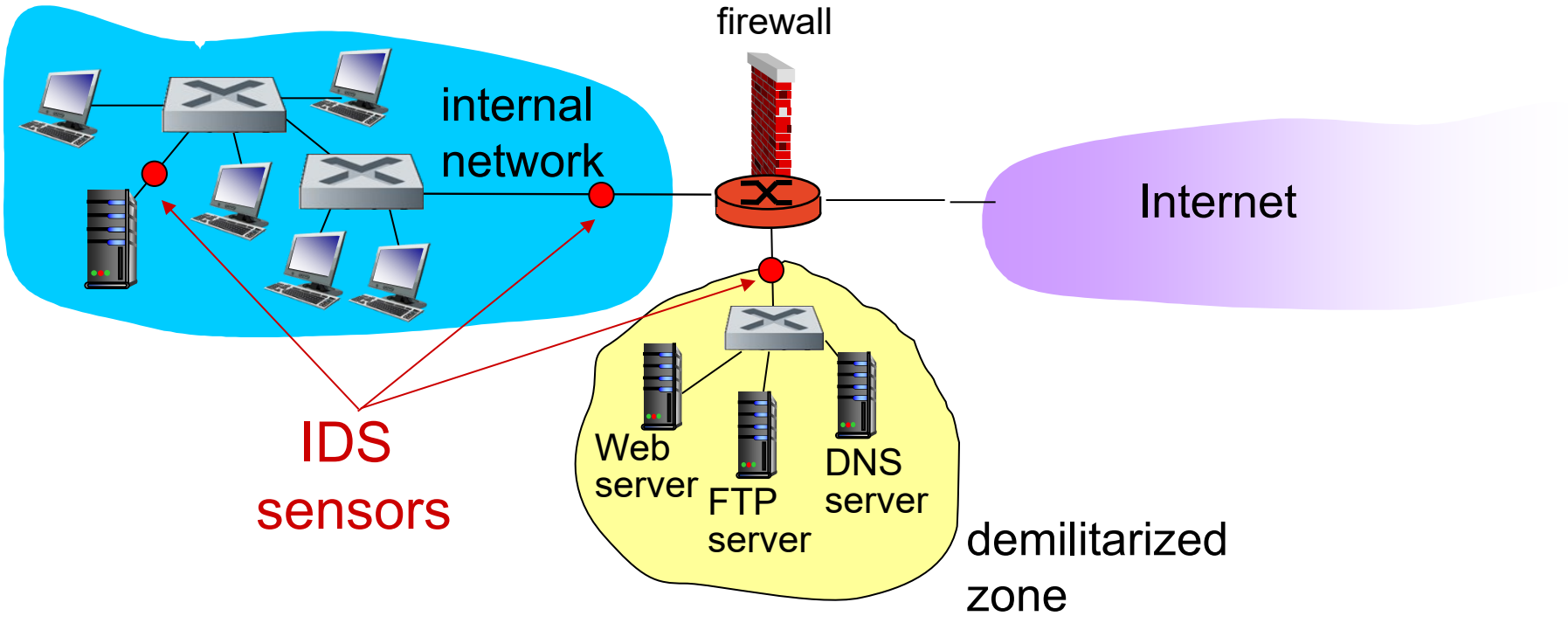
- *IP spoofing:* router can't know if data "really" comes from claimed source
- if multiple app's. need special treatment, each has own app. gateway
- client software must know how to contact gateway.
  - e.g., must set IP address of proxy in Web browser
- filters often use all or nothing policy for UDP
- *tradeoff:* degree of communication with outside world, level of security
- many highly protected sites still suffer from attacks

Intrusion detection systems

- packet filtering:
  - operates on TCP/IP headers only
  - no correlation check among sessions
- *IDS: intrusion detection system*
  - *deep packet inspection:* look at packet contents (e.g., check character strings in packet against database of known virus, attack strings)
  - examine correlation among multiple packets
    - port scanning
    - network mapping
    - DoS attack

Intrusion detection systems

multiple IDSs: different types of checking at different locations



Network Security (summary)

basic techniques…...

- cryptography (symmetric and public)
- message integrity
- end-point authentication

…. used in many different security scenarios

- secure email
- secure transport (SSL)
- IP sec

operational security: firewalls and IDS