Network Security Solutions

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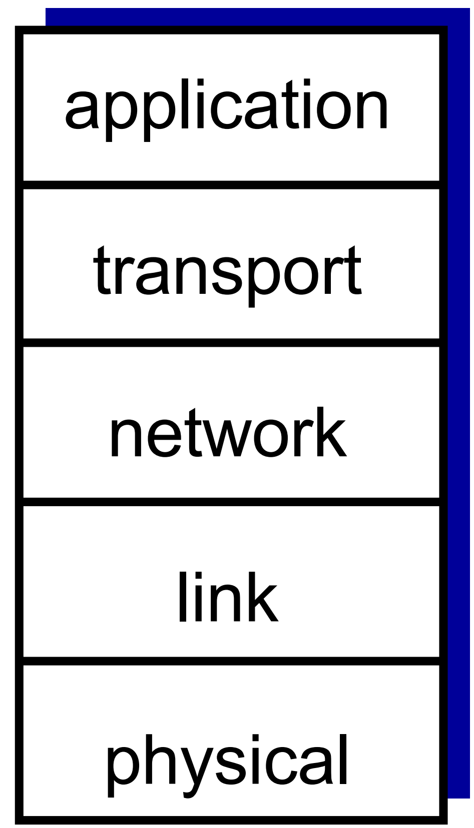
Learning Objectives

- Basic concepts
- Routing Security (Network Layer)
- IPSec (Network Layer)
- SSL/TLS (Transport Layer)
- Firewalls and Intrusion Detection Systems

Basic Concepts

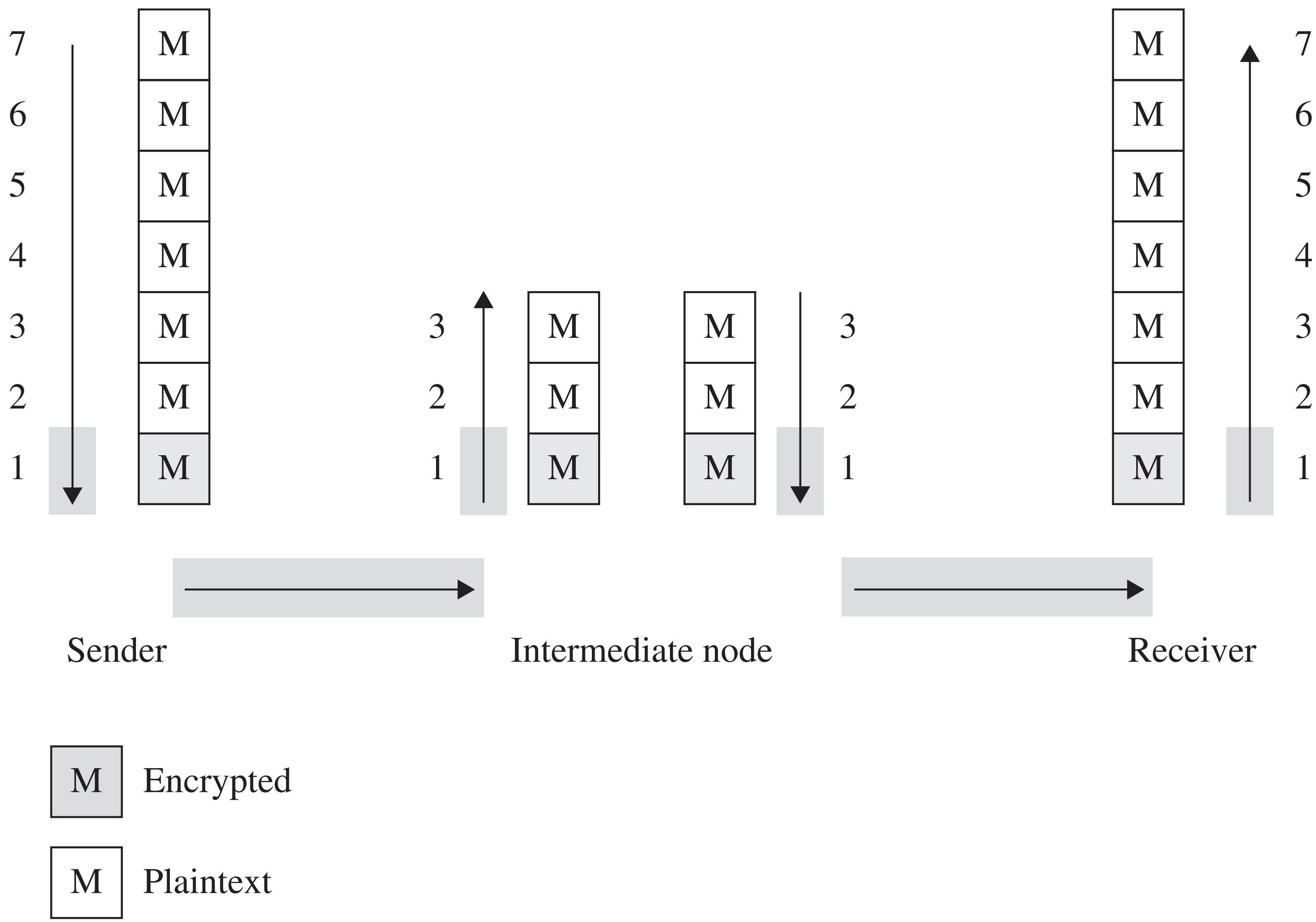
Layered Network Security

- We focus on the Internet
- Security attacks toward the Internet can happen at each layer
- Let's look at security defense at each layer
  - For example, what may happen at the physical layer?

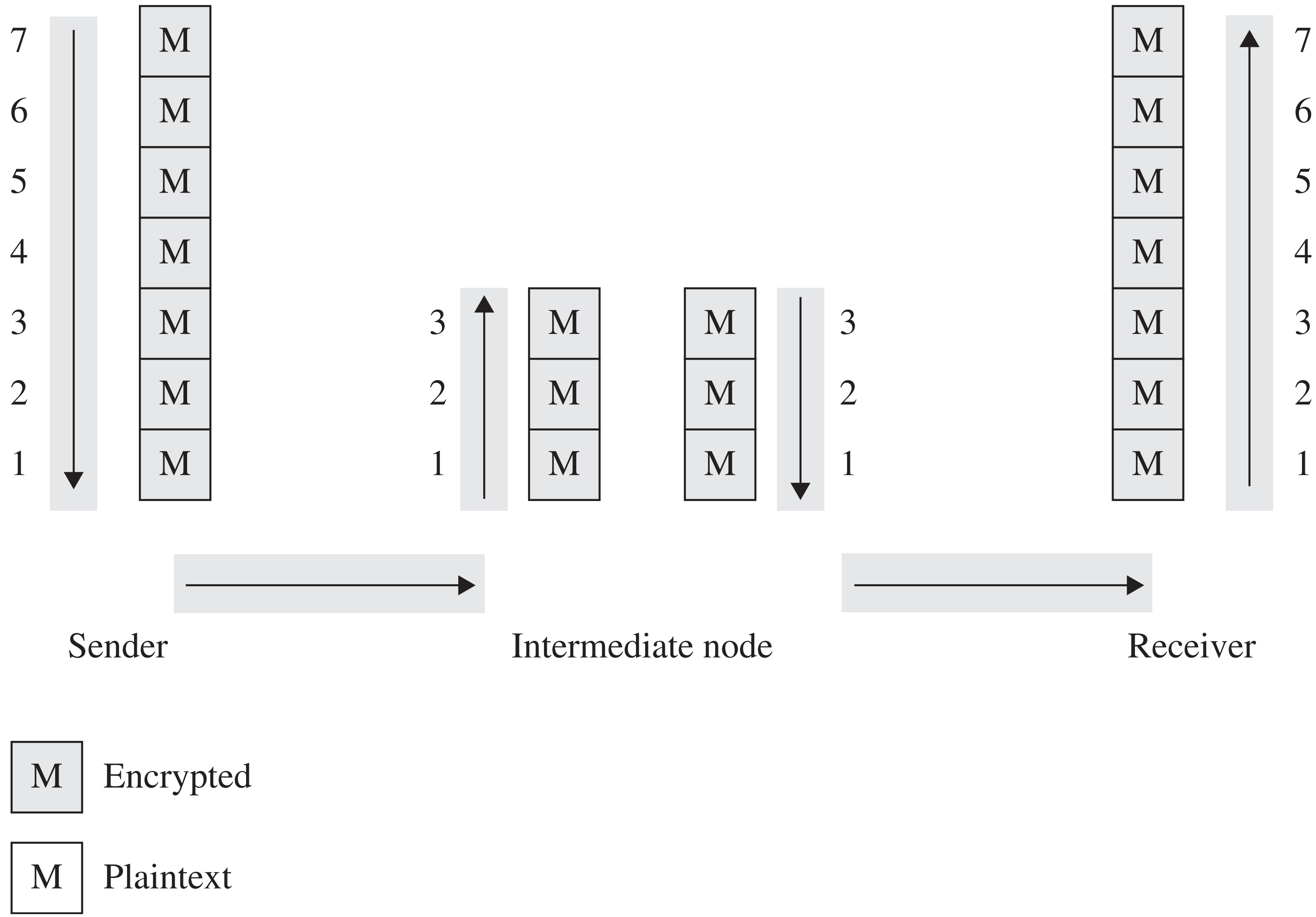


Link Layer

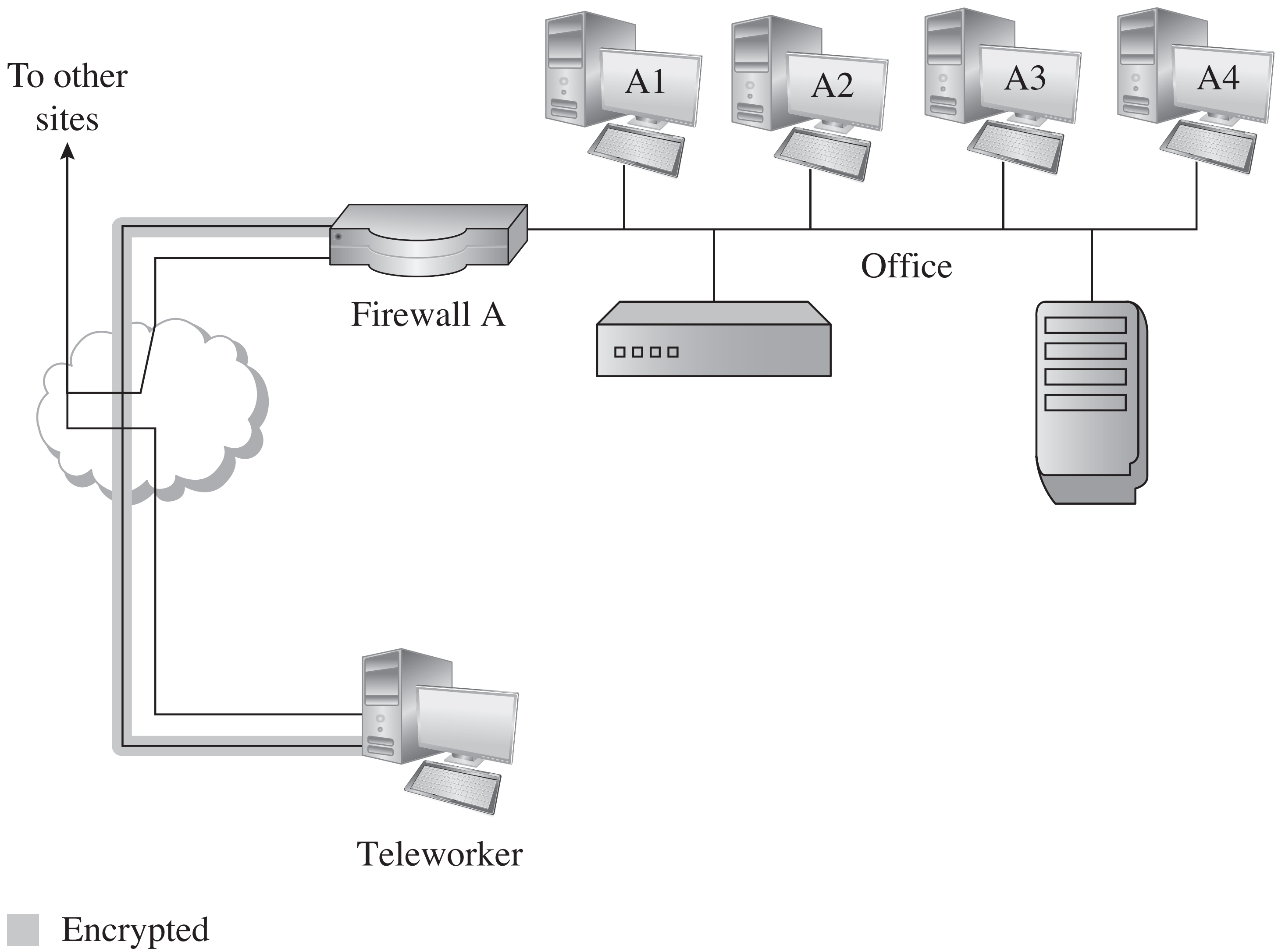
Link Encryption



End-to-End Encryption



VPN


To other sites
A1
A2
A3
A4
Firewall A
Office
Teleworker
Encrypted

Network Layer

Network Layer Security

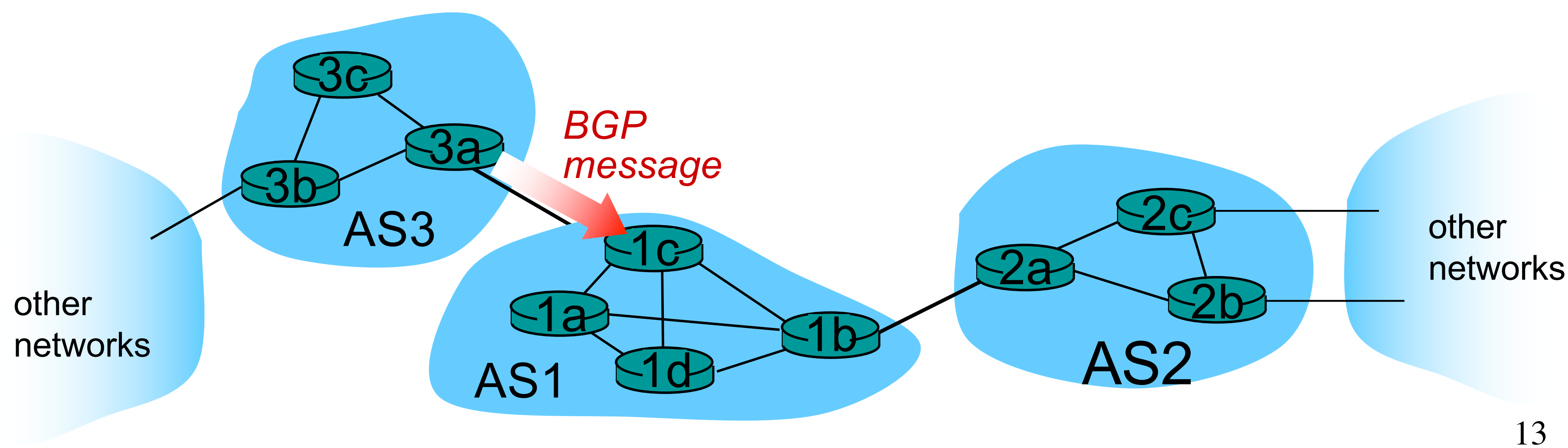
- Routing Security
- IPSec

Routing Security

BGP basics

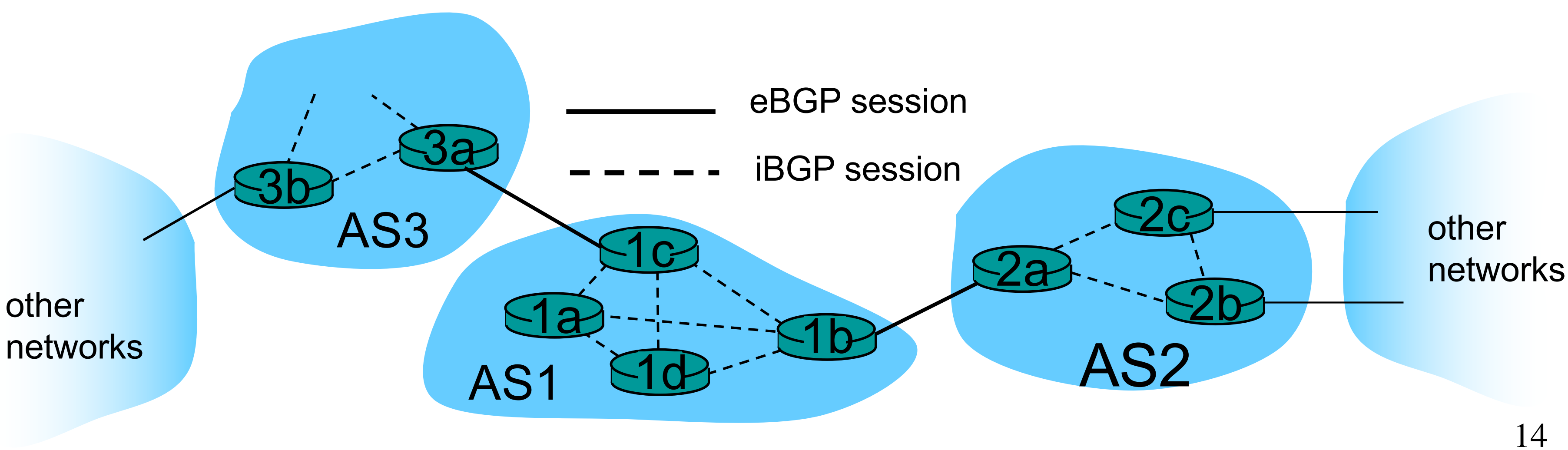
- **BGP session:** two BGP routers ("peers") exchange BGP messages:
  - advertising *paths* to different destination network prefixes ("path vector" protocol)
  - exchanged over semi-permanent TCP connections

- when AS3 advertises a prefix to AS1:
  - AS3 *promises* it will forward datagrams towards that prefix
  - AS3 can aggregate prefixes in its advertisement



BGP basics: distributing path information

- using eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1.
  - 1c can then use iBGP to distribute new prefix info to all routers in AS1
  - 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- when router learns of new prefix, it creates entry for prefix in its forwarding table.



Routing Attacks

- Internet routing is not secure
  - Routers trust each other?
  - Many routing attacks have happened
- Origin
  - Blackhole attack
- Path
  - Prefix hijacking

How to Secure Routing?

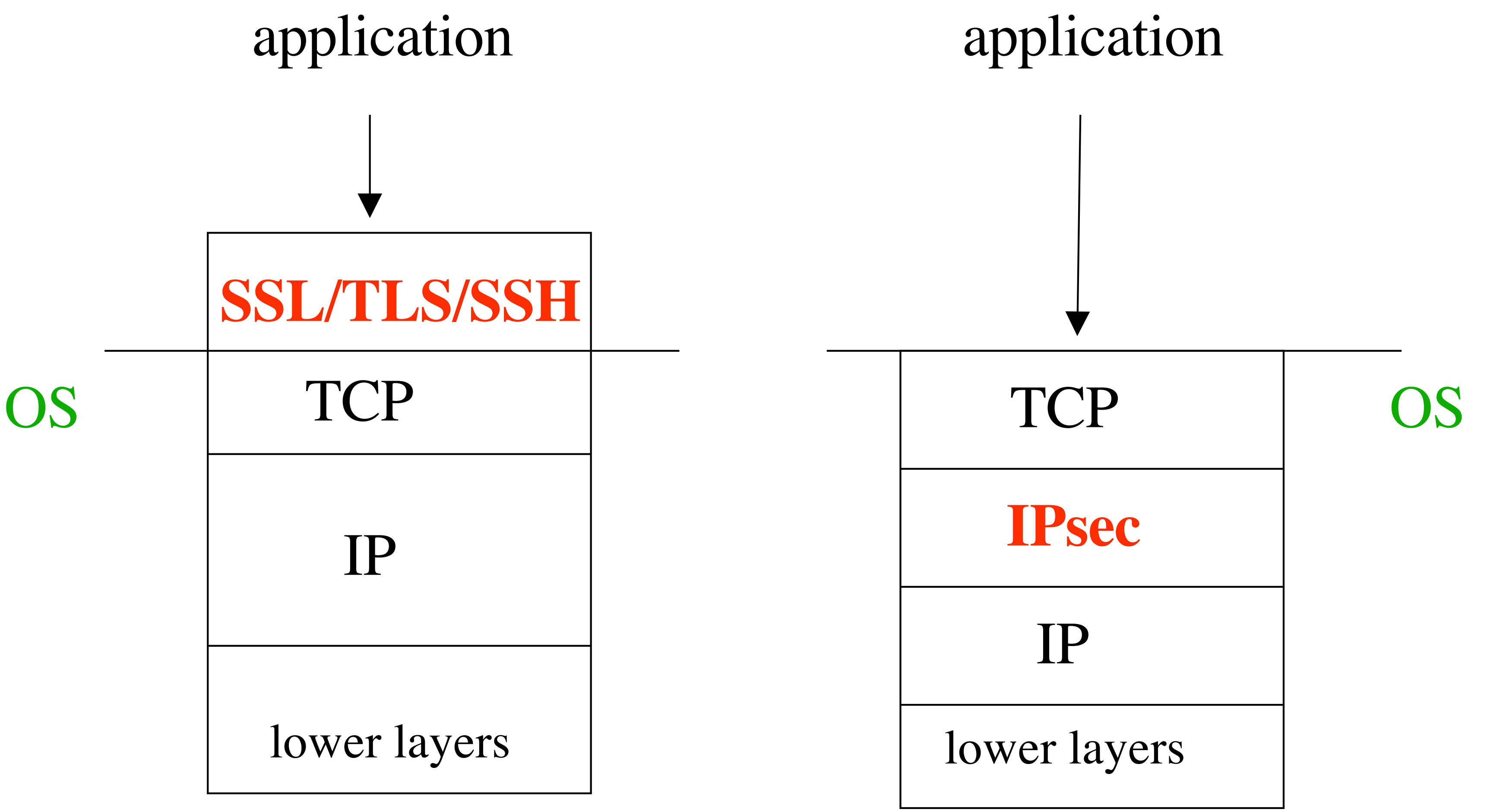
- Origin Authentication
  - Sign who you are
- Path Authentication
  - Sign your attestation: I have seen this path.
  - {A, sig_by_A}
  - {B, {A, sig(A)}, sig_by_B}
  - {C, {B, {A, sig(A)}}, sig_by_B}, sig_by_C
  - …

IPsec

IPsec as a Real-Time Protocol

- A real-time protocol is one where parties negotiate interactively to authenticate each other and establish a session key
  - The conversation protected using the session key is called **security association**
- Examples: IPsec, SSL/TLS, SSH
  - Public key based

Security at Layer 4 vs. 3



Assumption: TCP/IP are in the OS

Pros and Cons

- Security at layer 4 (SSL/TLS/SSH)
  - \+ No need to change OS
  - – Applications have to be modified
  - – No way to tell TCP layer whether newly received data is bogus or real
    - Such as a sequence number attack
- Security at layer 3 (IPsec)
  - \+ Transparent to applications
  - – OS needs to modified
  - – Security is in terms of IP addresses
    - IPsec authentication cannot distinguish between users

IPsec User Model

- Alice and Bob sets up a secure channel
  - Called **Security Association**
- Then rely on IPsec to protect the channel

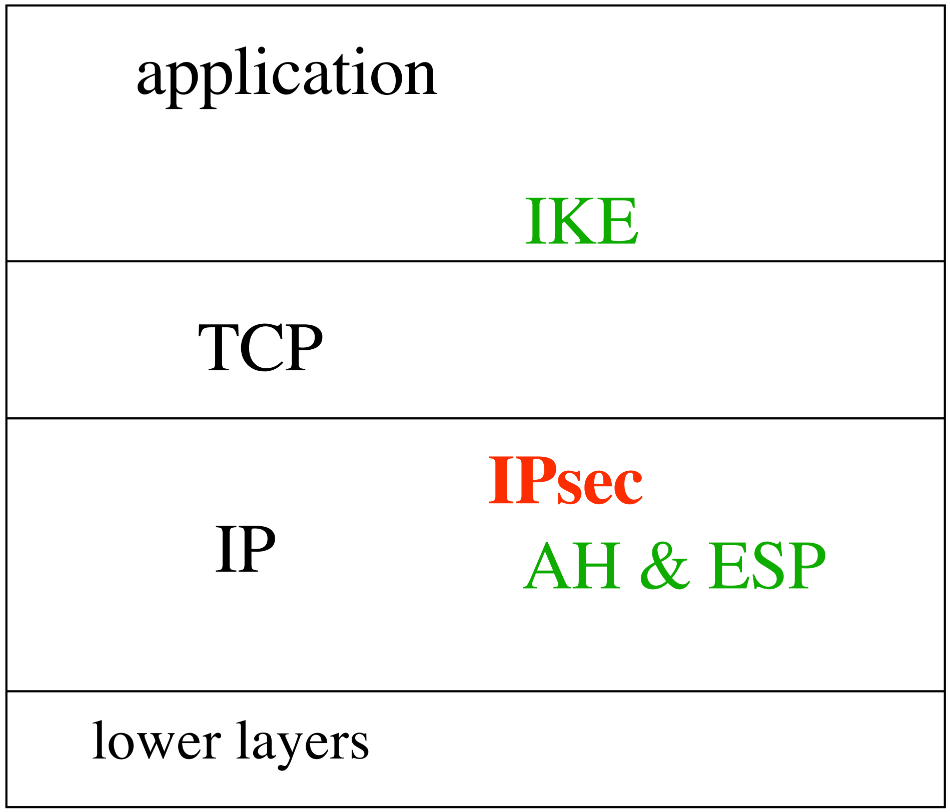
What does IPsec Accomplish?

- Encrypted traffic
- Connectionless Integrity
- Anti replay
- More secure authentication based on source IP address
- Enforced access control based on a policy database

- Similar to setting up two firewalls between two ends

Main Pieces

- AH & ESP
  - IP header extensions for carrying cryptographically protected data
- IKE
  - A protocol for establishing security associations (SA) and establishing session keys
  - Not required for IPsec but recommended
    - IPsec also supports manual SAs/keying


application
IKE
TCP
IPsec
IP
AH & ESP
lower layers

IPsec Deployment

- Individual host: an end system can implement its own protection end-to-end or hop-by-hop
- Host community: a single security gateway (e.g. a firewall) can protect an entire domain of hosts
- Pairings: host-to-host, host-to-gateway, gateway-to-gateway
  - Or combined

Security Association

- An unidirectional cryptographically protected connection
  - Communication between Alice and Bob consists of two SAs, one for each direction
- Each end remembers:
  - Id of the other end
  - A cryptographic key
  - Sequence number currently being used
  - Cryptographic services being used
    - Integrity only, encryption only, or both
    - Which cryptographic algorithms

Security Association Database

- A security association database **(SAD)** is used to remember those info above for every **active** security association
  - Indexed by **security parameter index (SPI)**
- Thus an IPsec-capable node knows how to communicate with a given destination
  - A packet from Alice to Bob should tell Bob the SPI value that Bob can use to locate the Alice-Bob SA entry in his SAD

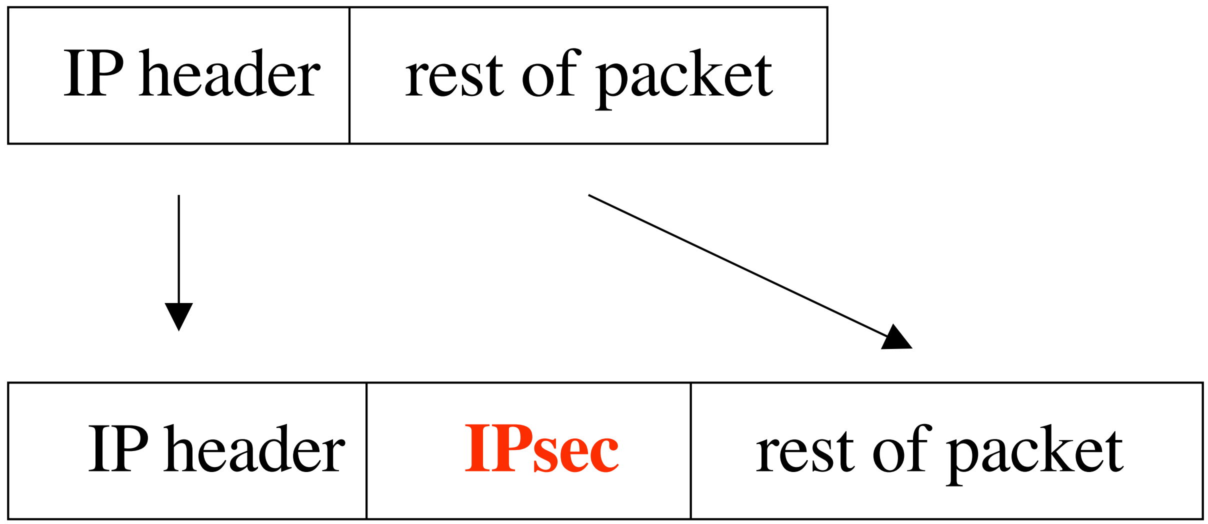
AH & ESP

- AH provides integrity protection
  - For payload and some fields in IP header
- ESP provides encryption and/or integrity protection
  - For payload
  - The encryption algorithm can be “null” or others

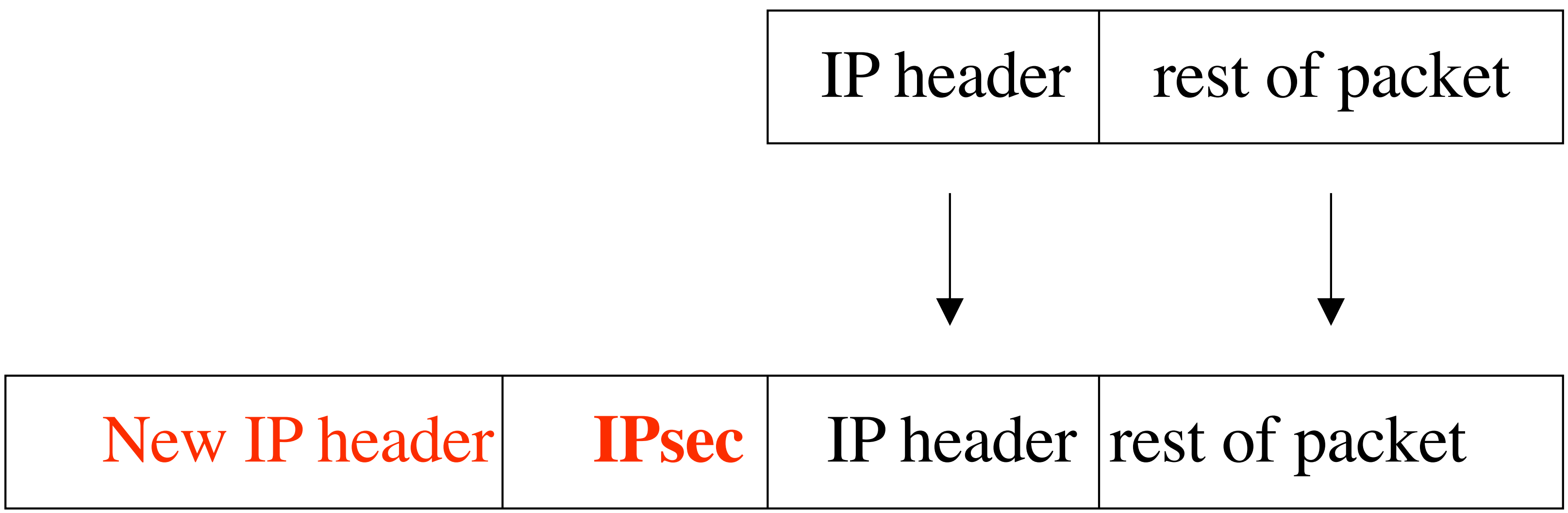
Two IPsec Modes

- Transport mode
- Tunnel mode

Transport Mode



Tunnel Mode


IP header
rest of packet
New IP header
IPsec
IP header
rest of packet

Mode Selection

- Transport mode is most logical when applying IPsec for end-to-end communication
- A tunnel mode is good for firewall-to-firewall, or end-to-firewall

An Example of Using Tunnel Mode

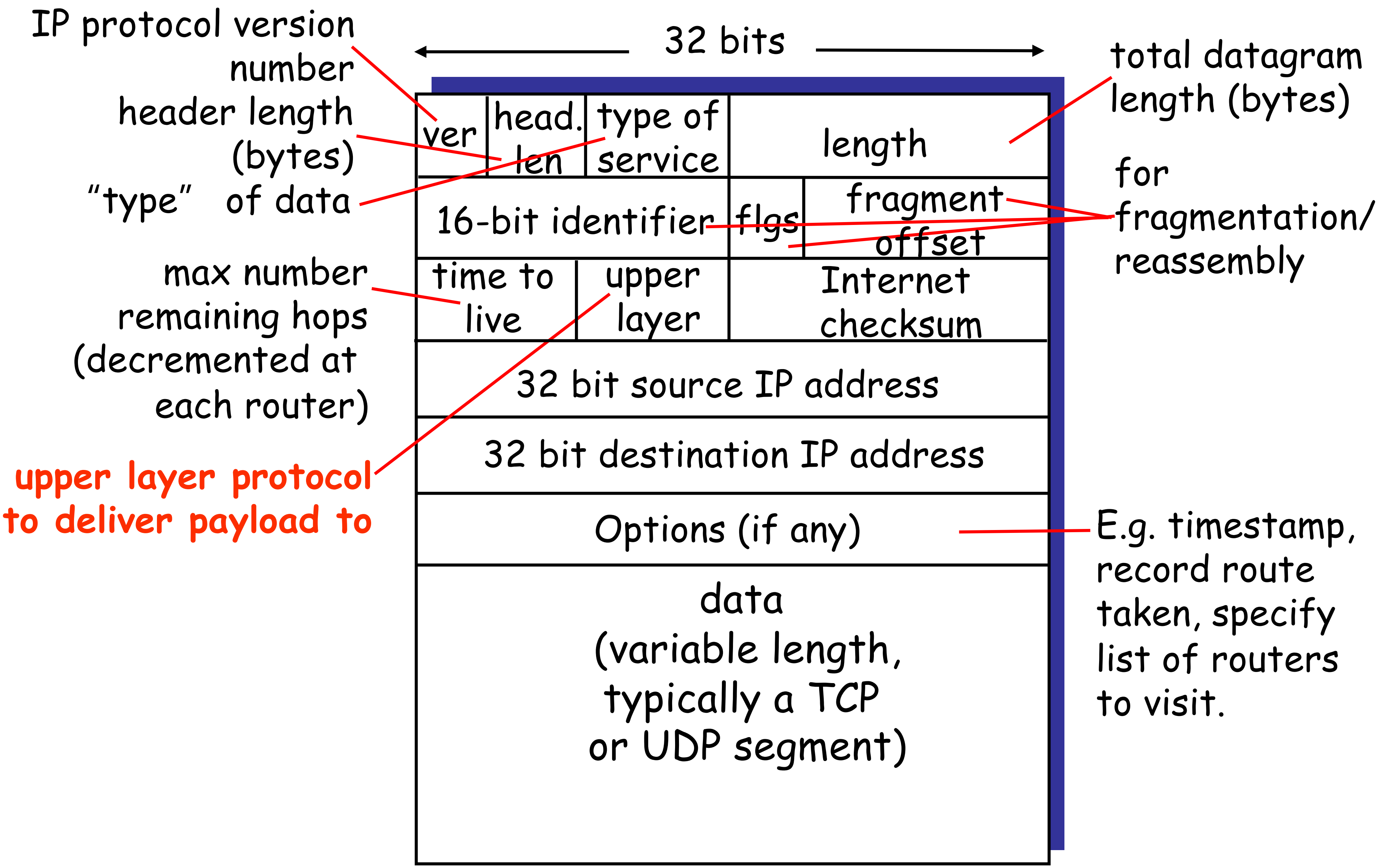
IP: src=F1, dst=F2	ESP	IP: src=A, dst=B	

Format of IPsec-Protected Packets

- A field in the IP header points to AH header or ESP header
  - "Protocol" field in IPv4
  - "Next header" field in IPv6

  - ESP = 50
  - AH = 51
  - (TCP = 6, UDP = 17)

IPv4 Datagram Format



AH - Authentication Header

# octets	
1	next header
1	payload length
2	unused
4	SPI (security parameter index)
4	sequence number
variable	authentication data

AH Fields

- Next header
  - Same as “protocol” field in IPv4
  - If TCP follows the AH header, this field is 6
- Payload length:
  - The size of the AH header (in 32-bit chunks)
- SPI
  - For the recipient to locate the SA entry in its SAD
- Sequence number:
  - For anti-replay purpose
- Authentication data
  - Cryptographic integrity check
  - Those immutable and mutable-but-predictable fields in an IP header are also protected

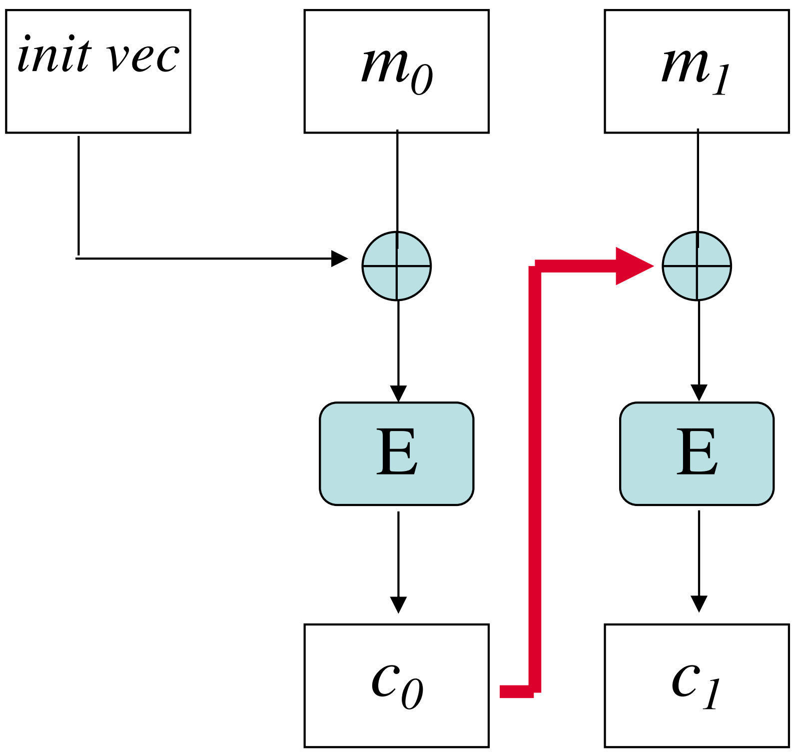
ESP - Encapsulating Security Header

# octets	
4	SPI (security parameter index)
4	sequence number
variable	IV (initialization vector)
variable	data
variable	padding
1	padding length
1	next header / protocol type
variable	authentication data

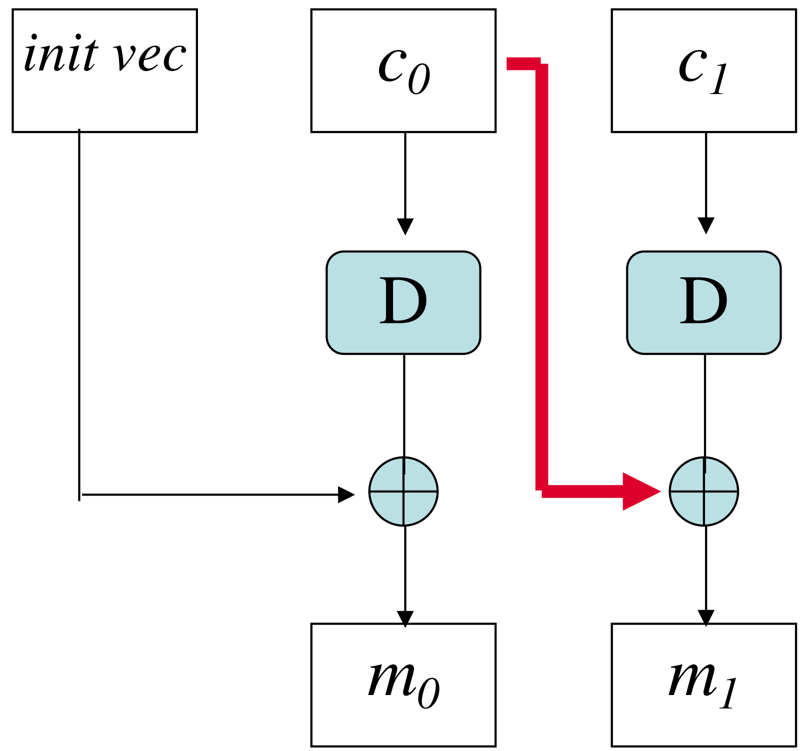
ESP Fields

- Same fields as in AH header:
  - SPI, sequence number, next header
- Initialization vector
  - Needed for some encryption algorithms
    - for example, when CBC mode is used (see next slide)
- Data: protected data, probably encrypted
- Padding: many 0's mainly in order to
  - make data be a multiple of a block size
    - Maybe required by adopted cryptographic algorithms
  - Or make [data, padding, padding length, next header] a multiple of four octets

CBC



Encipherment



Decipherment

(cont’d)

- Authentication data
  - Cryptographic integrity check
  - Zero length if ESP is providing only encryption

More on the Data Field in an ESP Header

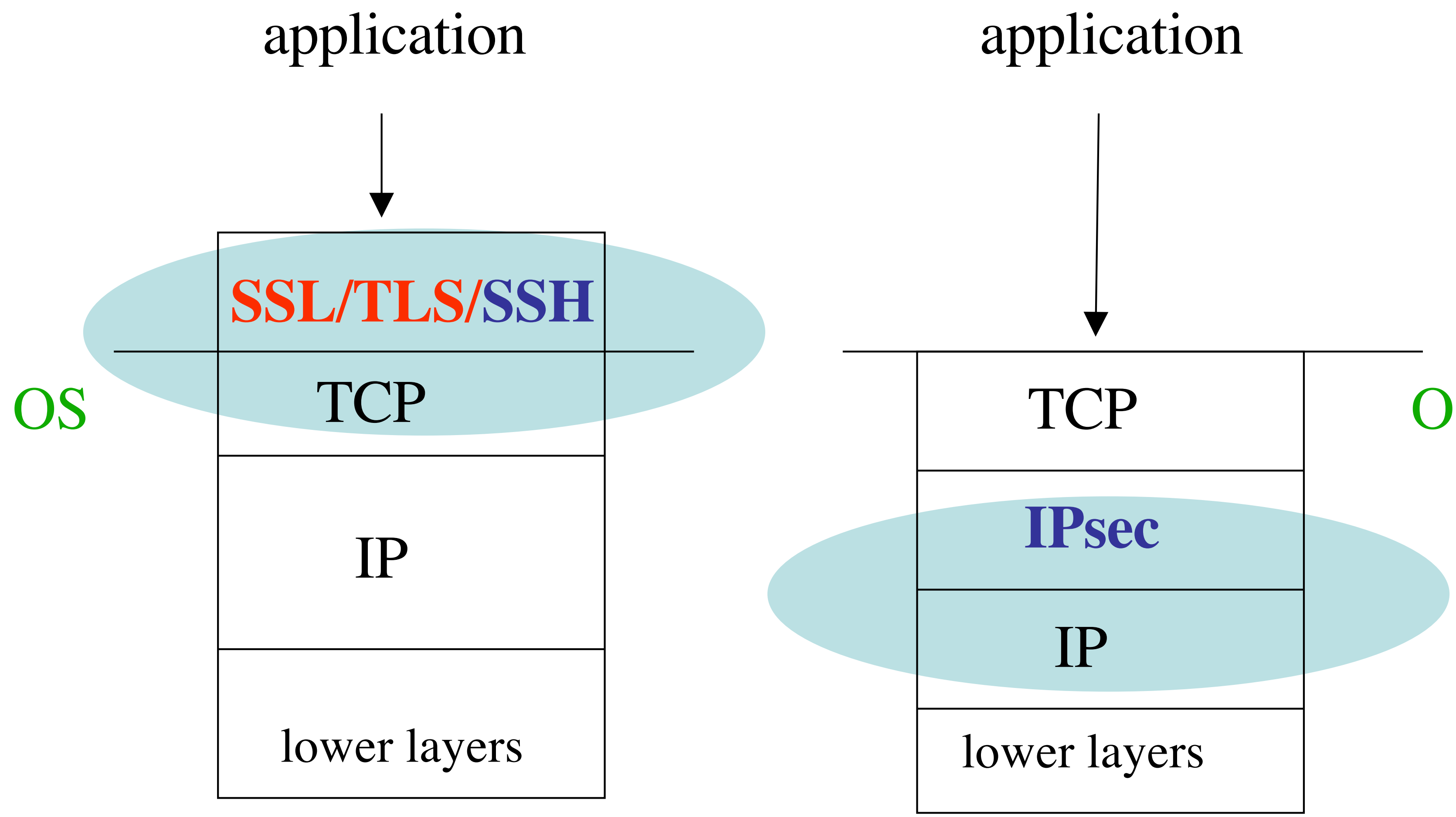
- In Tunnel Mode
  - Begin at the IP header
- In Transport Mode
  - Begin at the IP payload
  - Begin at TCP header if a TCP payload

SSL/TLS

SSL/TLS as Real-Time Protocols

- A real-time protocol is one where parties negotiate interactively to authenticate each other and establish a session key
- Examples: IPsec, SSL/TLS, SSH
  - Public key based
- SSL: Secure Socket Layer
- TLS: Transport Layer Security

Security at Layer 4 vs. 3

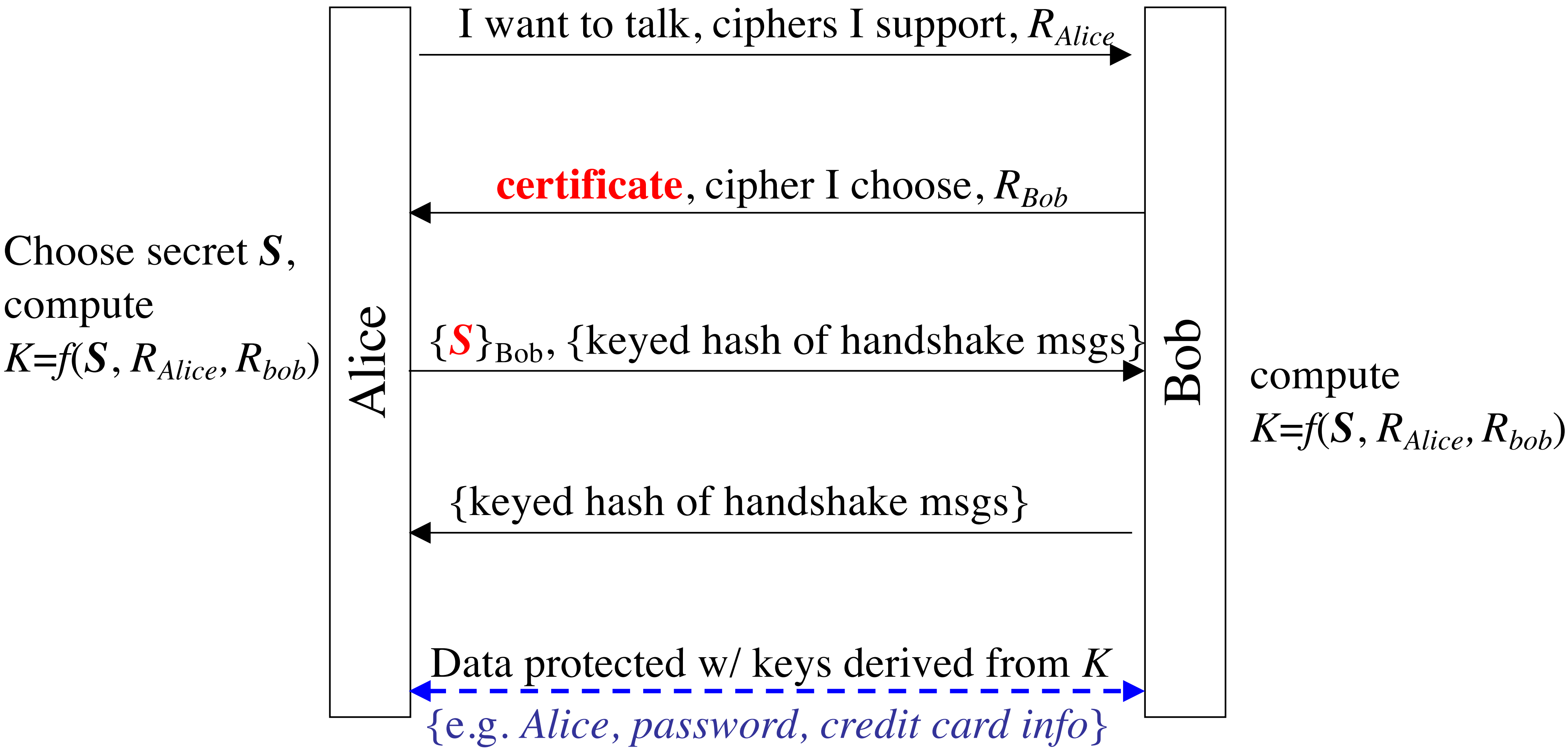


Assumption: TCP/IP are in the OS

Quick History

- SSLv1: never deployed
- SSLv2: deployed in Netscape Navigator 1.1 in 1995
- Microsoft introduced PCT (Private Communication Tech) by improving SSLv2
- Netscape overhauled the protocol as SSLv3
- IETF introduced TLS to unify all of them
  - Seems just another incompatible protocol

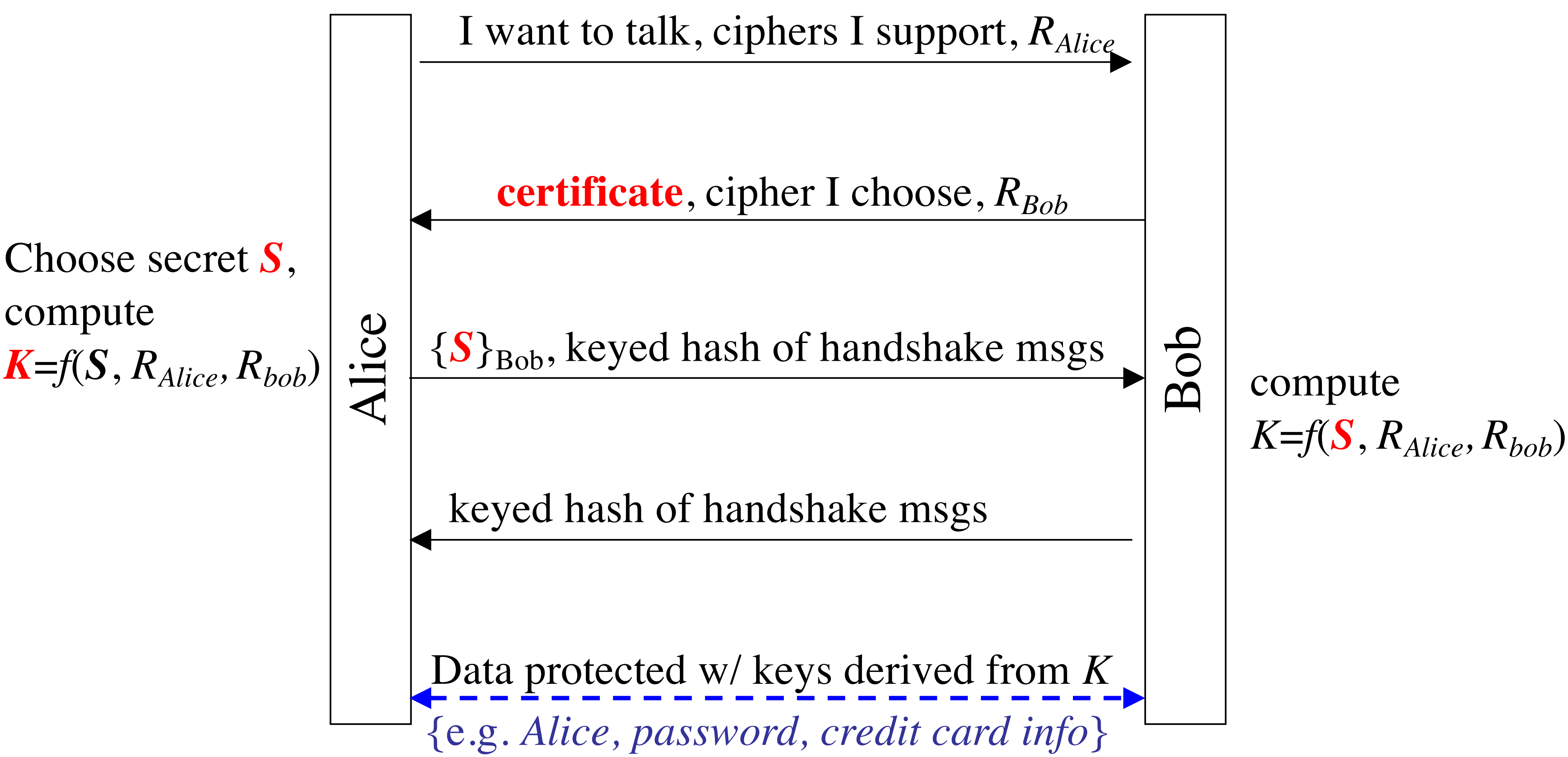
SSLv3/TLS Basic Protocol



Several Important Terms

- $\boldsymbol{R_{Alice}}$: a random number from Alice
- ***S***: pre-master secret
- ***K***: master secret
- $\{\}_{\mathrm{Bob}}$ stands for message encrypted with Bob's public key
- {} stands for **protected** message using encryption and/or integrity protection through secret key algorithm

If a Keyed Hash Result in ***Plaintext***



How Bob Verifies the Keyed Hash

- Decrypt $\{S\}_{\text{Bob}}$ using his private key
- Compute $\boldsymbol{K}=f(\boldsymbol{S}, R_{Alice}, R_{Bob})$
- Calculate $hash(\boldsymbol{K}, (\text{m1}, \text{m2}, \text{“CLNT”}))$
  - HMAC algorithm
- Compares the result with the received one
- Verified if equal

- Q: must the keyed hash be protected?

How Alice Verifies the Key Hash

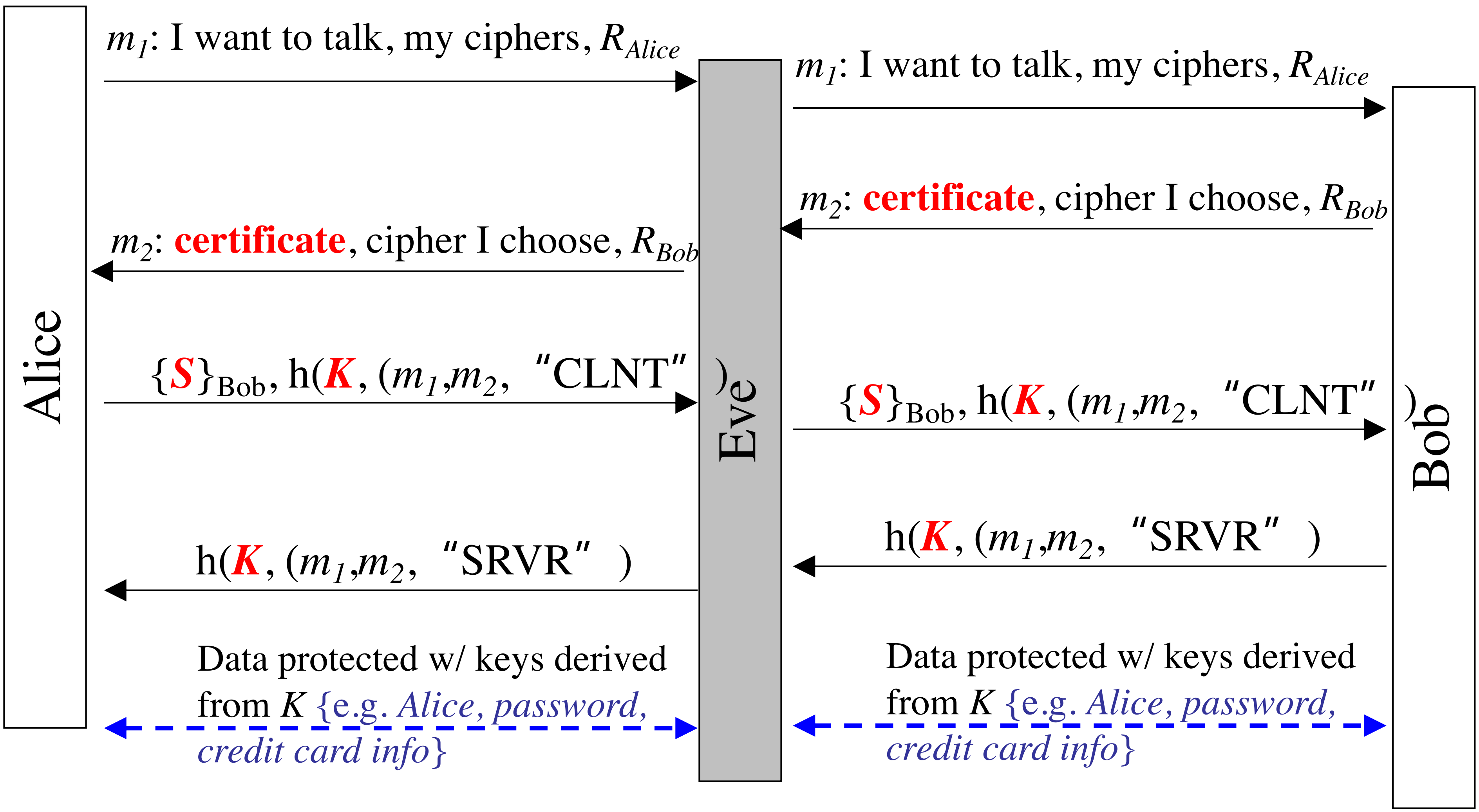
- Calculate *hash*(***K***, (m1, m2, "SRVR"))
  - HMAC algorithm
  - Recall Alice knows ***K*** already
  - The constant string make the hash different from what Bob receives
- Compares the result with the received one
- Verified if equal

- Q: must the keyed hash be protected?

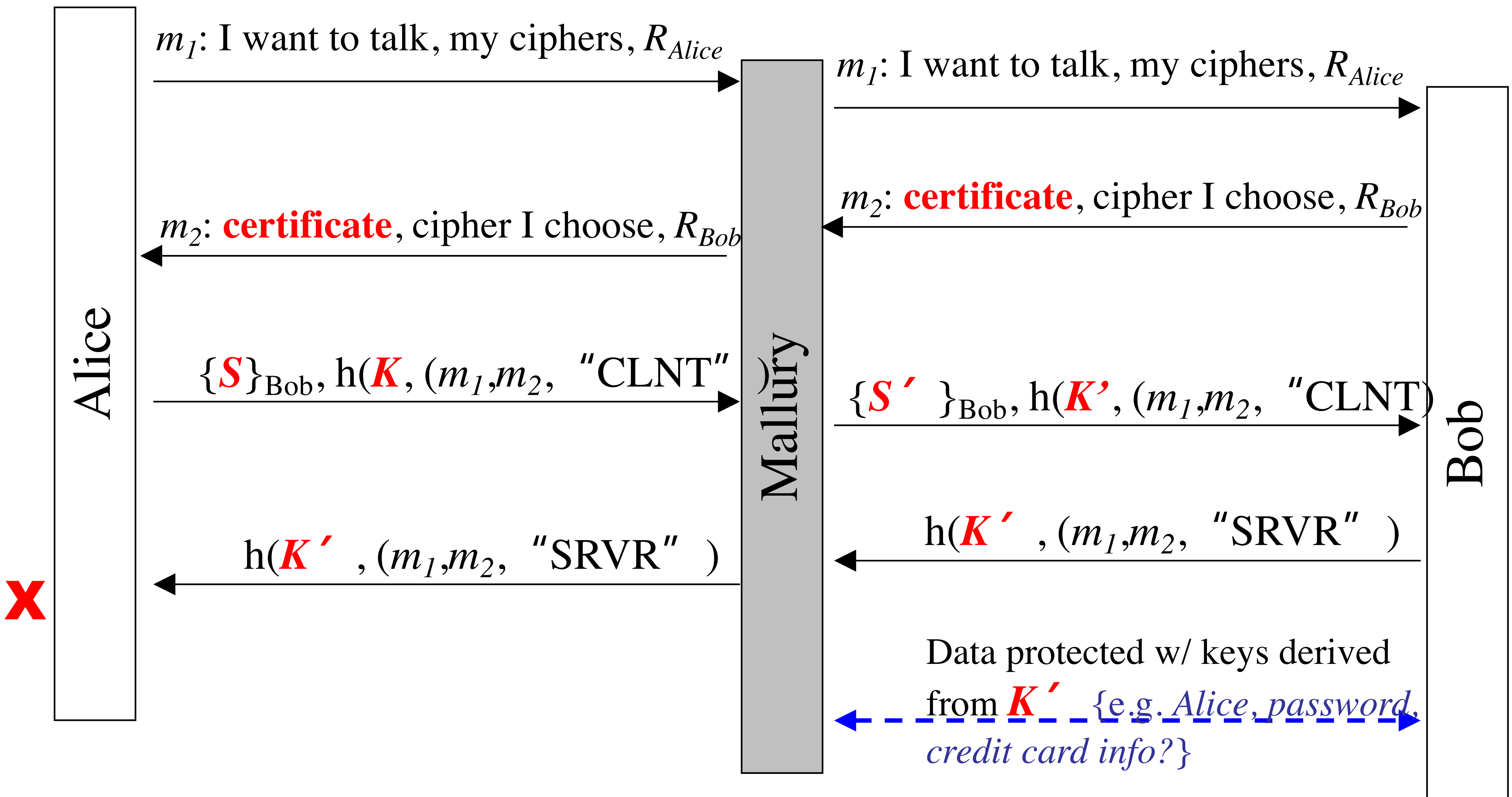
Questions

- Can Eve eavesdrop?
- Can Mallury manipulate the data stream?

When Eve is Eavesdropping



When Mallury is Manipulating



Questions

- When hashing, why add “CLNT” or “SRVR” ?
- What if not?

If Verified, What does Bob Prove?

- The following can be regarded as the same entity:
  - The one sending, or forwarding, message 1
  - the one computing the pre-master secret that Bob received
  - the one sending message 3
- But not necessarily Alice, even claimed so!
  - Could be Mallury!
  - But Alice won't be deceived

If Verified, What does Alice Prove?

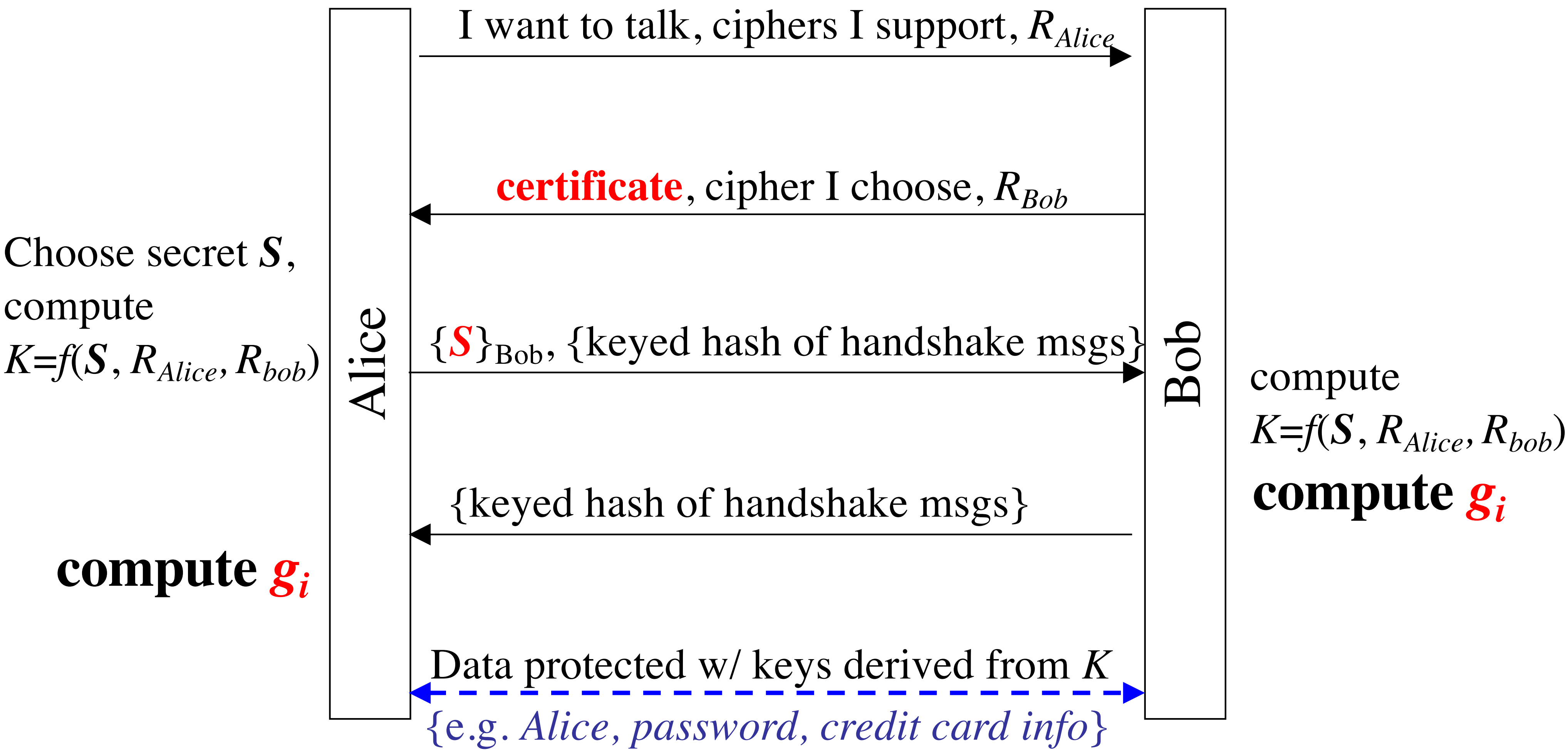
- The following are the same entity:
  - The one sending message 2
  - the one computing ***S*** and ***K*** on the other end, and
  - the one sending message 4
- And this entity is Bob!
  - Based on the certificate
- Also, this entity knows ***S*** and ***K***
  - ***S and K are decided by Alice***
- All handshake messages so far have NOT been tampered
  - Otherwise?

More on SSL/TLS

- Six secrets to protect Alice-Bob communication
- Handling a long *session* with many *connections*
- What if Alice also has a certificate

Six Secrets

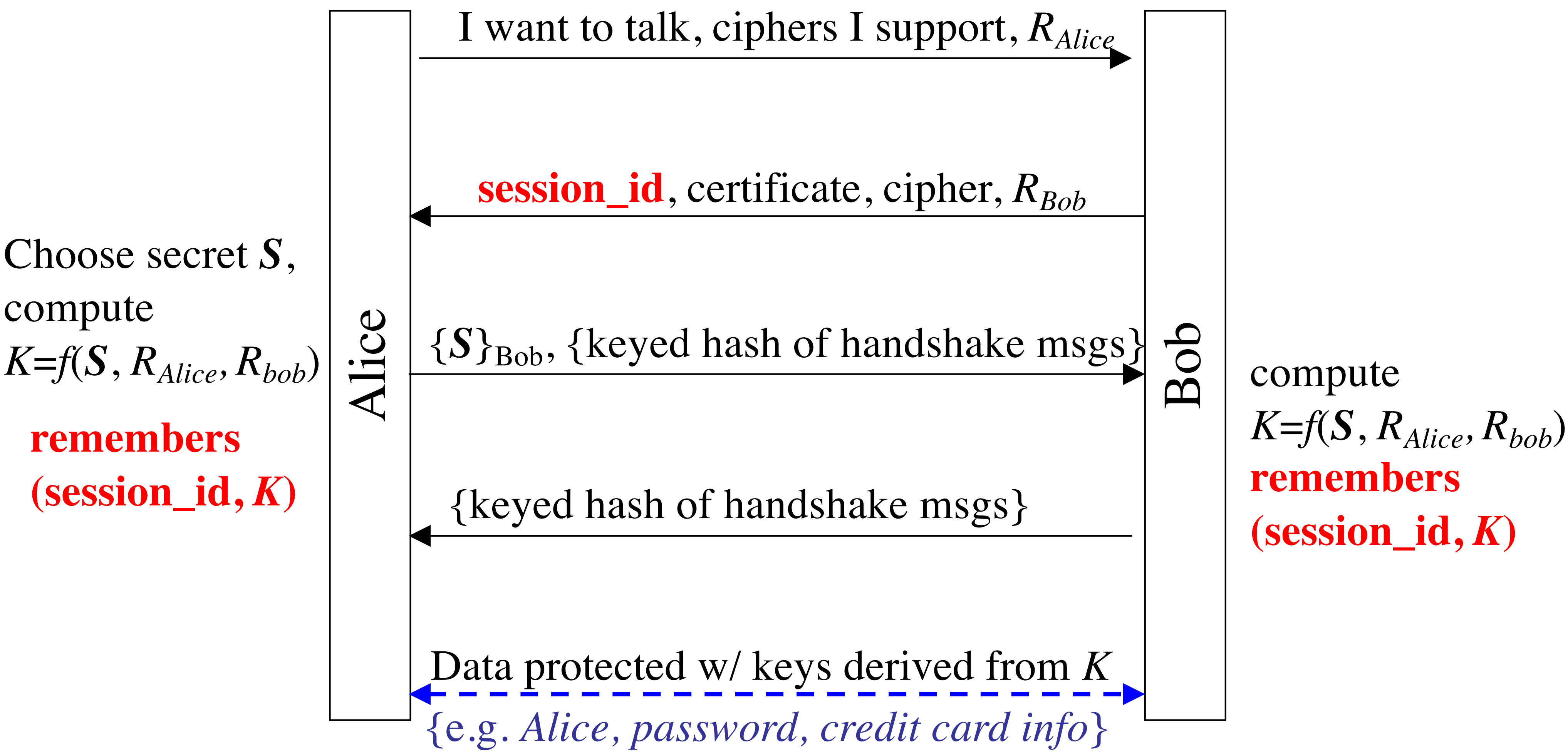
- In fact, it's not a single key ***K*** for a session
- Definition: write keys and read keys
  - Write keys: keys for transmission
  - Read keys: keys for reception
- Each direction needs three write keys
  - Integrity protection key
  - Encryption key
  - IV, if required by encryption algorithms
- And also three read keys
- Computed using $g_i(K, R_{Alice}, R_{Bob})$


I want to talk, ciphers I support, R_{Alice}
certificate, cipher I choose, R_{Bob}
Choose secret $\boldsymbol{S}$, compute $K=f(\boldsymbol{S}, R_{Alice}, R_{bob})$
Alice
$\{\boldsymbol{S}\}_{\mathrm{Bob}}$, {keyed hash of handshake msgs}
Bob
compute $K=f(\boldsymbol{S}, R_{Alice}, R_{bob})$
compute $\boldsymbol{g_i}$
{keyed hash of handshake msgs}
compute $\boldsymbol{g_i}$
Data protected w/ keys derived from K
{e.g. *Alice, password, credit card info*}

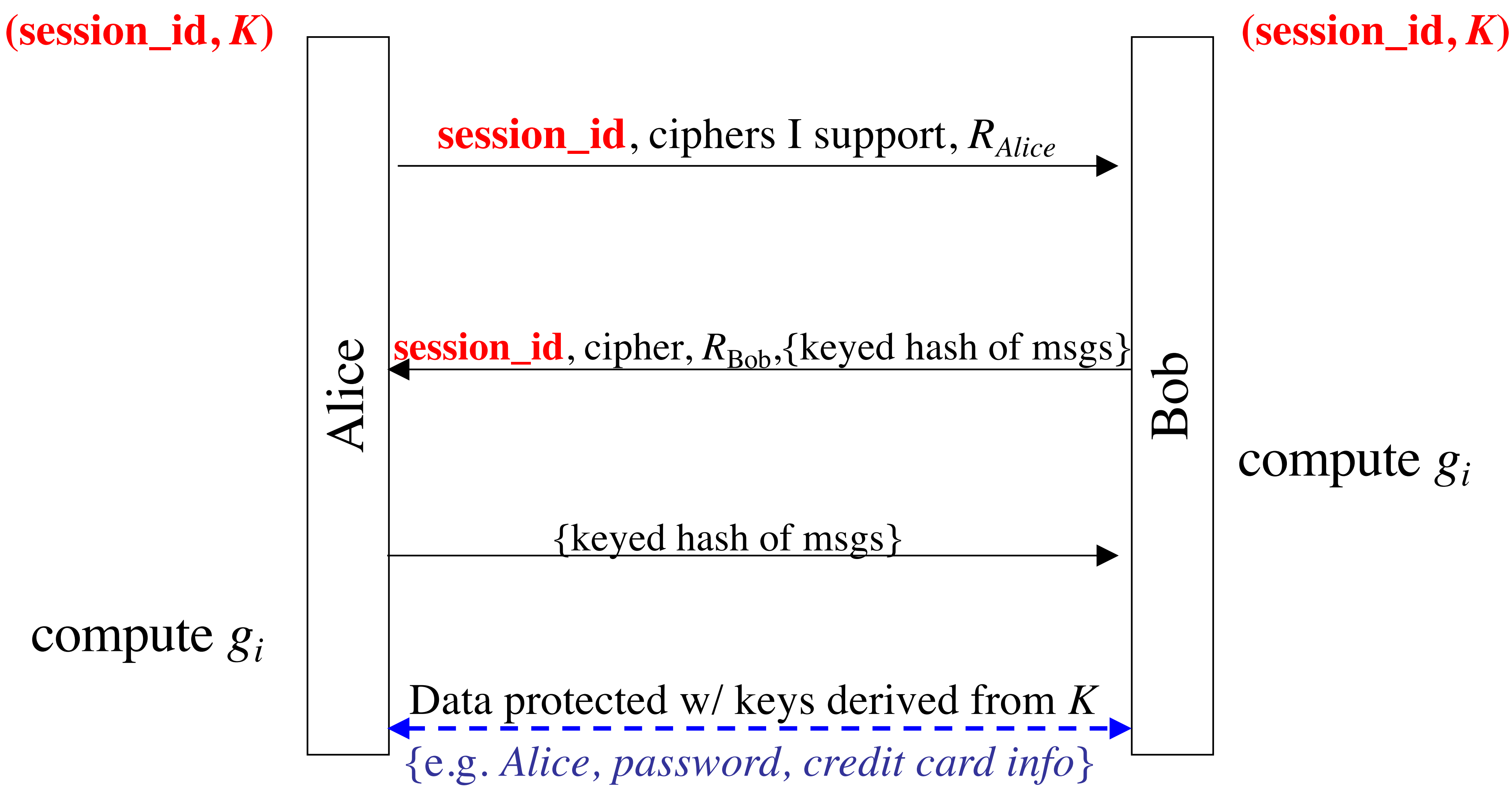
One Session w/ Multiple Connnections

- From a long SSL session, after one connection is set up, many other *connections* can further be derived
  - Alice (a browser) and Bob (a web site) can have many connections, for instance
- Simplify the SSL for later connections between Alice and Bob
  - They have gone through the pain anyway . . .

Session Initiation



Session Resumption



SSL/TLS is Asymmetrical

- Alice authenticated Bob
- But Bob does not authenticate Alice
  - Until Alice login to Bob
  - Could be Mallory handshaking with Bob
- SSL/TLS can be enhanced for mutual authentication
  - If the client has a certificate

Firewalls and Intrusion Detection Systems

Learning Objectives

- Basic concepts of firewalls (functions, types, configurations)
- Intrusion detection systems (how each type works)

What is a Firewall

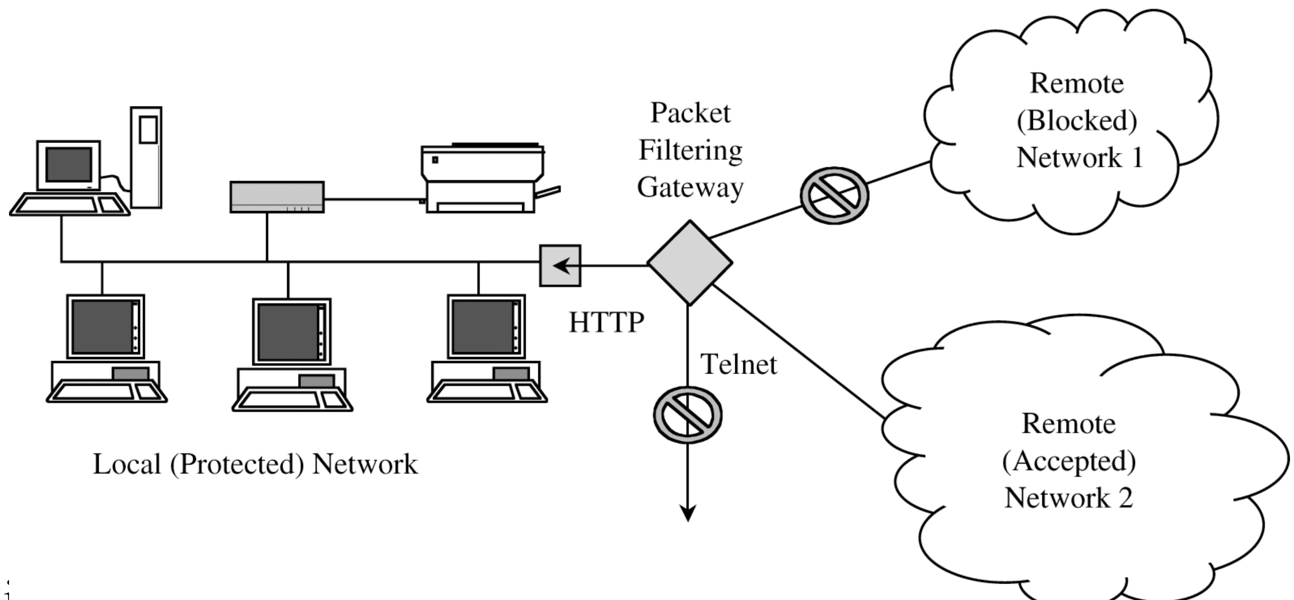
- A device that filters all traffic between a protected or “inside” network and a less trustworthy or “outside” network
- A special form of *reference monitor*
  - Default permit vs. default deny

Types of Firewalls

- Packet filtering
- Stateful inspection firewalls
- Application proxies
- Personal firewalls

Packet Filtering Firewall

- The simplest
  - Sometimes most effective
- On the basis of packet address (source or destination) or specific protocol type.

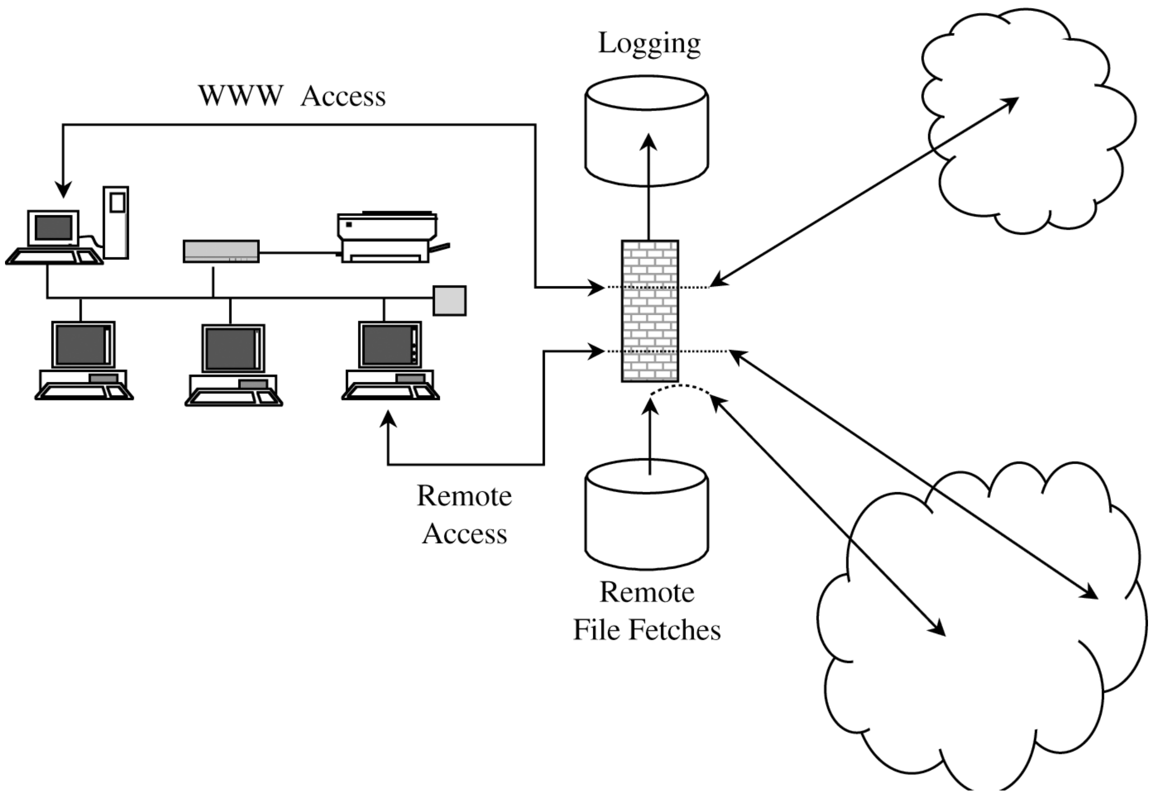


Stateful Inspection Firewall

- Maintains state information from one packet to another in the input stream
- Useful when an attacker breaks an attack into multiple packets
- The firewall can track the sequence of packets and conditions from one packet to another to thwart the attack

Application Proxy

- Inspect the application data



Personal Firewalls

- An application running on a workstation to block unwanted traffic from the network
- E.g., Combining virus scanner with the personal firewall
  – Forward all incoming packets to the virus scanner

Intrusion Detection Systems

- Signature-based vs. anomaly-based
- Host-based vs. network-based

- False negatives vs. false positives