Security Tunneling

Cyber Security

Spring 2010

Reading Material

- IPSec overview
  - Chapter 6 – Network Security Essentials, William Stallings
- SSH
  - RFCs 4251, 4252, 4253
- SSL/TLS overview
  - Slide material from Bishop
  - Chapter 7.2 – Network Security Essentials, William Stallings
- VLAN Security Paper –
  - http://www.cisco.com/warp/public/cc/pd/si/casi/ca6000

What is a tunnel?

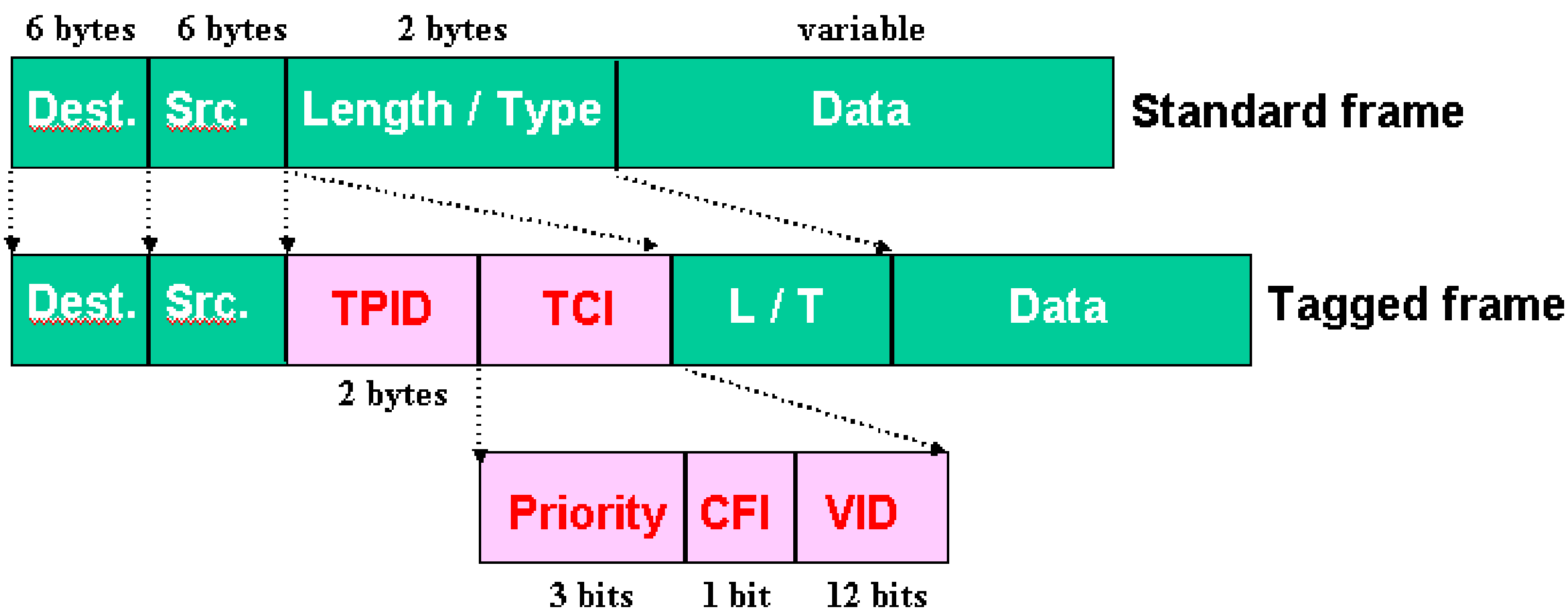
- A tunnel identifies packets in a data stream
  - Identify by encapsulation (new header possibly new trailer)
  - Identify by labeling.
- Entry into a tunnel gives the data stream different characteristics
  - E.g., Privacy, authentication, different routing characteristics
  - Security is not always the goal of the tunnel
- Also called virtual private networks (VPNs) in many situations

Tunnel Protocols for all Levels

- Layer 2
  - 802.1Q VLANs – labels ethernet frames for traffic separation
  - Proprietary link encryption
- Layer 3
  - IPSec
  - IPv6 in IPv4 – Carry IPv6 traffic over IPv4 networks
  - Generic Routing Encapsulation (GRE)
  - Multiprotocol Label Switching (MPLS) – uses labels to implement circuit switching at layer 3
- Layer 4
  - SSL/TLS
  - SSH port forwarding
- Layer 7
  - SMIME
  - DNSSec

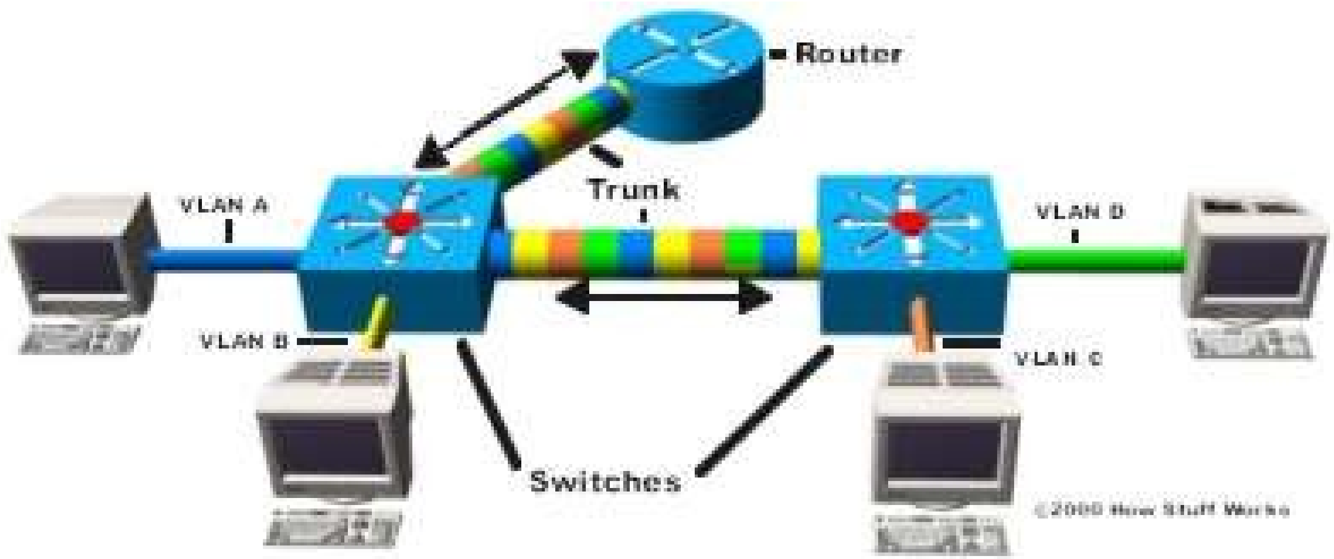
802.1Q VLAN

- Supported by many switches
- Augments ethernet frame with tag



VLAN Trunking

- Enables multiple VLANs to be carried over a single physical link between switches



VLAN used in Siebel

- Using VLANs in the lab configuration to create virtual wires between firewalls, hosts, and the outside world
- CS Department uses VLAN trunking to virtually connect machines
- VLAN trunking provides lab access to a virtual devices running on a VMWare server in a far distant machine room.

VLAN Security Issues

- Classic case of security being an after thought
  - Designed for traffic separation, not security!
- VLAN security requires physical security
- Cisco white paper on VLAN security
  - http://www.cisco.com/en/US/products/hw/switc

VLAN 1

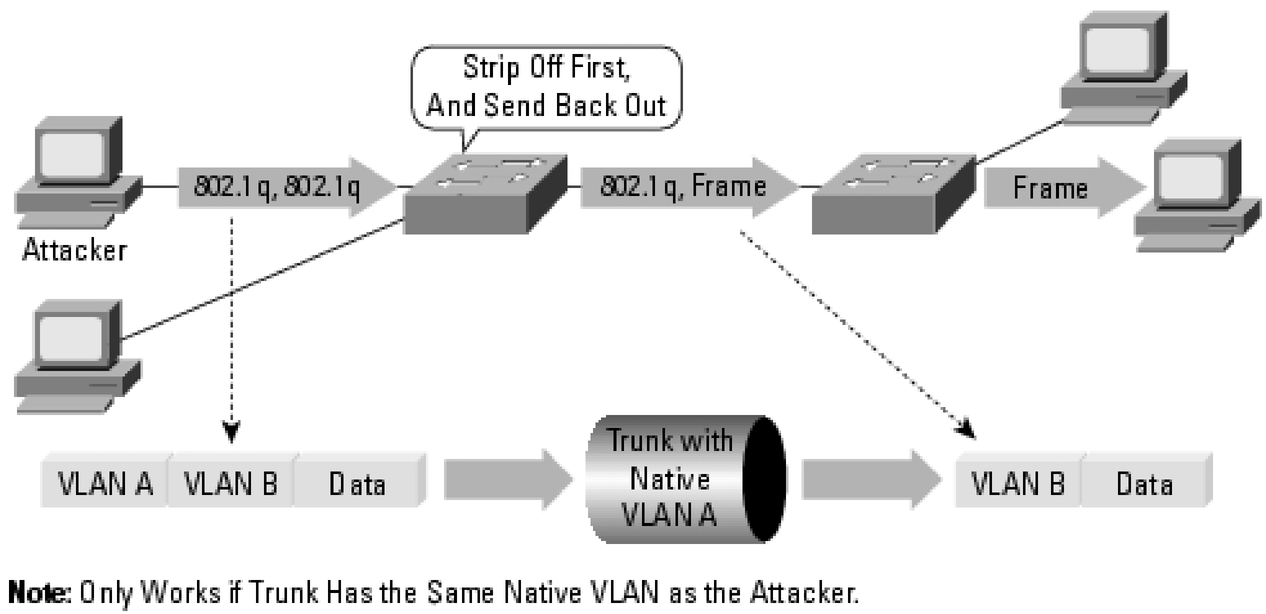
- By default Ports are configured to be in VLAN 1
  - Means VLAN 1 tends to appear on multiple switches
  - Bad activity on VLAN 1 will affect the entire network
- Understand where VLAN 1 is used and prune back unnecessary uses

Differentiate Trusted and Untrusted Ports

- Reduce protocols on untrusted ports
  - Limit points of attack
- For example, VLAN Trunking Protocol (VTP) or Dynamic Trunking Protocol (DTP)
  - Cisco proprietary protocol that allows for automatic propagation of VLAN configuration across the network
  - If VTP could be co-opted by bad guy can reconfigure the network.

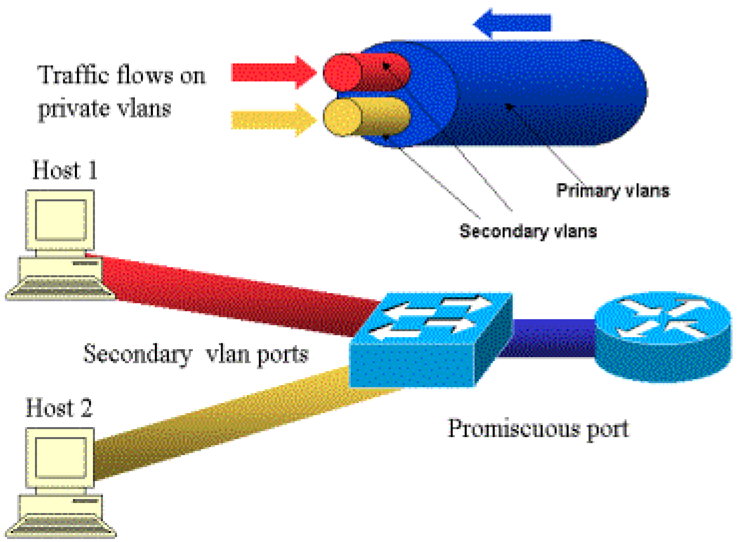
Native VLANs

- Created for backwards compatibility
  - One of the VLANs associated with port can be native
  - All untagged packets to with the native VLAN
  - All tagged packets in native VLAN get stripped



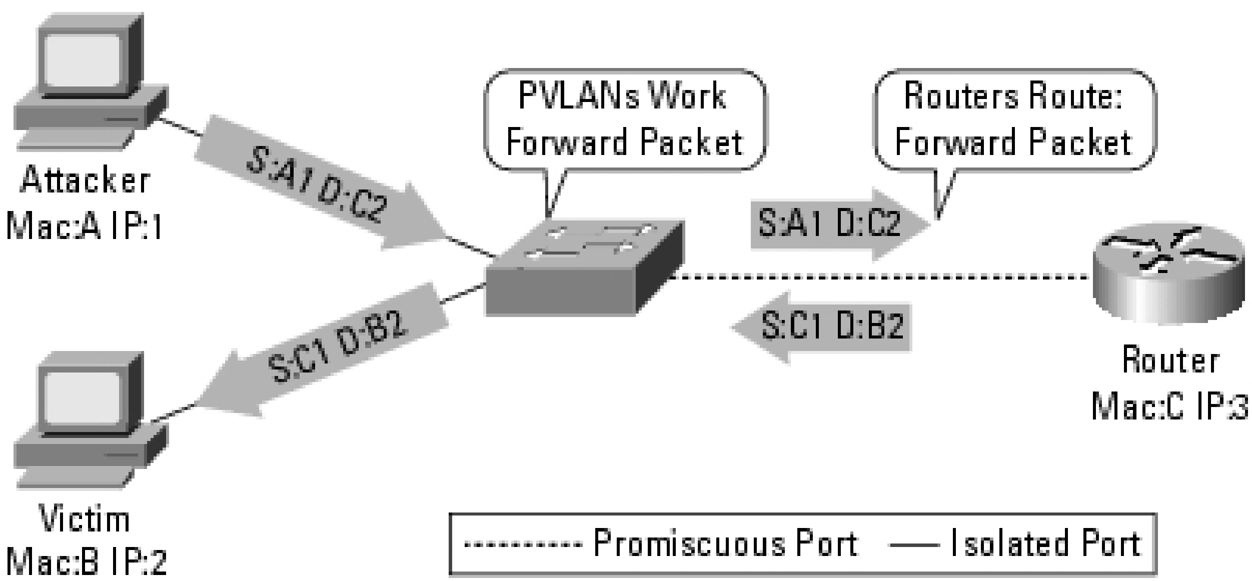
Private VLANs

- Bundle singleton vlans (secondaries) with promiscuous vlan (primary)
- Restrict who can initiate communication within segment



Private VLAN Attack

- Private VLAN
  - An escape to let routed traffic pass between L2 constraints
  - L2 Proxy



Other Layer 2 Attacks

- MAC Flooding
- ARP Spoofing
- 802.1Q tagging attack
  - Attacker creates DTP packets. Trick port into going into trunk mode.
- Spanning Tree Protocol (STP) Attacks
  - Broadcast protocol to agree on a tree of bridges to avoid broadcast loops
  - Attacker attempts to insert packets claiming he is new root bridge

IPSec Operational Architecture

- IPSec Security Architecture, RFC 2401
- Designed by the Security Working Group of the IETF.
  - http://ietf.org/html.charters/ipsec-charter.html
- Motivated from IPv6 design
  - Add arbitrary number of extension headers to store information about the security protocols
  - First IPv4 implementations around ‘97

Security Association (SA)

- Records on the endpoints that store operational information
  - E.g., encryption protocol, keying information, traffic stream filters
- One SA per endpoint to represent a simplex connection
  - Two pairs of SAs to represent duplex connectivity
- The SA memory footprint can be a limiting factor in the number of tunnels
  - Smaller routers cannot support very many simultaneous SAs
- Must know the ID of your peer's SA to communicate
  - Addressed by the Security Parameters Index (SPI)
  - SPI identified in the security protocol headers
  - SPI + Peer address + security protocol will uniquely identify a SA

SA Attributes

- Sequence number counter and overflow flag
- Anti-Replay Window
- AH Info or ESP info
- SA Lifetime
- IPSec Protocol mode (transport or tunnel)
- Path MTU

Security Policy Database

- Implementation specific approach to filter traffic to SA's
  - E.g., ACLs in Cisco devices

IPSec Protocols

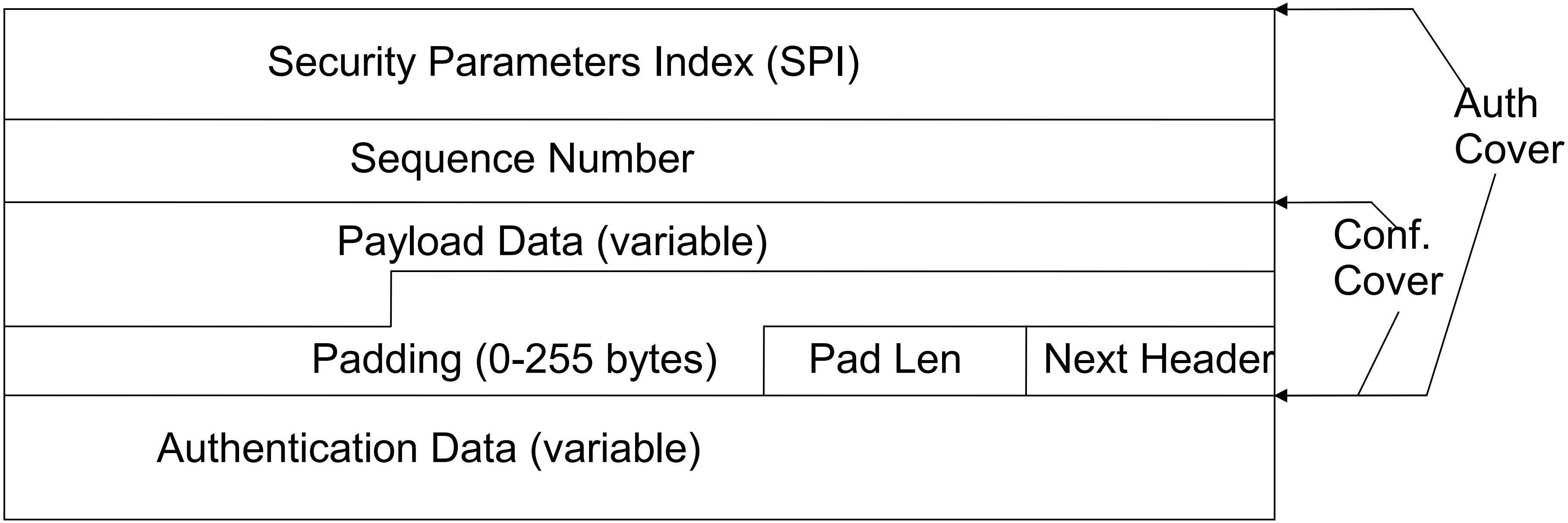
- The IPSec framework describes how a number of different IPSec security protocols can be applied to a tunnel
- Two protocols implemented
  - Encapsulating Security Payload (ESP) – provides privacy (encryption) and message authentication (detection of change)
  - Authentication Header (AH) – provides authentication (detection of change)

ESP

- RFC 2406
- Initially ESP only provided confidentiality not message authentication
  - You were supposed to use AH get authentication
  - People argued that ESP as not useful without authentication, so it was added in as an option
  - Now AH is not so valuable, since you can use a null encryption in ESP to get essentially the same thing

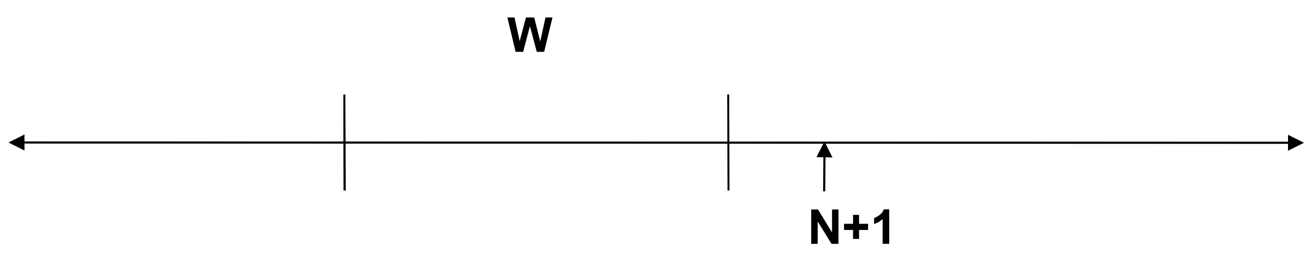
ESP Header

- Both confidentiality and message authentication cover part of the header
- Payload is the encrypted original packet
- Sequence number is used to avoid replay attacks



Replay Protection

- Monotonically increasing sequence number
  - Starts at 1
  - Must renegotiate if number wraps
- Window (default 64) to deal with out of order deliver



Tunnel and Transport Modes

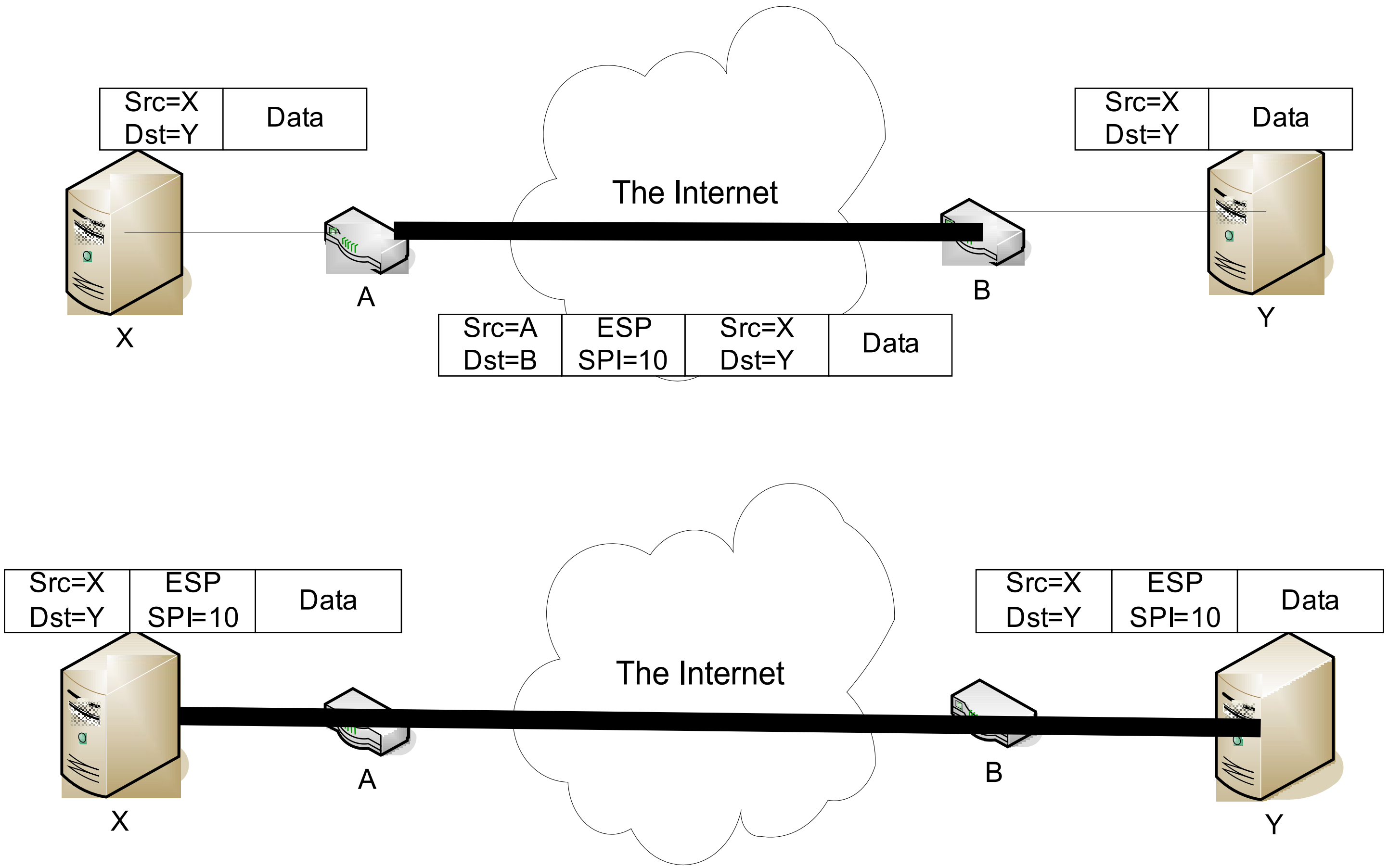
- IPSec tunnels can be set up in two modes
- Tunnel mode
  - Creates a new IP header and encapsulates the original
  - Used by gateways

GW IP Hdr	ESP Hdr	Original Packet including orig IP hdr

- Transport mode
  - Just encapsulates the transport layer and beyond
  - Can be used of the source and destination of the traffic are also the tunnel endpoints

Orig IP Hdr	ESP Hdr	Original Packet minus IP Hdr

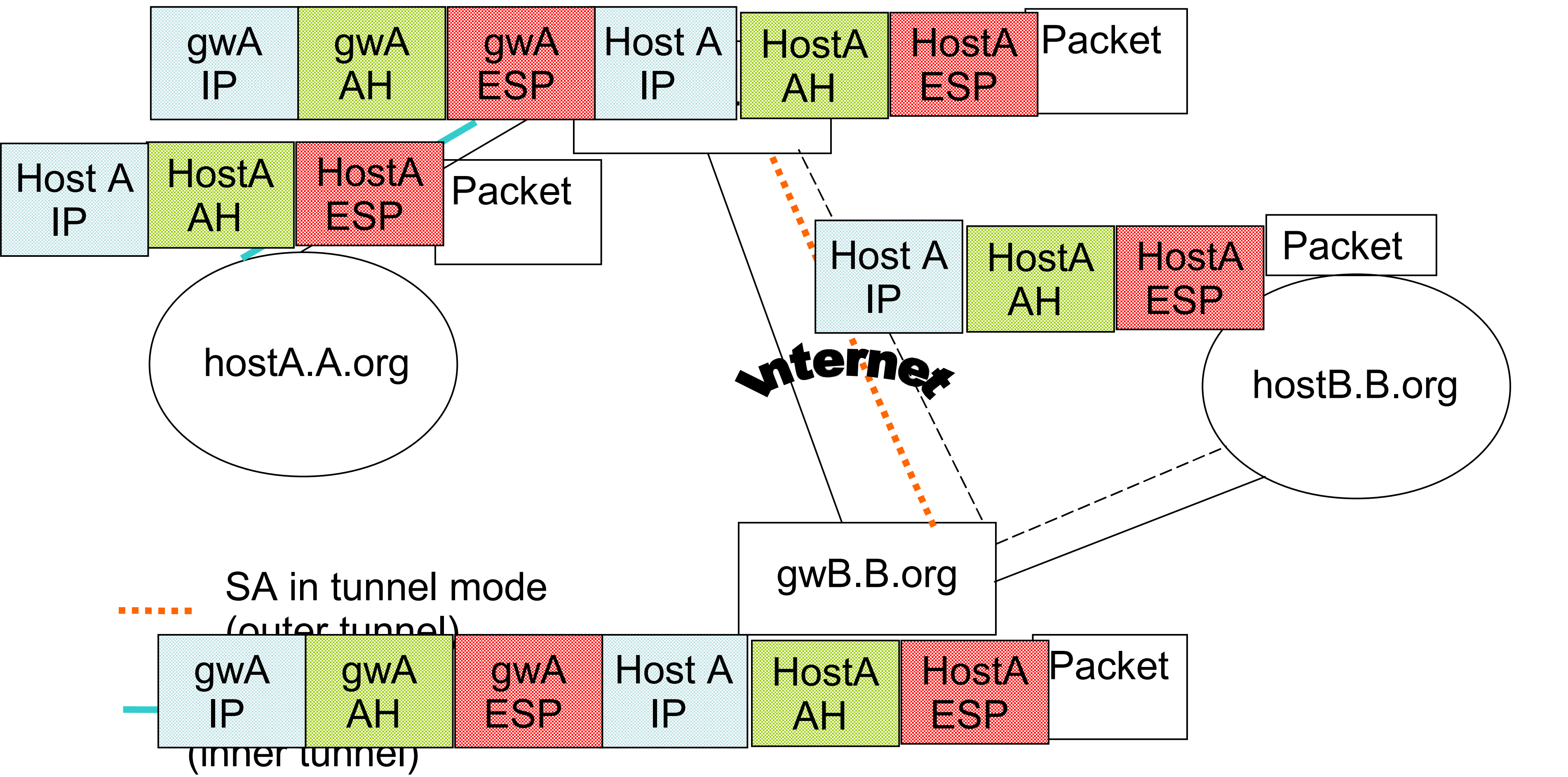
Tunnel and Transport Modes



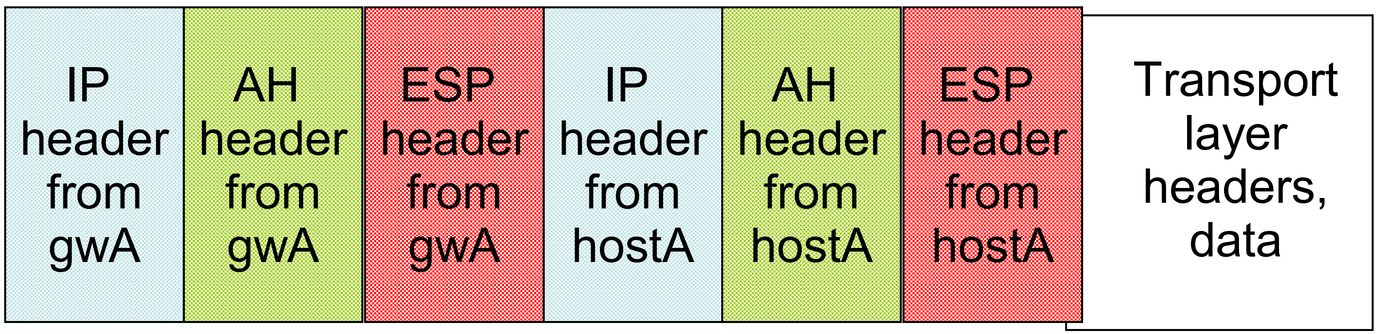
Example: Nested Tunnels

- Group in A.org needs to communicate with group in B.org
- Gateways of A, B use IPsec mechanisms
  - But the information must be secret to everyone except the two groups, even secret from other people in A.org and B.org
- Inner tunnel: a SA between the hosts of the two groups
- Outer tunnel: the SA between the two gateways

Example: Systems



Example: Packets



- Packet generated on hostA
- Encapsulated by hostA's IPsec mechanisms
- Again encapsulated by gwA's IPsec mechanisms
  - Above diagram shows headers, but as you go left, everything to the right would be enciphered and authenticated, *etc*.

IPSec Startup Negotiations

- To start a tunnel need to have the endpoints agree on certain things
  - Keying material
  - Protocols to use on which types of traffic
    - E.g., use ESP with 3DES on HTTP traffic
  - Belief that the peer is who he says he is
- Some of this can be hard coded in the endpoint configuration
  - All of it was initially using manual keying
- Now much of it can be negotiated with Internet Key Exchange (IKE) Protocol

Internet Key Exchange (IKE)

- RFC 2409
- Uses the ISAKMP SA framework (RFC 2408) and the Oakley key negotiation protocol (RFC 2412)
- Performs mutual endpoint authentication
  - Shared key authentication
  - Certificate authentication
  - Plus a few other
- Protocol (transform) agreement
- Key exchange and re-keying

Security Boot Strapping

- Endpoints must share some sort of information to start communicating
  - Shared secret with peer
  - Knowledge of the peer's certificate
- Extended authentication mode (Xauth) allows the human input of authentication data that is validated against a Radius server
- If you weren't using IKE, you could use a manual key for all communication

Oakley Key Determination

- Optionally uses Diffie-Hellman to provide perfect forward secrecy
  - If private key is compromised, previously captured data is not at risk
  - Must re-key often and cannot simply exchange data keys by encrypting with the main private key
  - Fixed set of groups defined by standard
    - http://www.faqs.org/rfcs/rfc5114.html

Diffie-Hellman Key Exchange

- Original Public Key encryption scheme
  - Relies on difficulty of computing discrete logrithm
  - Can be computationally expensive
- Alice and Bob agree on large prime n and a g that is primitive mod n (g is often 2)
  - Good n's and g's are published. Oakely defines 6 well-known groups.
- Alice (Bob)
  - chooses a large random number x (y)
  - computes X = g^x mod n (Y = g^y mod n)
  - sends X to Bob (sends Y to Alice)
- Alice computes k=Y^x mod n
- Bob computes k'=X^y mod n
- k = k' so they now have a shared key

ISAKMP

- ISAKMP negotiations take place over a fixed SA
- Divided into two phases
  - First phase negotiates the security of communication over the ISKMP SA itself
  - Second phase negotiates security attributes of the target SA
- The results of the first phase can be used over multiple second phase negotiations

Transform Negotiation

- The initiator provides a list of security protocols and transforms it is willing to use on the negotiated SA. The proposals are ordered by preference
- The responder selects from one or rejects the negotiation if none of the proposals are match that peer’s capabilities or policy requirements

Main Mode and Aggressive Mode

- ISAKMP can be run in two modes
- Main mode uses more message exchanges
  - Exchanges minimal information each round trip
  - Enables identity protection
- Aggressive mode reduces number of messages exchanged
  - At the cost of not being able to protect as much data during the exchanges

Main Mode Example

- ->Initiator: SA;
- <-Responder: SA;
  - Now peers agree on a SA. The SA negotiation involves agreeing on a set of protocols, e.g. ESP with 3DES vs ESP with DES
- ->Initiator: KE; nonce
- <-Responder: KE; nonce
  - Each side has now generated a key. Last exchange is encrypted with this key
- ->Initiator: IDi; Auth
  - Responder verifies initiators identity.
- <-Responder: IDr; Auth
  - Initiator verifies responder's identity.

Aggressive Mode Example

- ->Initiator: Hdr; SA; KE; Nonce; IDii
- <-Responder: Hdr; SA; KE; Nonce; IDir; Auth
- ->Initiator: Hdr*;Auth First protected traffic
- Give up identity protection

ISAKMP anti-clogging

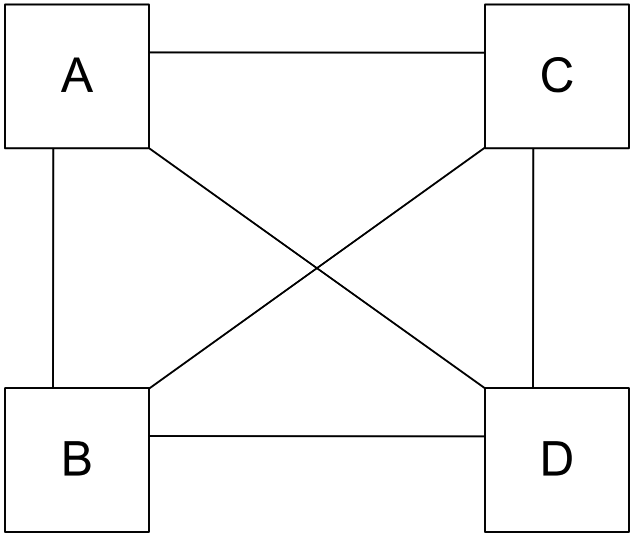
- Uses cookies for simple denial of service avoidance
  - Goal is to prevent simple IP spoofing from causing endpoint to perform many computationally intensive calculations
    - Stalling suggests cookie of hash(Source Addr, Dest Addr, Source Port, Dest Port, local secret)
  - Each end selects a value that includes information about the endpoint addresses and ports, time, and a secret value
  - Each end can determine if it’s cookie is stale to avoid simple DOS
  - Still need to aggressively cleanup requests that end up being bogus

NAT Transparent IPSec

- Initially IPSec could not handle address translation in the middle
  - RFC 3715 describes the problems
  - AH includes the addresses in the outer IP header in its authentication calculation
  - Changes to the IP addresses affect the TCP/UDP checksums, which are encrypted in ESP
  - Addresses and ports encrypted or authenticated
  - For remote users this was a big use case
- Introduced NAT-traversal extensions RFC 3947
- Detect NAT during IKE
  - Move from standard IKE port on 500 to negotiate on port 4500
  - Encapsulate the IPSec traffic using UDP to preserve the original headers from NAT
- One endpoint must fixup the translated addresses after untunneling the traffic

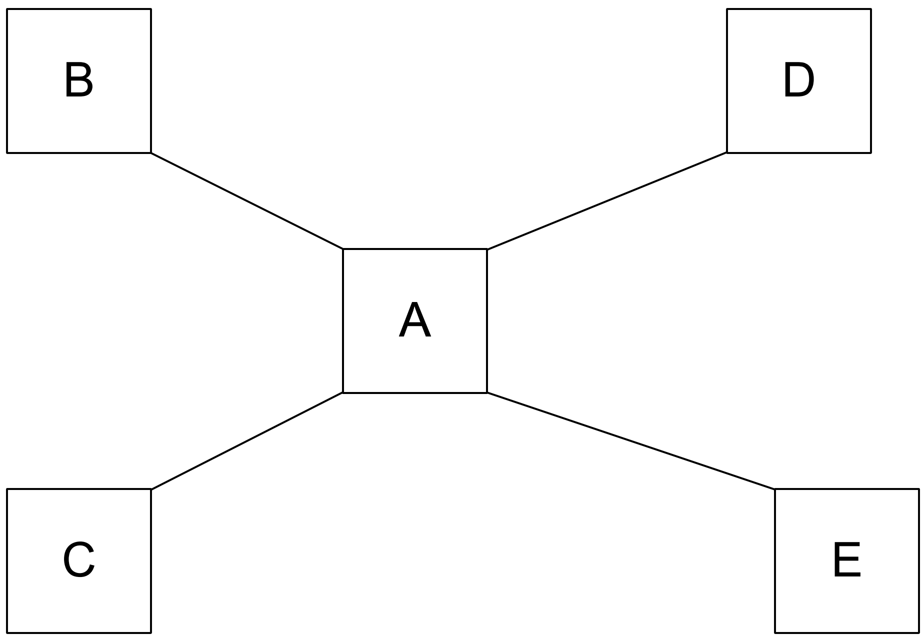
Classic IPSec Architectures

- Mesh - n^2



More Classic Architectures

- Hub and Spoke - N

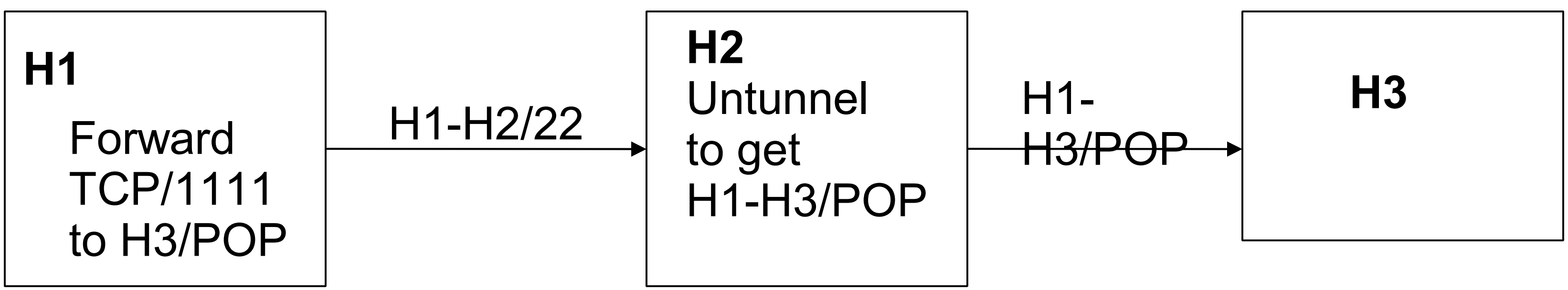


IPSec challenges

- Scaling
  - Numerous security associations eat up too much memory for small routers
  - Configurations on the hub in a hub and spoke network grow n^2 in the number of spokes
    - Dynamic Multipoint VPN (DMVPN)
- Performance
  - Even symmetric encryption can be too much for high bandwidth environments
- Symmetry
  - Both sides must have a means to prove identity to each other
  - Implies the need for a PKI or other broad identity proof mechanism

SSH Port Forwarding

- Negotiation sequences similar to IPSec and SSL
- Operates on TCP/22 by default
- Can map local port to remote port



SSL

- Transport layer security
  - Provides confidentiality, integrity, authentication of endpoints
  - Developed by Netscape for WWW browsers and servers
- Internet protocol version: TLS
  - Compatible with SSL
  - Standard rfc2712

Working at Transport Level

- Data link, Network, and Transport headers sent unchanged
- Original transport header can be protected if tunneling

Ethernet Frame Header	IP Header	TCP Header	TCP data stream Encrypted/authenticated Regardless of application

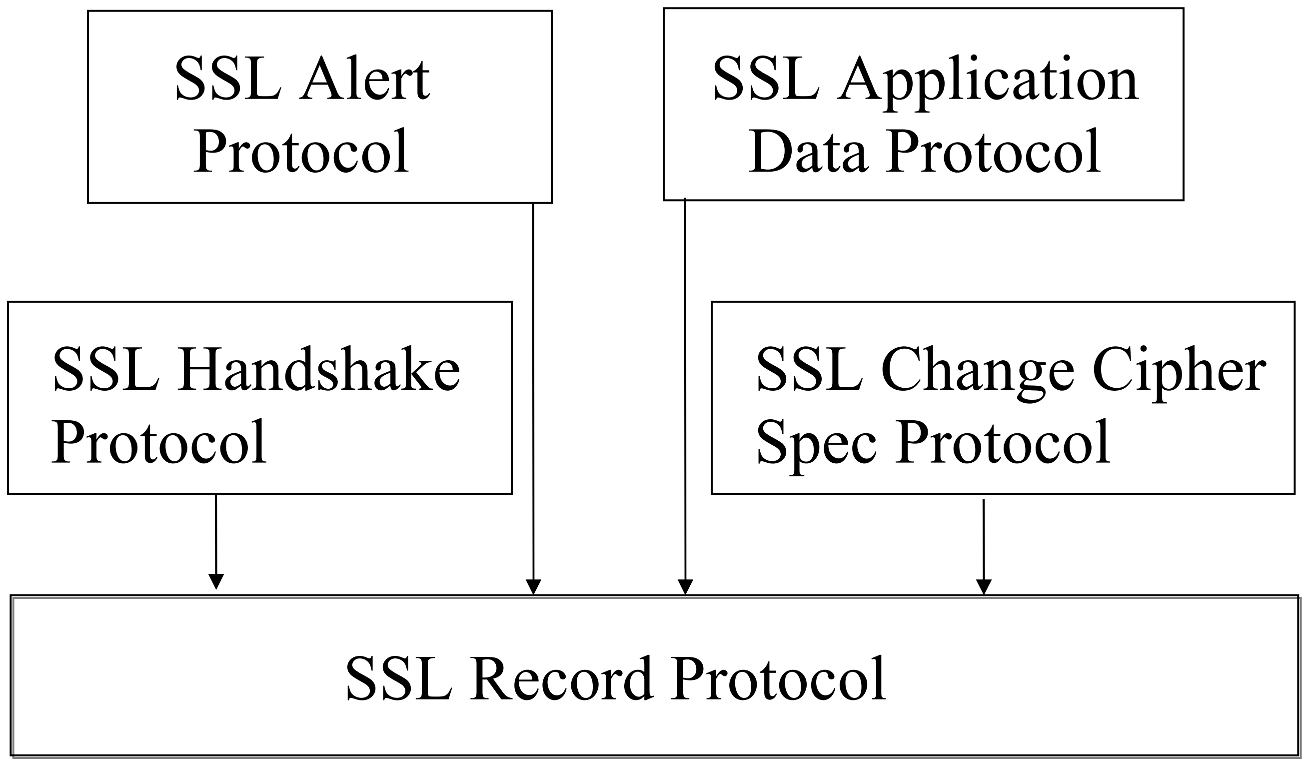
SSL Session

- Association between two peers
  - May have many associated connections
  - Information for each association:
    - Unique session identifier
    - Peer’s X.509v3 certificate, if needed
    - Compression method
    - Cipher spec for cipher and MAC
    - “Master secret” shared with peer
      - 48 bits

SSL Connection

- Describes how data exchanged with peer
- Information for each connection
  - Random data
  - Write keys (used to encipher data)
  - Write MAC key (used to compute MAC)
  - Initialization vectors for ciphers, if needed
  - Sequence numbers

Structure of SSL



Supporting Crypto

- All parts of SSL use them
- Initial phase: public key system exchanges keys
  - Classical ciphers ensure confidentiality, cryptographic checksums added for integrity
  - Only certain combinations allowed
    - Depends on algorithm for interchange cipher
  - Interchange algorithms: RSA, Diffie-Hellman, Fortezza
  - AES added in 2002 by rfc3268

RSA: Cipher, MAC Algorithms

Interchange cipher	***Classical cipher***	***MAC Algorithm***
RSA, key ≤ 512 bits	*none*	MD5, SHA
	RC4, 40-bit key	MD5
	RC2, 40-bit key, CBC mode	MD5
	DES, 40-bit key, CBC mode	SHA
RSA	*None*	MD5, SHA
	RC4, 128-bit key	MD5, SHA
	IDEA, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

Diffie-Hellman: Types

- Diffie-Hellman: certificate contains D-H parameters, signed by a CA
  - DSS or RSA algorithms used to sign
- Ephemeral Diffie-Hellman: DSS or RSA certificate used to sign D-H parameters
  - Parameters not reused, so not in certificate
- Anonymous Diffie-Hellman: D-H with neither party authenticated
  - Use is “strongly discouraged” as it is vulnerable to attacks

D-H: Cipher, MAC Algorithms

Interchange cipher	*Classical cipher*	*MAC Algorithm*
Diffie-Hellman, DSS Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA
Diffie-Hellman, key ≤ 512 bits RSA Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

Ephemeral D-H: Cipher, MAC Algorithms

Interchange cipher	***Classical cipher***	***MAC Algorithm***
Ephemeral Diffie-Hellman, DSS Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA
Ephemeral Diffie-Hellman, key ≤ 512 bits, RSA Certificate	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

Anonymous D-H: Cipher, MAC Algorithms

Interchange cipher	*Classical cipher*	*MAC Algorithm*
Anonymous D-H, DSS Certificate	RC4, 40-bit key	MD5
	RC4, 128-bit key	MD5
	DES, 40-bit key, CBC mode	SHA
	DES, CBC mode	SHA
	DES, EDE mode, CBC mode	SHA

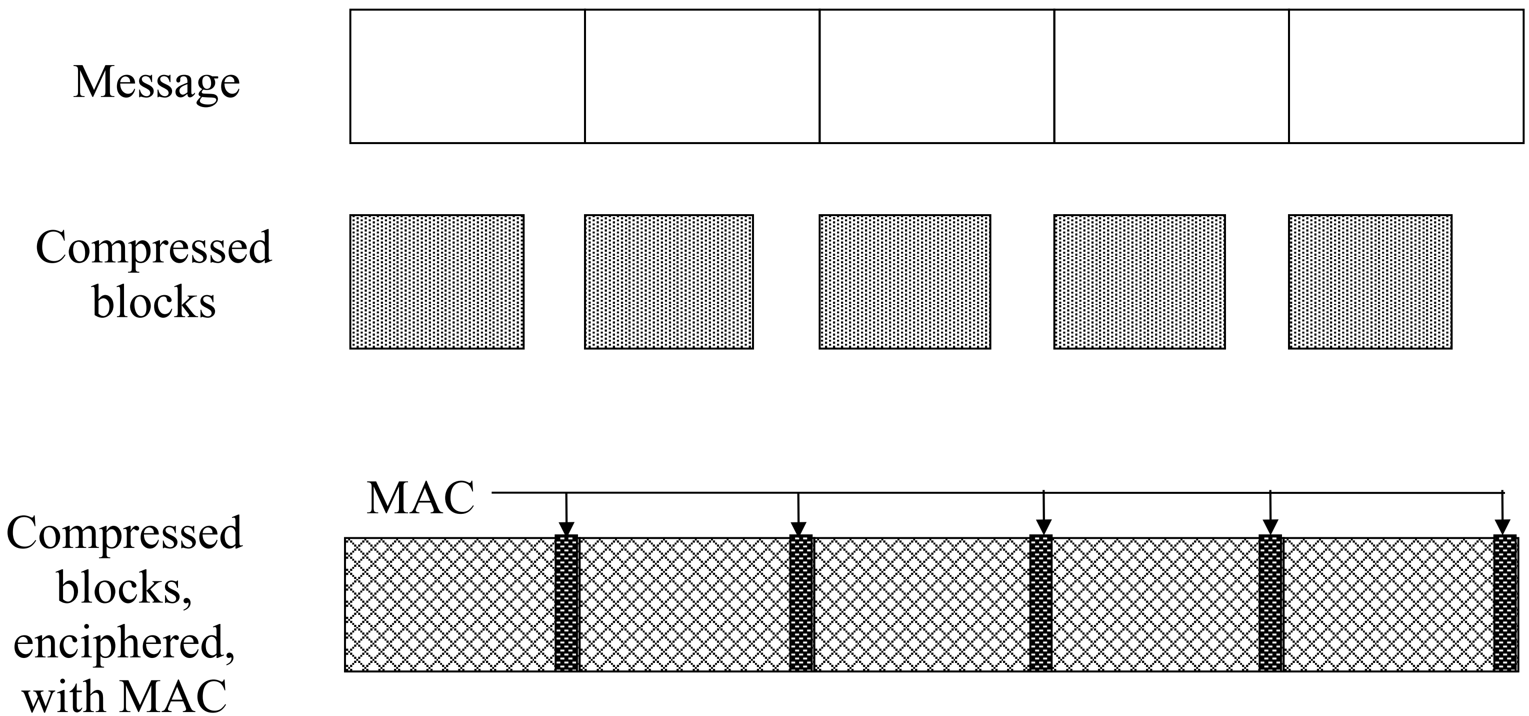
Fortezza: Cipher, MAC Algorithms

Interchange cipher	***Classical cipher***	***MAC Algorithm***
Fortezza key exchange	*none*	SHA
	RC4, 128-bit key	MD5
	Fortezza, CBC mode	SHA

Digital Signatures

- RSA
  - Concatenate MD5 and SHA hashes
  - Sign with public key
- Diffie-Hellman, Fortezza
  - Compute SHA hash
  - Sign appropriately

SSL Record Layer



Record Protocol Overview

- Lowest layer, taking messages from higher
  - Max block size 16,384 bytes
  - Bigger messages split into multiple blocks
- Construction
  - Block *b* compressed; call it b_c
  - MAC computed for b_c
    - If MAC key not selected, no MAC computed
  - b_c, MAC enciphered
    - If enciphering key not selected, no enciphering done
  - SSL record header prepended

SSL MAC Computation

- Symbols
  - h hash function (MD5 or SHA)
  - k_w write MAC key of entity
  - *ipad* = 0x36, *opad* = 0x5C
    - Repeated to block length (from HMAC)
  - *seq* sequence number
  - *SSL_comp* message type
  - *SSL_len* block length
- MAC

$$h(k_w || opad || h(k_w || ipad || seq || SSL\_comp || SSL\_len || block))$$

SSL Handshake Protocol

- Used to initiate connection
  - Sets up parameters for record protocol
  - 4 rounds
- Upper layer protocol
  - Invokes Record Protocol
- Note: what follows assumes client, server using RSA as interchange cryptosystem

Overview of Rounds

- Create SSL connection between client, server
- Server authenticates itself
- Client validates server, begins key exchange
- Acknowledgments all around

Handshake Round 1

$$\{\ v_C \,\|\, r_1 \,\|\, s_1 \,\|\, ciphers \,\|\, comps\ \}$$

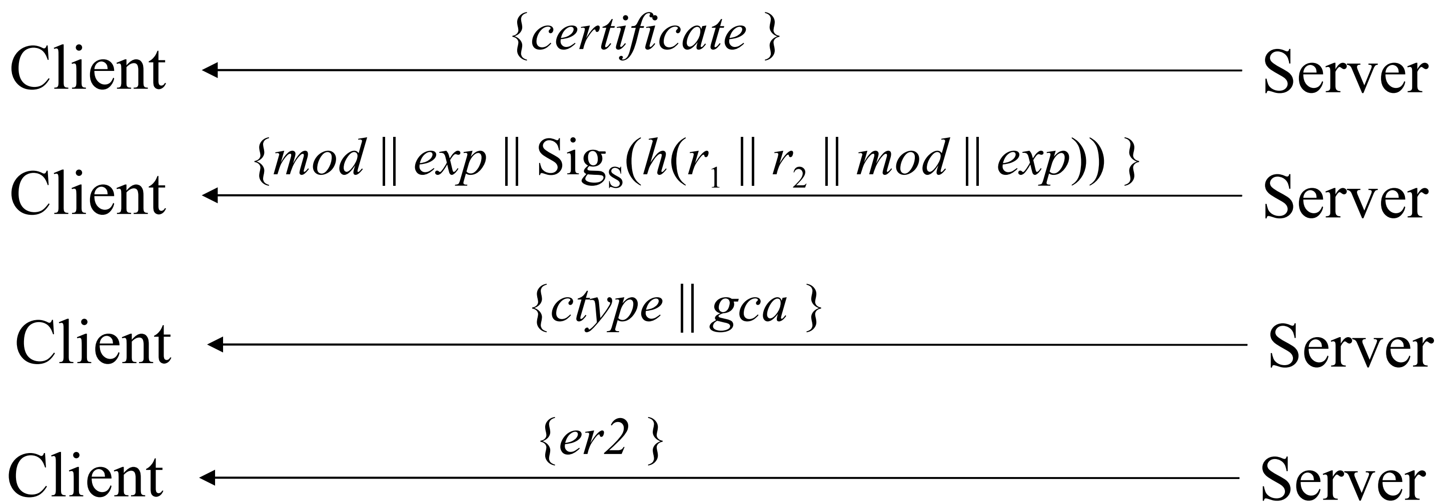
Client ⟶ Server

$$\{v \,\|\, r_2 \,\|\, s_1 \,\|\, cipher \,\|\, comp\ \}$$

Client ⟵ Server

v_C	Client's version of SSL
v	Highest version of SSL that Client, Server both understand
r_1, r_2	nonces (timestamp and 28 random bytes)
s_1	Current session id (0 if new session)
ciphers	Ciphers that client understands
comps	Compression algorithms that client understand
cipher	Cipher to be used
comp	Compression algorithm to be used

Handshake Round 2



Note: if Server not to authenticate itself, only last message sent; third step omitted if Server does not need Client certificate

k_S Server's private key

ctype Certificate type requested (by cryptosystem)

gca Acceptable certification authorities

er2 End round 2 message

Handshake Round 3

Client $\xrightarrow{\{\ client\_cert\ \}}$ Server

Client $\xrightarrow{\{\ pre\ \}\text{Pub}_S}$ Server

Both Client, Server compute master secret *master*:

$$master = \text{MD5}(pre \,||\, \text{SHA}(\text{‘A’} \,||\, pre \,||\, r_1 \,||\, r_2) \,||$$
$$\text{MD5}(pre \,||\, \text{SHA}(\text{‘BB’} \,||\, pre \,||\, r_1 \,||\, r_2) \,||$$
$$\text{MD5}(pre \,||\, \text{SHA}(\text{‘CCC’} \,||\, pre \,||\, r_1 \,||\, r_2)$$

Client $\xrightarrow{\{\ h(master \,||\, opad \,||\, h(msgs \,||\, master \,|\, ipad))\ \}}$ Server

msgs	Concatenation of previous messages sent/received this handshake
opad, *ipad*	As above

Handshake Round 4

Client sends "change cipher spec" message using that protocol

Client → Server

$\{\ h(\mathit{master} \mid\mid \mathit{opad} \mid\mid h(\mathit{msgs} \mid\mid \text{0x434C4E54} \mid\mid \mathit{master} \mid\mid \mathit{ipad}\ ))\ \}$

Client → Server

Server sends "change cipher spec" message using that protocol

Client ← Server

$\{\ h(\mathit{master} \mid\mid \mathit{opad} \mid\mid h(\mathit{msgs} \mid\mid \mathit{master} \mid \mathit{ipad}))\ \}$

Client ← Server

msgs Concatenation of messages sent/received this handshake in *previous* rounds (does notinclude these messages)

opad, *ipad*, *master* As above

SSL Change Cipher Spec Protocol

- Send single byte
- In handshake, new parameters considered "pending" until this byte received
  - Old parameters in use, so cannot just switch to new ones

SSL Alert Protocol

- Closure alert
  - Sender will send no more messages
  - Pending data delivered; new messages ignored
- Error alerts
  - Warning: connection remains open
  - Fatal error: connection torn down as soon as sent or received

SSL Alert Protocol Errors

- Always fatal errors:
  - unexpected_message, bad_record_mac, decompression_failure, handshake_failure, illegal_parameter
- May be warnings or fatal errors:
  - no_certificate, bad_certificate, unsupported_certificate, certificate_revoked, certificate_expired, certificate_unknown

SSL Application Data Protocol

- Passes data from application to SSL Record Protocol layer