COMP3028 Lecture 13
Network Security

Objectives

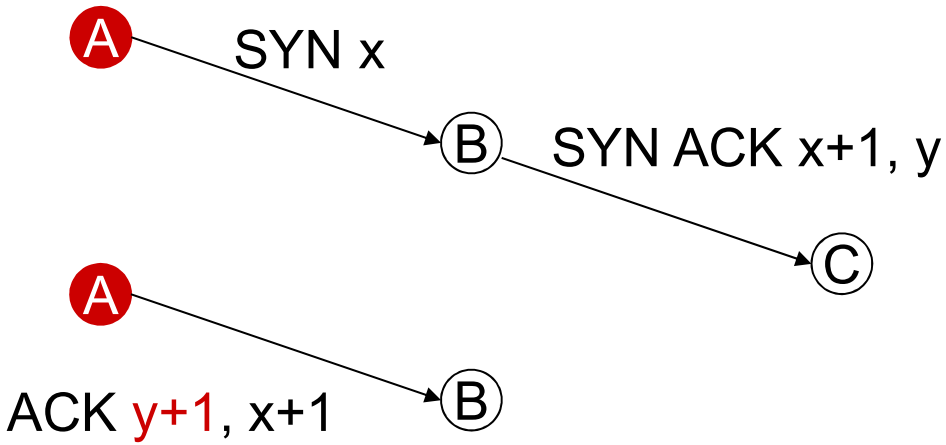
- Brief survey of network security challenges.
- Show how network security contributes to and depends on computer security.
- Introduction to the design of network security protocols, based on the Internet security protocols IPsec and SSL/TLS.
- Network boundaries as security perimeters.
- Principles and limitations of firewalls and Intrusion Detection Systems.

Network Attacks

- Passive attacker: listens to traffic (eavesdropping, wiretapping, sniffing).
- Active attacker: modifies messages, inserts new messages, corrupts network management information; active attacks are not necessarily more difficult to mount than passive attacks.
- Spoofing attack: send messages with forged sender addresses.
- Flooding (bombing) attack: large number of messages sent to victim.
- Traffic analysis: identify communications patterns; may be possible even when the attacker cannot read individual messages.

TCP Session Hijacking

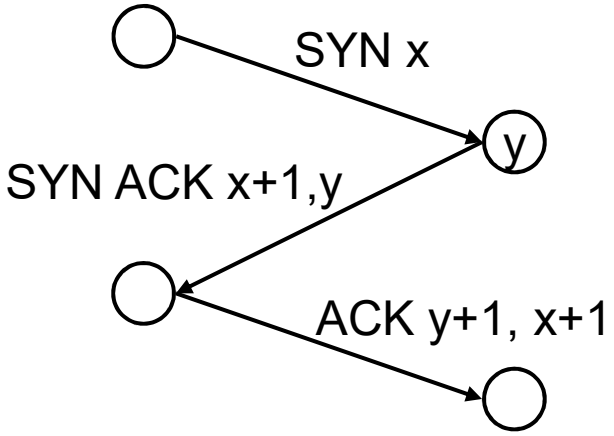
- Predict challenge to send messages that appear to come from a trusted host.



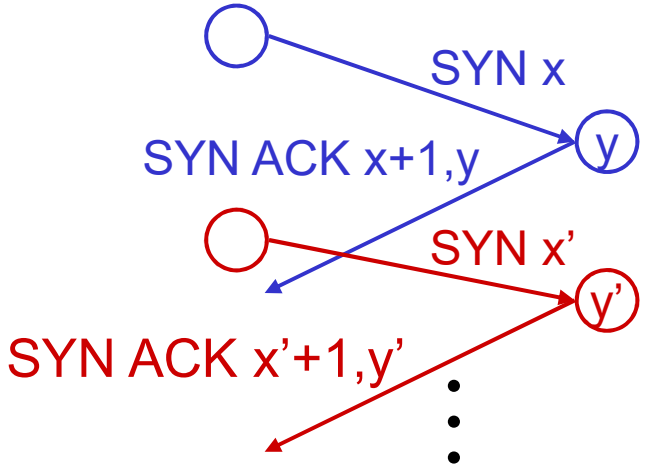
1. A spoofs SYN packet from C.
2. B sends SYN ACK to C.
3. A guesses the value y+1 to conclude the handshake.

TCP SYN Flooding Attacks

- Exhaust responder's resources by creating half-open TCP connection requests.

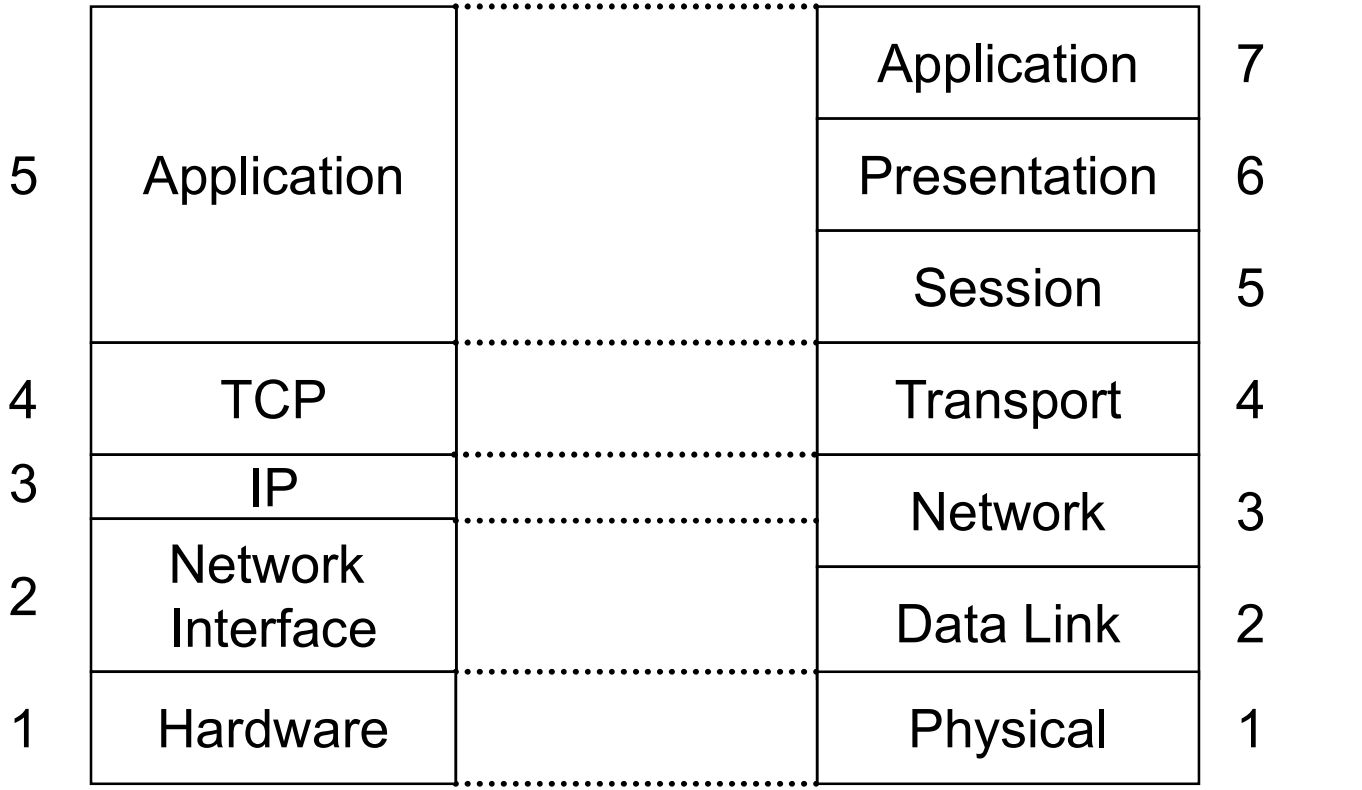


TCP handshake

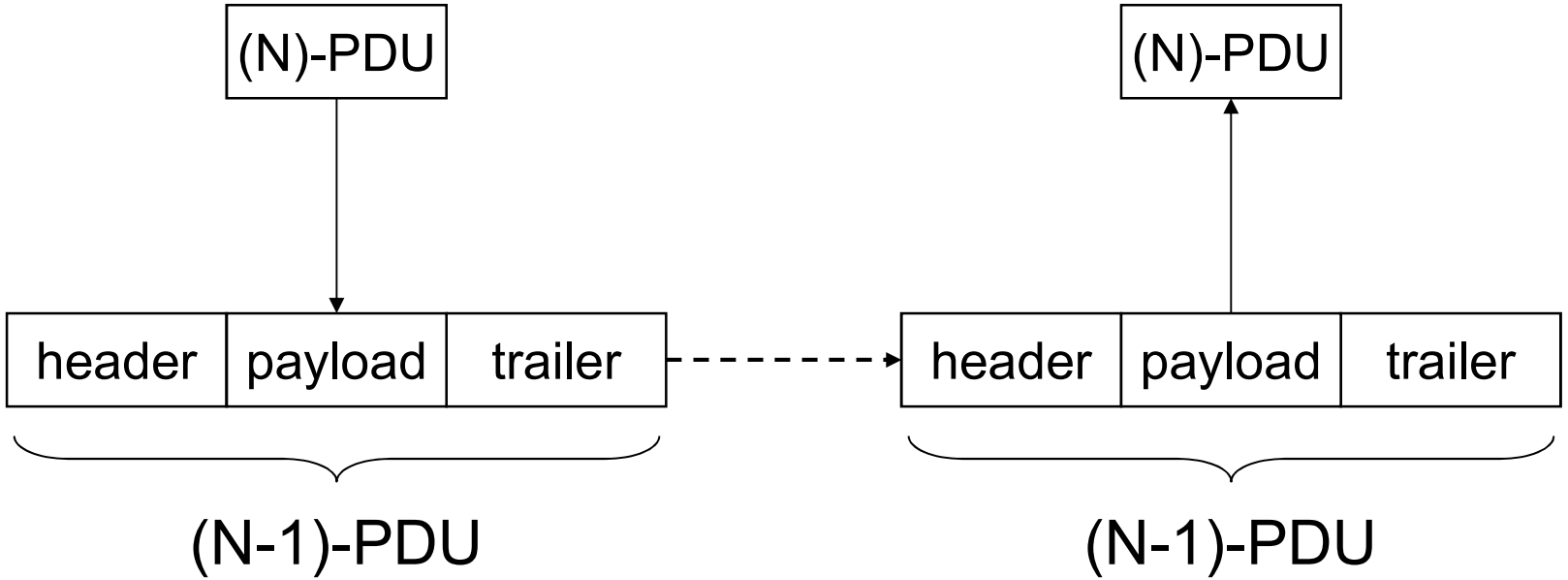


SYN flooding attack

Protocol Layering



Protocol Layering



PDU … Protocol Data Unit

Implementing Security Services

- Header in (*N*-1)-PDU is convenient location for storing security relevant data.
- Upper layer protocol can be aware of lower layer security services:
  - Upper layer protocol has to change its calls so that they refer to the security facilities provided.
- Lower layer security services can be transparent to upper layer protocol:
  - Upper layer protocol need not be changed at all.

IPsec

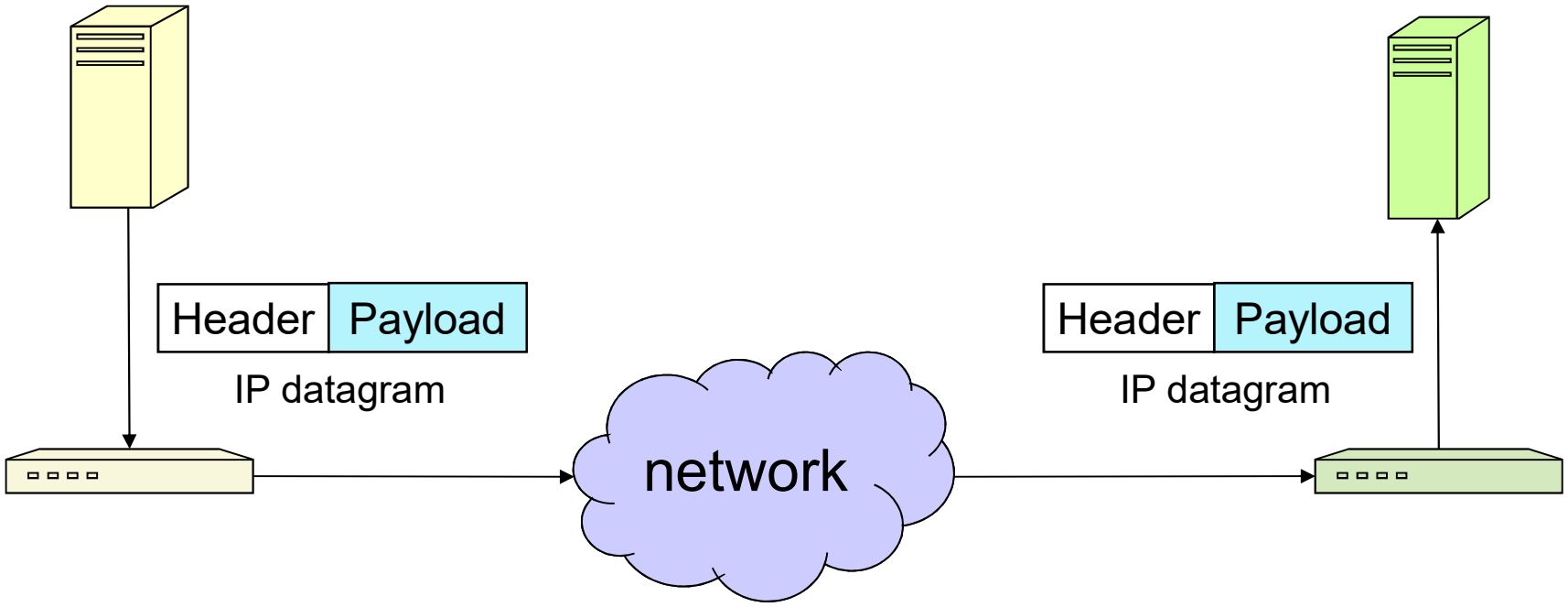
- Defined in IETF RFCs 2401–2412.
- Provides security at network (Internet) layer.
  - All IP datagrams covered.
  - No re-engineering of applications.
  - Transparent to upper layer.
- Mandatory for next generation IPv6, optional for current generation (IPv4).
- Two basic modes of use:
  - Transport mode: IPsec-aware hosts as endpoints.
  - Tunnel mode: for IPsec-unaware hosts, tunnel established by intermediate gateways or host OS.

IPsec

- Authentication and/or confidentiality services for data:
  - AH protocol [RFC 2402]
  - ESP protocol [RFC 2406]
- Use of AH is being deprecated in favour of ESP.
  - Political reasons for introducing an authentication-only protocol in the 1990s have faded.
- (Too?) flexible set of key establishment methods:
  - IKE; IKEv2 under development.

IPsec Transport Mode

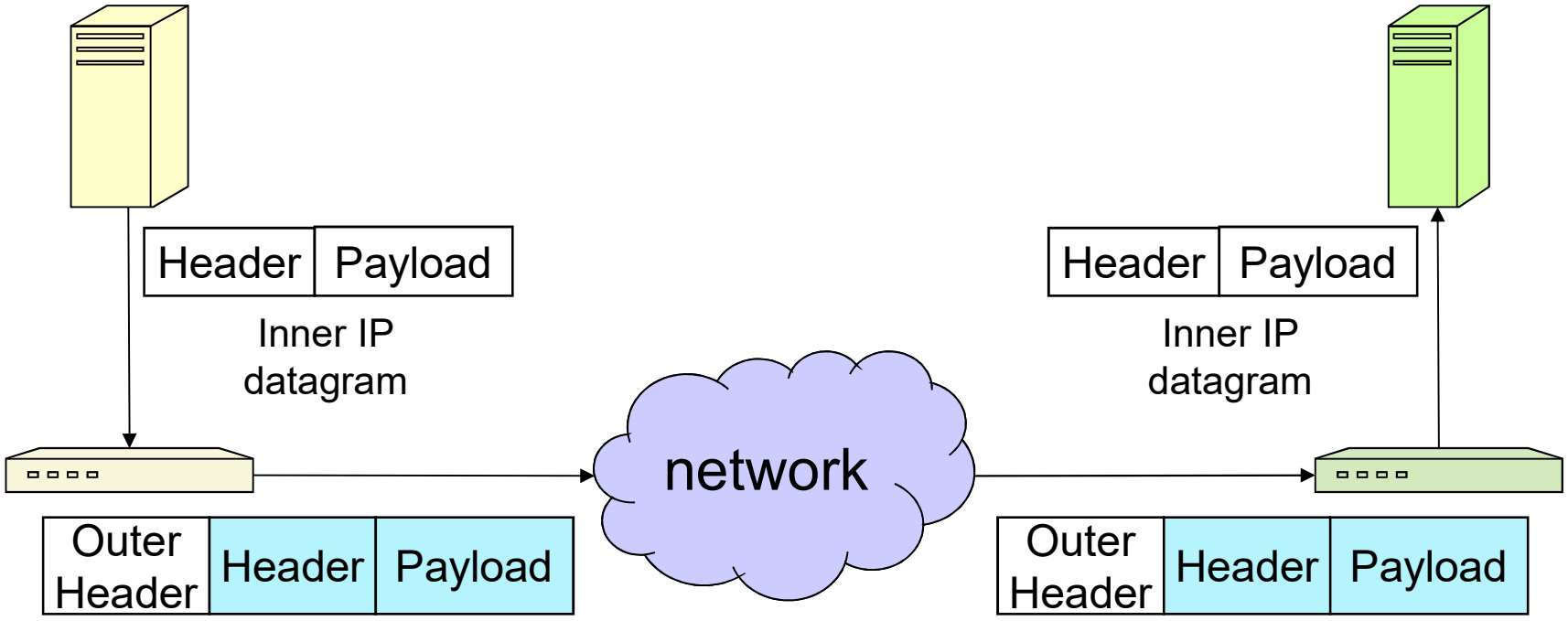
- Host-to-host (end-to-end) security:
  - IPsec processing performed at endpoints of secure channel.
  - Endpoint hosts must be IPsec-aware.



IPsec Tunnel Mode

- Entire IP datagram plus security fields treated as new payload of ‘outer’ IP datagram.
  - Original ‘inner’ IP datagram encapsulated within ‘outer’ IP datagram.
- IPsec processing performed at security gateways on behalf of endpoint hosts.
  - Gateway could be perimeter firewall or router.
  - Gateway-to-gateway but not end-to-end security.
  - Hosts need not be IPsec-aware.
- Encrypted inner IP datagram, including original source and destination addresses, not visible to intermediate routers.

IPSec Transport Mode



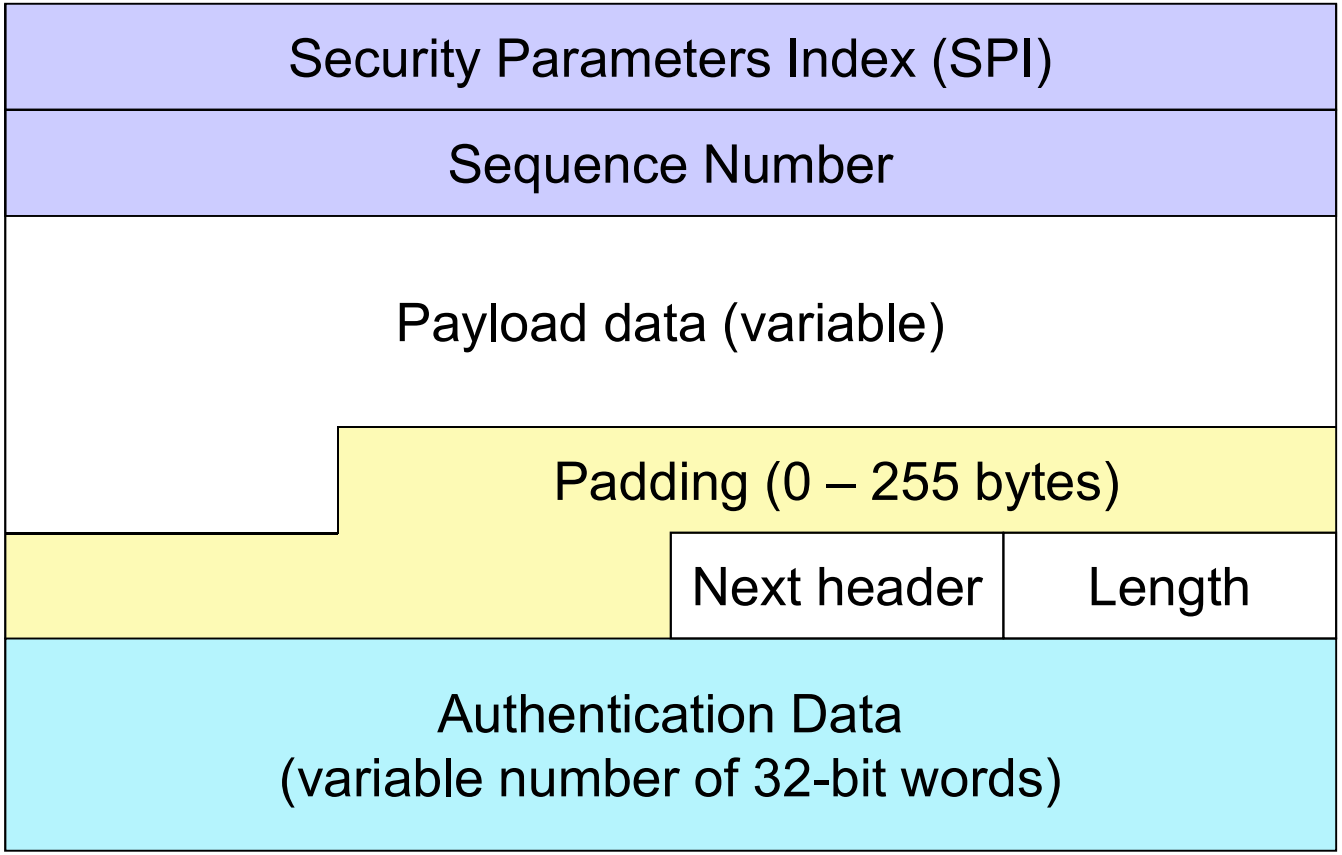
ESP Protocol

- Encapsulating Security Payload [RFC 2406].
- Provides one or both of:
  - confidentiality for payload/inner datagram; sequence number not protected by encryption.
  - Authentication of payload/inner datagram, but not of outer IP header.
- Traffic-flow confidentiality in tunnel mode.
- Symmetric encryption and MACs based on secret keys shared between endpoints.

ESP Headers

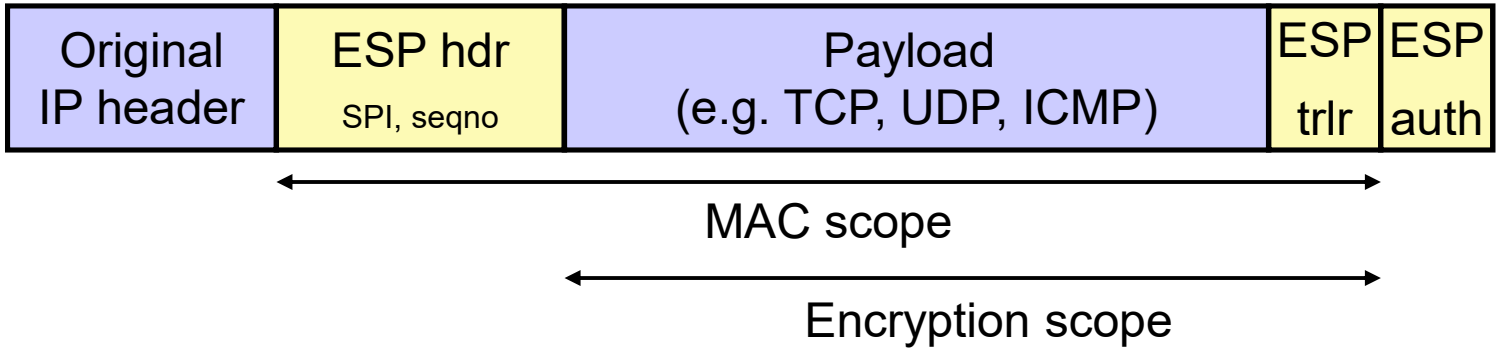
- ESP specifies header and trailer to be added to IP datagrams.
- Header fields include:
  - SPI (Security Parameters Index): identifies which algorithms and keys are to be used for IPsec processing (more later).
  - Sequence number.
- Trailer fields include:
  - Any padding needed for encryption algorithm (may also help disguise payload length).
  - Padding length.
  - Authentication data (if any), i.e. the MAC value.

ESP Header (RFC 2406)

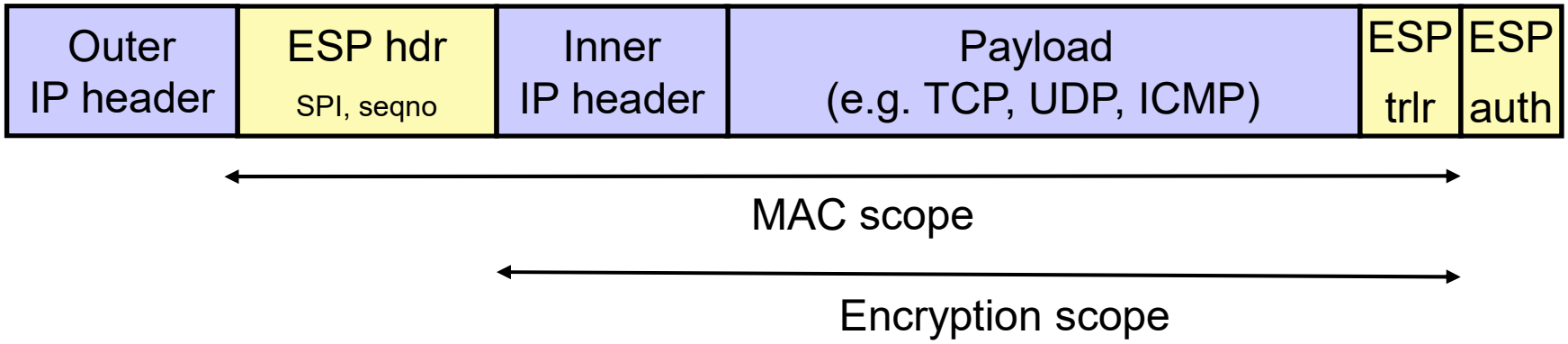


ESP Protocol – Transport & Tunnel

ESP in transport mode:



ESP in tunnel mode:



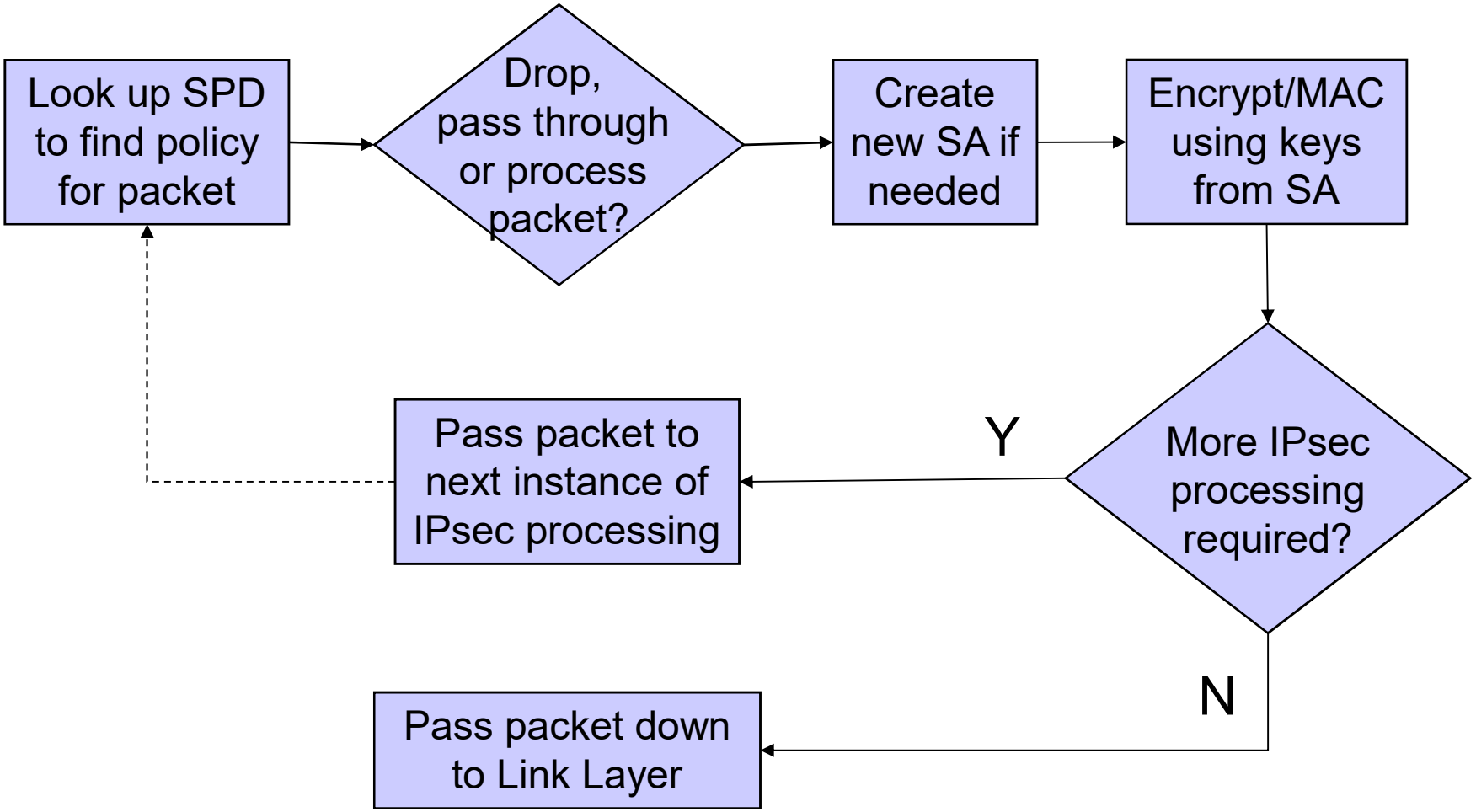
IPsec Security Policy

- IPsec aware hosts need rules for processing packets:
  - Drop, pass through, encrypt, MAC?
  - Which key and algorithm to apply?
- Rules stored in a Security Policy Database (SPD).
- SPD consulted for each outbound and inbound packet.
- Fields in packet matched against fields in SPD entries:
  - Based on source and destination addresses (address ranges), transport layer protocol, transport layer port numbers, …
  - Match identifies a Security Association (SA), or a group of SAs, or the need for a new SA.

IPsec Security Association (SA)

- A SA is a one-way (simplex) relationship between sender and receiver.
  - Specifies processing to be applied to *this* datagram from *this* sender to *this* receiver.
- List of active SAs held in SA database (SADB).
- SA identified by SPI, source address, destination address; contains:
  - Sequence number counter and anti-replay window,
  - AH/ESP info: algorithms, IVs, keys, key lifetimes,
  - SA lifetime,
  - Protocol mode: tunnel or transport,
  - …

IPsec Outbound Processing

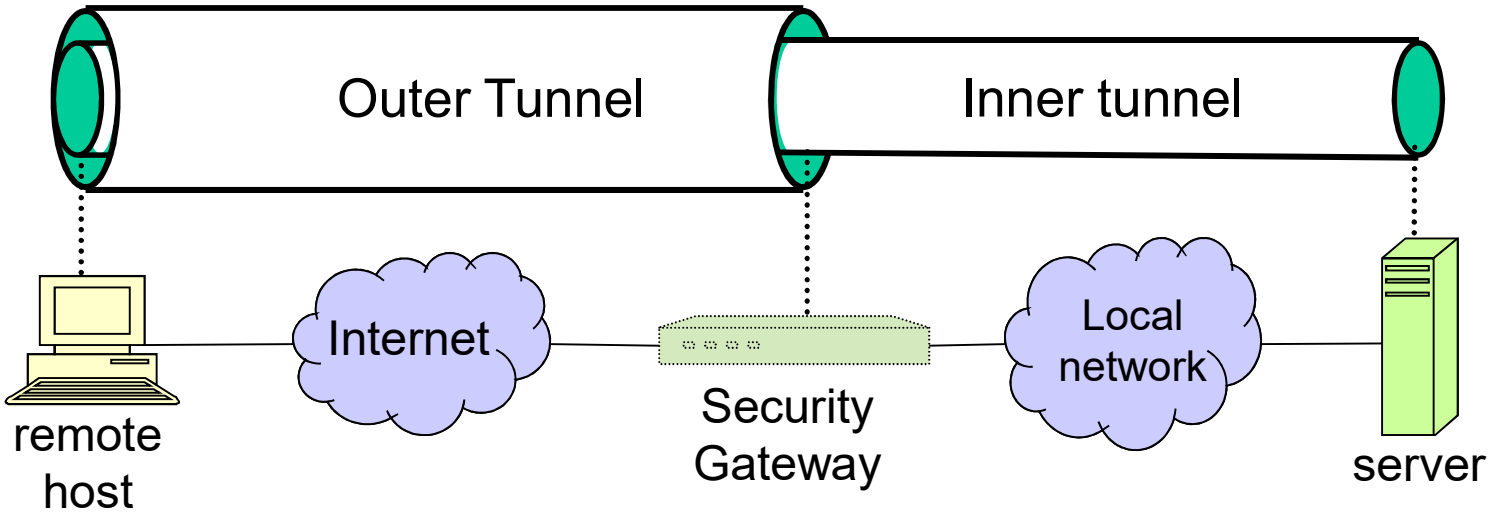


Combining SAs

- IPsec security services may be provided at different points in network.
  - Host-to-host.
  - Gateway-to-gateway for Virtual Private Network (VPN).
- SAs can be combined using:
  - Transport adjacency: more than one SA applied to same IP datagram without tunnelling.
  - Iterated tunnelling: multiple levels of nesting of IPsec tunnels; each level has its own SA; each tunnel can begin/end at different IPsec site along route.

Example

- Remote host has Internet access to gateway, then gains access to server behind gateway.
- Traffic to server protected in inner tunnel.
- Outer tunnel protects inner traffic over Internet.



IPsec Key Management

- IPsec needs a lot of symmetric keys:
  - One key for each SA.
  - Different SA for each combination of {ESP,AH} × {tunnel,transport} × {sender, receiver}.
- Two sources for SAs and keys:
  - Manual keying: works for small number of nodes but hopeless for reasonably sized networks of IPsec-aware hosts; requires manual re-keying.
  - IKE: Internet Key Exchange [RFC 2409]; many options and parameters.

IKE Security Goals

- Entity authentication of participating parties.
- Establish a fresh shared secret, used to derive further keys:
  - for protecting IKE management channel,
  - for SAs for general use.
- Secure negotiation of all algorithms.
  - Authentication method, key exchange method, encryption and MAC algorithms, hash algorithms.
- Resistance to Denial-of-Service attacks: cookie mechanism.
- Options for perfect forward secrecy, deniable authentication and identity protection.

SSL

SSL/TLS Overview

- SSL = Secure Sockets Layer.
  - unreleased v1, flawed but useful v2, good v3.
- TLS = Transport Layer Security [RFC 2246]
  - TLS1.0 = SSL3.0 with minor tweaks (see later)
- SSL/TLS provides security ‘at TCP layer’.
  - Uses TCP to provide reliable end-to-end transport.
  - Usually a thin layer between TCP and HTTP.
  - Applications need to be aware of SSL/TLS..
- Widely used in Web browsers and servers to support ‘secure e-commerce’ over HTTP.

SSL/TLS Basic Features

- SSL Record Protocol: Provides secure, reliable channel to second layer.
- Second layer carries SSL Handshake Protocol, Change Cipher Spec. Protocol, Alert Protocol, HTTP, and other application protocols.
- SSL Handshake Protocol establishes keys for MAC and encryption at Record Layer.
- Different keys in each direction.

SSL Handshake Protocol – Goals

- Entity authentication of participants.
  - Participants are ‘client’ and ‘server’.
  - Server nearly always authenticated, client more rarely.
  - Appropriate for most e-commerce applications.
- Establish a fresh, shared secret.
  - Shared secret used to derive further keys.
  - For confidentiality and authentication in SSL Record Protocol.
- Secure ciphersuite negotiation.
  - Encryption and hash algorithms
  - Authentication and key establishment methods.

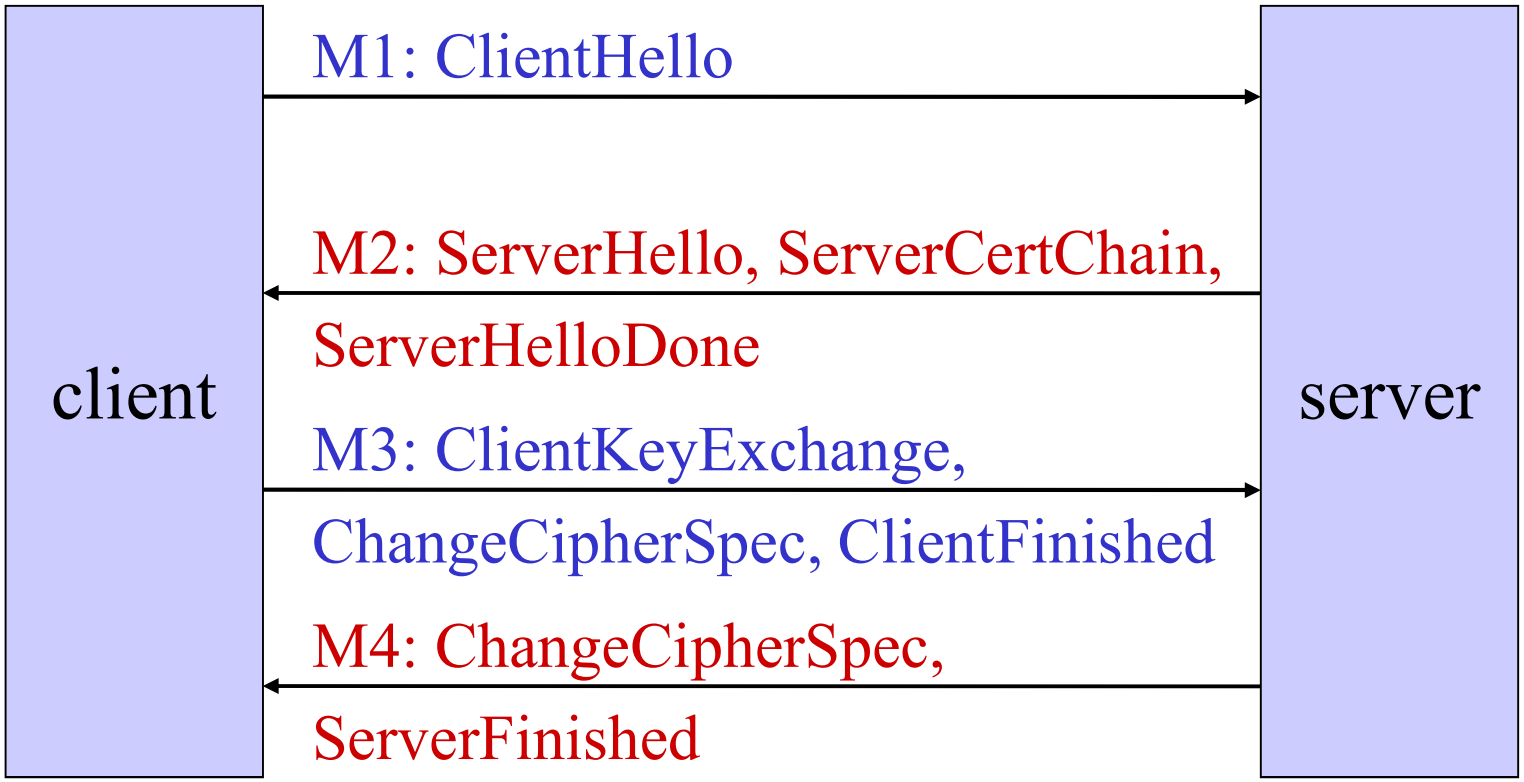
Sessions & Connections

- Session:
  - Created by handshake protocol.
  - Defines set of cryptographic parameters (encryption and hash algorithm, master secret, certificates).
  - Carries multiple connections to avoid repeated use of expensive handshake protocol.
- Connection:
  - State defined by nonces, secret keys for MAC and encryption, IVs, sequence numbers.
  - Keys for many connections derived from single master secret created during handshake protocol.

SSL Handshake Protocol: Run

- We sketch the most common use of SSL:
  - No client authentication.
  - Client sends **`pre_master_secret`** using Server's public encryption key from Server certificate.
  - Server authenticated by ability to decrypt to obtain **`pre_master_secret`**, and construct correct **`finished`** message.
- Other protocol runs are similar.

SSL Handshake Protocol Run



M1: `ClientHello`

- Client initiates connection.
- Sends client version number.
  - 3.1 for TLS.
- Sends **`ClientNonce`**.
  - 28 random bytes plus 4 bytes of time.
- Offers list of ciphersuites:
  - Key exchange and authentication options, encryption algorithms, hash functions.
  - E.g. **`TLS_RSA_WITH_3DES_EDE_CBC_SHA`**.

M2: `ServerHello, …`

- Sends server version number.
- Sends **`ServerNonce`** and **`SessionID`**.
- Selects single ciphersuite from list offered by client.
- Sends **`ServerCertChain`** message.
  - Allows client to validate server's public key back to acceptable root of trust.
- (optional) **`CertRequest`** message.
  - Omitted in this protocol run – no client authentication.
- Finally, **`ServerHelloDone`**.

M3: `ClientKeyExchange,…`

- **`ClientKeyExchange`** contains encryption of **`pre_master_secret`** under server's public key.
- **`ChangeCipherSpec`** indicates that client is updating cipher suite to be used on this session.
  - Sent using SSL Change Cipher Spec. Protocol.
- Optional (only when client is authenticated): **`ClientCertificate`**, **`ClientCertificateVerify`** messages.
- Finally, **`ClientFinished`** message.
  - MAC on all messages sent so far (both sides).
  - MAC computed using **`master_secret`**.

M4: `ChangeCipherSpec, …`

- **`ChangeCipherSpec`** indicates that server is updating cipher suite to be used on this session.
  - Sent using SSL Change Cipher Spec. Protocol.
- Finally, **`ServerFinished`** message.
  - MAC on all messages sent so far (both sides).
  - MAC computed using **`master_secret`**.
  - Server can only compute MAC if it can decrypt **`pre_master_secret`** in M3.

SSL Handshake Protocol Run

1. Is the client authenticated to the server in this protocol run?
   - No!
2. Can an adversary learn the value of `pre_master_secret`?
   - No! Client has validated server's public key; To learn `pre_master_secret` the server's private key is needed to decrypt ClientKeyExchange
3. Is the server authenticated to the client?
   - Yes! ServerFinished includes MAC on nonces computed using key derived from **`pre_master_secret`**.

SSL/TLS Applications

- Secure e-commerce using SSL/TLS.
- Client authentication not needed until client decides to buy something.
- SSL provides secure channel for sending credit card information.
- Client authenticated using credit card information, merchant bears (most of) risk.
- Widely deployed (de-facto standard).

Firewalls

Introduction

- Cryptographic mechanisms protect data in transit (confidentiality, integrity).
- Authentication protocols verify the source of data.
- We may also control which traffic is allowed to enter our system (ingress filtering) or to leave our system (egress filtering).
- Access control decisions based on information like addresses, port numbers, ...

Firewall

- Firewall: a network security device controlling traffic flow between two parts of a network.
- Often installed between an entire organisation's network and the Internet.
- Can also be installed in an intranet to protect individual departments.
- All traffic has to go through the firewall for protection to be effective.
  - Dial-in lines, wireless LANs!?

Purpose

- Firewalls control network traffic to and from the protected network.
- Can allow or block access to services (both internal and external).
- Can enforce authentication before allowing access to services.
- Can monitor traffic in/out of network.

Types of Firewalls

- Packet filter
- Stateful packet filter
- Circuit-level proxy
- Application-level proxy

Packet Filter

- Inspect headers of IP packets, also TCP and UDP port numbers.
- Rules specify which packets are allowed through the firewall, and which are dropped.
  - Actions: bypass, drop, protect (IPsec channel).
- Rules may specify source / destination IP addresses, and source / destination TCP / UDP port numbers.
- Rules for traffic in both directions.
- Certain common protocols are difficult to support securely (e.g. FTP).

Example

- TCP/IP packet filtering router.
  - Router which can throw packets away.
- Examines TCP/IP headers of every packet going through the Firewall, in either direction.
- Packets can be allowed or blocked based on:
  - IP source & destination addresses
  - TCP / UDP source & destination ports
- Implementation on router for high throughput.

Stateful Packet Filter

- Packet filter that understands requests and replies (e.g. for TCP: SYN, SYN-ACK, ACK).
- Rules need only specify packets in one direction (from client to server – the direction of the first packet in a connection).
- Replies and further packets in the connection are automatically processed.
- Supports wider range of protocols than simple packet filter (eg: FTP, IRC, H323).

Stateful Packet filter & FTP

- Client sends ftp-request to server
- Firewall stores connection state
  - FTP-Server Address
  - state of connection (SYN, ACK, ...)
- If correct FTP-server tries to establish data connection, packets are not blocked.

Circuit-level Proxy

- Similar to a packet filter, except that packets are not routed.
- Similar to gateway using IPsec in tunnel mode.
- Incoming TCP/IP packets accepted by proxy.
- Rules determine which connections will be allowed and which blocked.
- Allowed connections generate new connection from firewall to server.
- Similar specification of rules as packet filter.

Application-level proxy

- Layer-7 proxy server.
- “Client and server in one box”.
- For every supported application protocol.
- SMTP, POP3, HTTP, SSH, FTP, NNTP...
- Packets received and processed by server.
- New packets generated by client.

Application-level proxy

- Complete server & client implementation in one box for every protocol the firewall should handle.
- Client connects to firewall.
- Firewall validates request.
- Firewall connects to server.
- Response comes back through firewall and is also processed through client/server.
- Large amount of processing per connection.
- Can enforce application-specific policies.

Firewall Policies

- Permissive: allow by default, block some.
  - Easy to make mistakes.
  - If you forget something you should block, it's allowed, and you might not realise for a while.
  - If somebody finds a protocol is allowed, they might not tell you ....
- Restrictive: block by default, allow some.
  - Much more secure.
  - If you forget something, someone will complain and you can allow the protocol.

Firewall Policies – Examples

- Permissive policies: Allow all traffic, but block ...
  - Irc
  - telnet
  - snmp
  - …
- Restrictive policies: block all traffic, but allow ...
  - http
  - Pop3
  - Smtp
  - ssh
  - …

Rule Order

- A firewall policy is a collection of rules.
- Packets can contain several headers ($\rightarrow$ IPsec).
- When setting a policy, you have to know in which order rules (and headers) are evaluated.
- Two main options for ordering rules:
  - Apply first matching entry in the list of rules.
  - Apply the entry with the best match for the packet.

Typical Firewall Ruleset

- Allow from internal network to Internet:
  - HTTP, FTP, HTTPS, SSH, DNS
- Allow reply packets
- Allow from anywhere to Mail server:
  - TCP port 25 (SMTP) only
- Allow from Mail server to Internet:
  - SMTP, DNS
- Allow from inside to Mail server:
  - SMTP, POP3
- Block everything else

Firewall Location

- A Firewall can only filter traffic which goes through it.
- Where to put, for example, a mail server?
- Requires external access to receive mail from the Internet.
  - Should be on the inside of the firewall
- Requires internal access to receive mail from the internal network.
  - Should be on the outside of the firewall
- Solution: “perimeter network” (aka DMZ).

Intrusion Detection Systems

Reminder: Security Strategies

- Prevention: take measures that prevent your assets from being damaged.
- Detection: take measures so that you can detect when, how, and by whom an asset has been damaged.
- Reaction: take measures so that you can recover your assets or to recover from a damage to your assets.

Comment

- Cryptographic mechanisms and protocols are fielded to prevent attacks.
- Perimeter security devices (e.g. firewalls) mainly prevent attacks by outsiders.
- Although it would be nice to prevent all attacks, in reality this is rarely possible.
- New types of attacks occur: denial-of-service (where crypto may make the problem worse).
- We will now look at ways of detecting network attacks.

Vulnerability Assessment

- Examines the “security state” of a network:
  - Open ports
  - Software packages running (which version, patched?)
  - Network topology
  - Returns prioritized lists of vulnerabilities
- Only as good as the knowledge base used.
  - Have to be updated to handle new threats
- Vulnerability Assessment Methods.
  - Software solutions (ISS Scanner, Stat, Nessus etc.)
  - Audit Services (manual Penetration tests etc)
  - Web based commercial (Qualys, Security Point etc)

Intrusion Detection Systems

- An IDS consists of a set of sensors gathering data, located on the hosts or on the network.
- Sensors managed from a central console, where data is analyzed, intrusions are reported, and reactions may be triggered.
- Two approaches for IDS: misuse detection and anomaly detection.
- Protect communications between sensors and console, signature database and logs generated.
- Needs secure scheme for getting signature updates from the IDS vendor.

Misuse Detection

- Based on attack signatures:
  - specific patterns of network traffic or activity in log files that indicate suspicious behaviour.
- Example signatures might include:
  - a number of recent failed login attempts on a sensitive host;
  - a certain pattern of bits in an IP packet, indicating a buffer overflow attack;
  - certain types of TCP SYN packets, indicating a SYN flood DoS attack.
- Method used by all commercial IDS products.

Misuse Detection

- Rules based on security policy, known vulnerabilities of particular OS and applications. known attacks.
- Only as good as the information in the database of attack signatures:
  - new vulnerabilities not in the database are constantly being discovered and exploited;
  - vendors need to keep up to date with latest attacks and issue database updates; customers need to install these;
  - large number of vulnerabilities and different exploitation methods, so effective database difficult to build;
  - large database makes IDS slow to use.

Anomaly Detection

- Statistical Anomaly Detection (or behaviour-based detection) uses statistical techniques to detect penetrations and attacks.
- First establish base-line statistical behaviour: what is “normal” for this system?
- Then gather new statistical data and measure the deviation from the base-line.
- If a threshold is exceeded, issue an alarm.

Anomaly Detection

- Example: monitor the number of failed login attempts at a sensitive host over a period;
  - if a burst of failures occurs, an attack may be under way;
  - or maybe the admin just forgot his password?
- False positives (false alarm): attack is flagged when one is not taking place
- False negatives: attack was missed because it fell within the bounds of normal behaviour
- False negatives are also a major issue in misuse detection.

Anomaly Detection

- IDS does not need to know about security vulnerabilities in a particular system; detects deviation from normal behaviour.
- Problem: normal behaviour may overlap with forbidden behaviour
  - Legitimate users may deviate from normality, causing false positives (e.g. user works late, forgets password, starts to use a new application).
  - If the base-line is adjusted dynamically, an attacker may be able to gradually change this base-line so that the final attack does not generate an alarm.

Host-based & Network-based IDS

- Network-based IDS (NIDS): looks for attack signatures in network traffic.
- Host-based IDS (HIDS): looks for attack signatures in log files of hosts
  - E.g. monitors system, event, and security logs on Windows and syslog in Unix environments.
- The most effective IDS System will make use of both kinds of information.
- There is a trend towards to host-based IDSs.

Honeypots

- Technology used to track, learn and gather evidence of hacker activities
- Strategically placed systems designed to mimic production systems, but not reveal “real” data
- Definition:
  - “… a resource whose value is being attacked or compromised”

Laurence Spitzner, “The value of honeypots”, SecurityFocus, October 2001

Honeypot Types

- Level of Involvement
  - Low Involvement: Port Listeners
  - Mid Involvement: Fake Daemons
  - High Involvement: Real Services
- Risk increases with level of involvement.
- Tools to detect honeypots are now available.