Computer Security

11. Firewalls & VPNs

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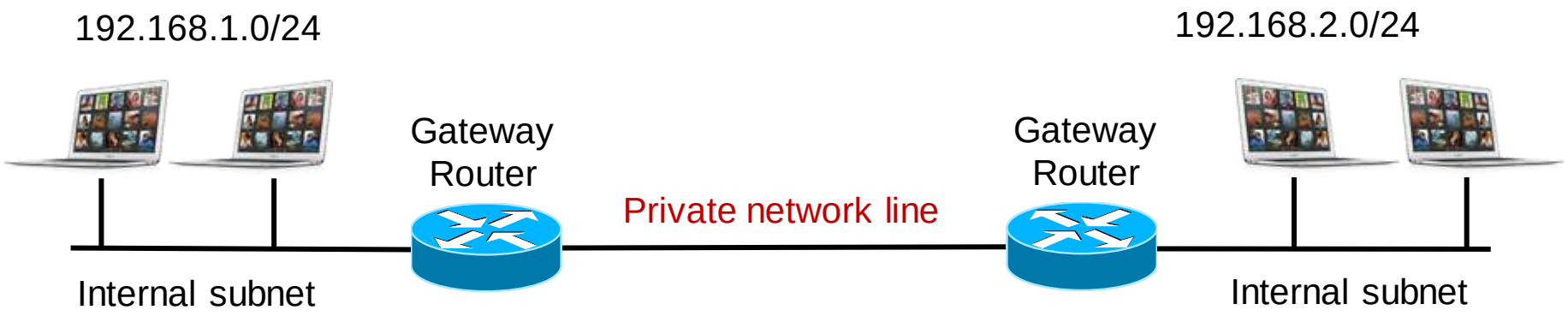
Conversation Isolation

Fundamental Layer 2 & 3 Problems

- IP relies on store-and-forward networking
  - Network data passes through untrusted hosts
  - Routes may be altered to pass data through malicious hosts
- Packets can be sniffed
- TCP session state can be examined or guessed …
  … and TCP sessions can be hijacked
- No source authentication on IP packets

Solution: Use private networks

Connect multiple geographically-separated private subnetworks together

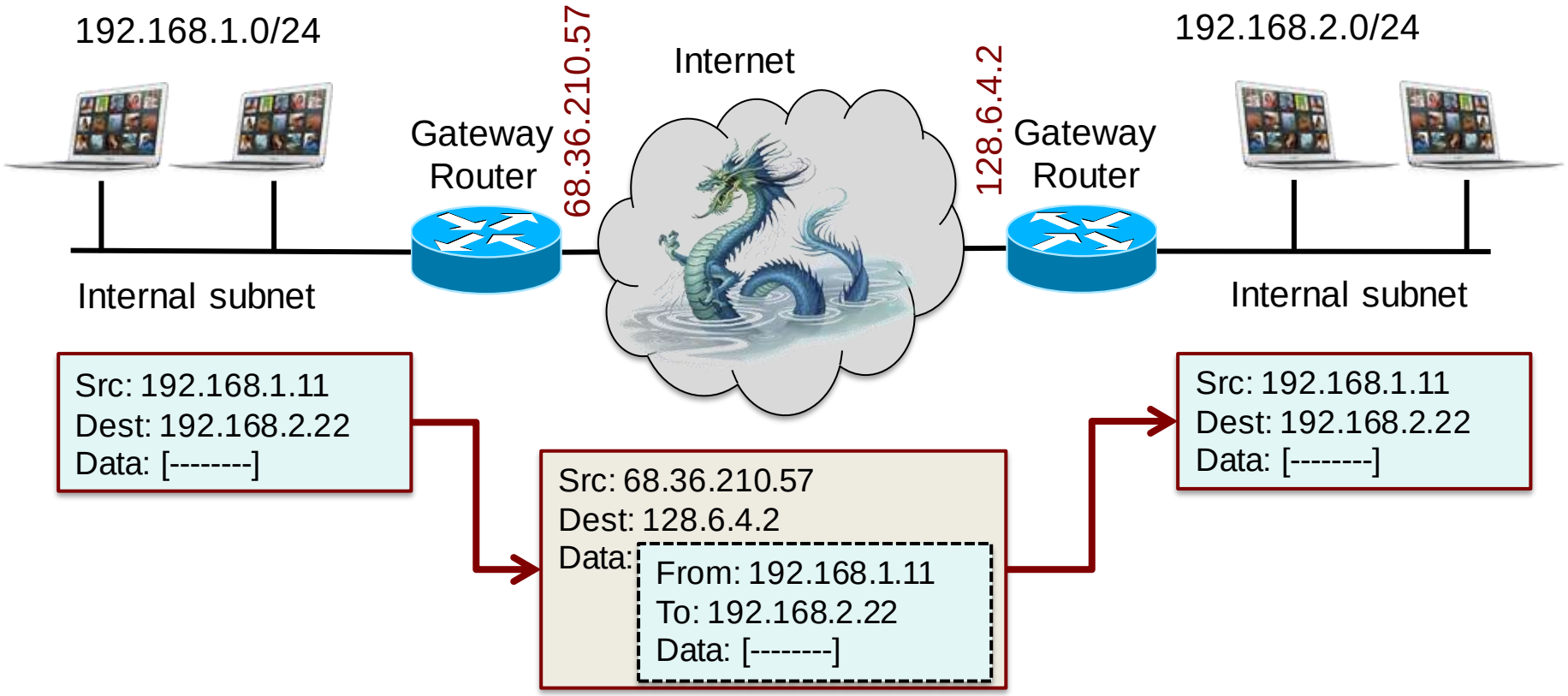


But this is expensive … and not feasible in many cases (e.g., cloud servers)

Tunneling

Tunnel = Packet encapsulation

Treat an entire IP datagram as payload on the public network



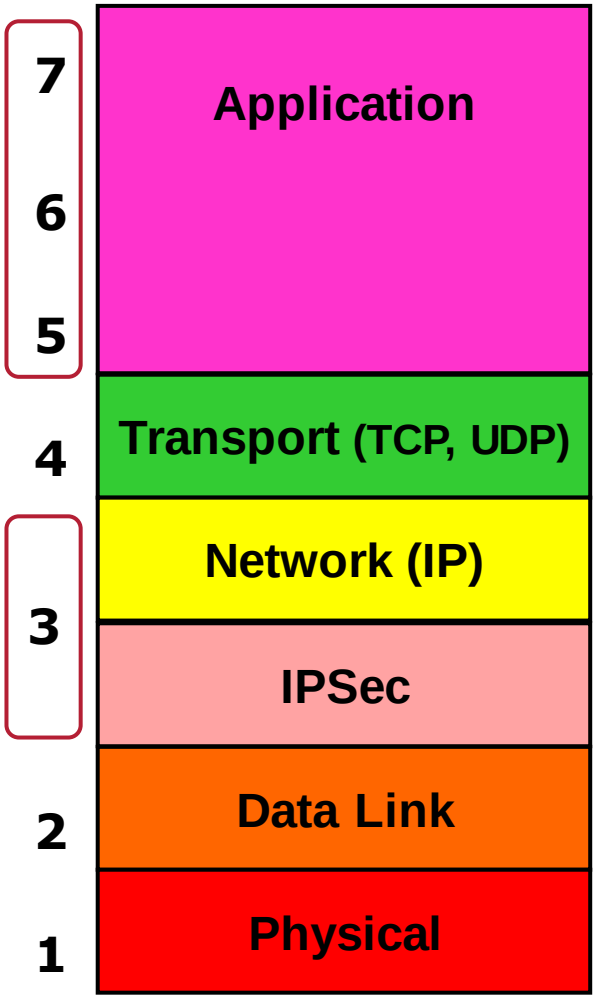
Tunnel mode vs. transport mode

- Tunnel mode
  - Communication between gateways: *network-to-network*
  - Or *host-to-network*
  - Entire datagram is encapsulated

- Transport mode
  - Communication between hosts
  - IP header is not modified

IPsec

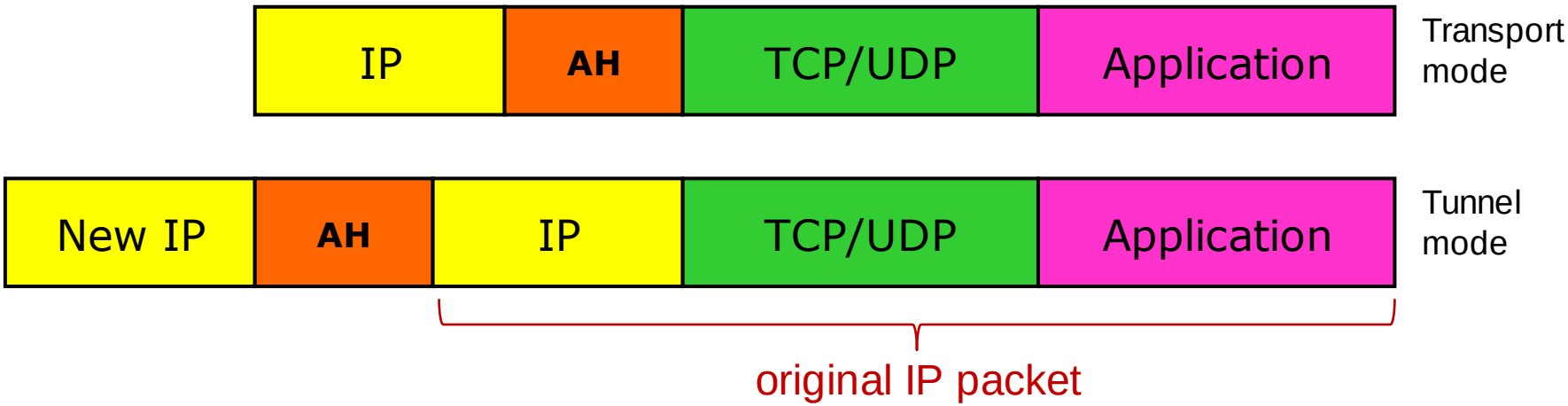
- Internet Protocol Security
- End-to-end solution at the IP layer
- Two protocols:
  - **IP Authentication Header** Protocol (AH)
    - Authentication & integrity of payload and header
  - **Encapsulating Security Payload** (ESP)
    - AH + Confidentiality of payload



IPsec Authentication Header (AH)

Guarantees integrity & authenticity of IP packets

- MAC for the contents of the entire IP packet
- Over unchangeable IP datagram fields (e.g., not TTL or fragmentation)



Protects from:

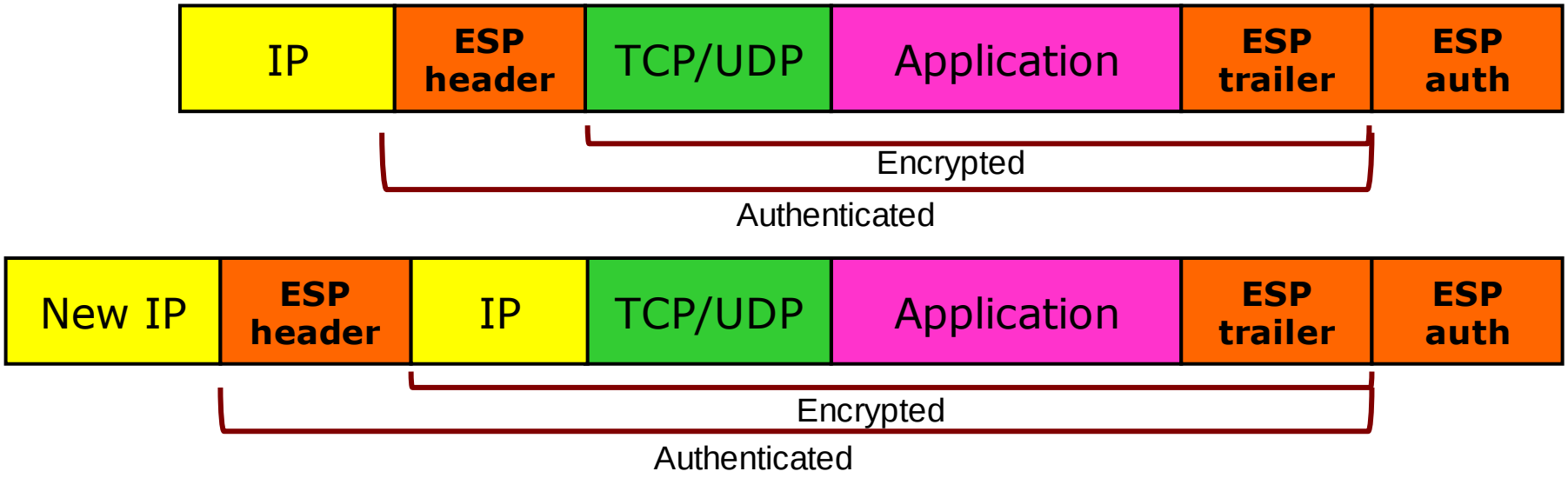
- Tampering
- Forging addresses
- Replay attacks (signed sequence number in AH)

Layered directly on top of IP (protocol 51) - not UDP or TCP

IPsec Encapsulating Security Payload (ESP)

Encrypts entire payload

- Plus authentication of payload + IP header (everything AH does)
  (may be optionally disabled – but you don't want to)



Directly on top of IP (protocol 51) - not UDP or TCP

IPsec algorithms

- Integrity protection & authenticity
  - HMAC-SHA1
  - HMAC-SHA2
- Confidentiality
  - 3DES-CBC
  - AES-CBC
- Authentication
  - Kerberos, certificates, or pre-shared key authentication
- Key generation
  - Diffie-Hellman to exchange keying material for key generation
  - Key lifetimes determine when new keys are regenerated
  - Perfect forward secrecy
    - "Main mode master key PFS" – requires reauthentication & is CPU-intensive
    - "Quick mode session key PFS" – no reauthentication

Conversation Isolation: Transport Layer SSL/TLS

Transport Layer Security

- Provide a transport layer security protocol
- After setup, applications feel like they are using TCP sockets

SSL: Secure Socket Layer

- Created with HTTP in mind
  - Web sessions should be secure
  - Mutual authentication is usually not needed
    - Client needs to identify the server but the server won't know all clients
    - Rely on passwords after the secure channel is set up
- SSL evolved to TLS (Transport Layer Security)
  - SSL 3.0 was the last version of SSL … and is considered insecure
  - We use TLS now … but often still call it SSL

TLS Protocol

- Goal
  - Provide authentication (usually one-way), privacy, & data integrity between two applications
- Principles
  - Use symmetric cryptography to encrypt data
  - Keys generated uniquely at the start of each session
  - Include a MAC with transmitted data to ensure message integrity
  - Use public key cryptography & X.509 certificates for authentication
    - Optional – can authenticate 0, 1, or both parties
  - Support many different key exchange, encryption, integrity, & authentication protocols – negotiate what to use at the start of a session

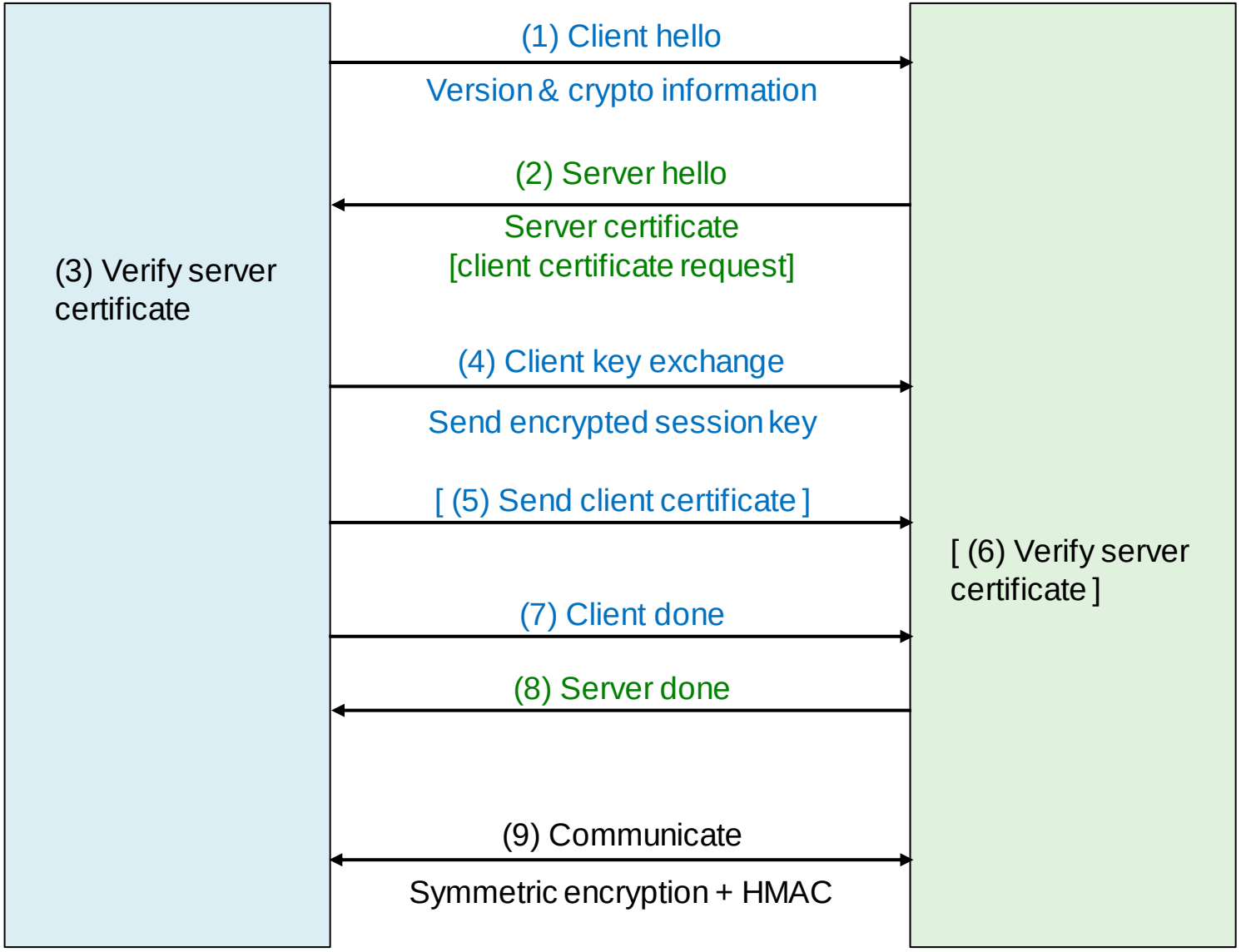
TLS Protocol & Ciphers

Two sub-protocols

1. Authenticate & establish key
2. Communicate
   - HMAC used for message authentication

- Key exchange
  - Public keys (RSA or Elliptic Curve)
  - Diffie Hellman keys
  - Ephemeral Diffie-Hellman keys (generated for each session)
  - Pre-shared key
- Data encryption
  - AES GCM, AES CBC, ARIA (GCM/CBC), ChaCha20-Poly1305, …
- Data integrity
  - HMAC-MD5, HMAC-SHA1, HMAC-SHA256/384, …

TLS Protocol



Benefits of TLS

- Benefits
  - Protects integrity of communications
  - Protects the privacy of communications
  - Validates the authenticity of the server (if you trust the CA)

Problems with TLS

- Attacks
  - Man-in-the-middle: BEAST attack in TLS 1.0
    - Attacker was able to see Initialization Vector (IV) for CBC and deduce plaintext (known HTML headers & cookies)
    - Fixed by using explicit IVs for each new block
  - Man-in-the-middle: crypto renegotiation
    - Attacker can renegotiate the handshake protocol to disable encryption
    - Proposed fix: have client & server verify info about previous handshakes
  - THC-SSL-DoS attack
    - Attacker initiates a TLS handshake & requests a renegotiation of the encryption key – repeat over & over, using up server resources

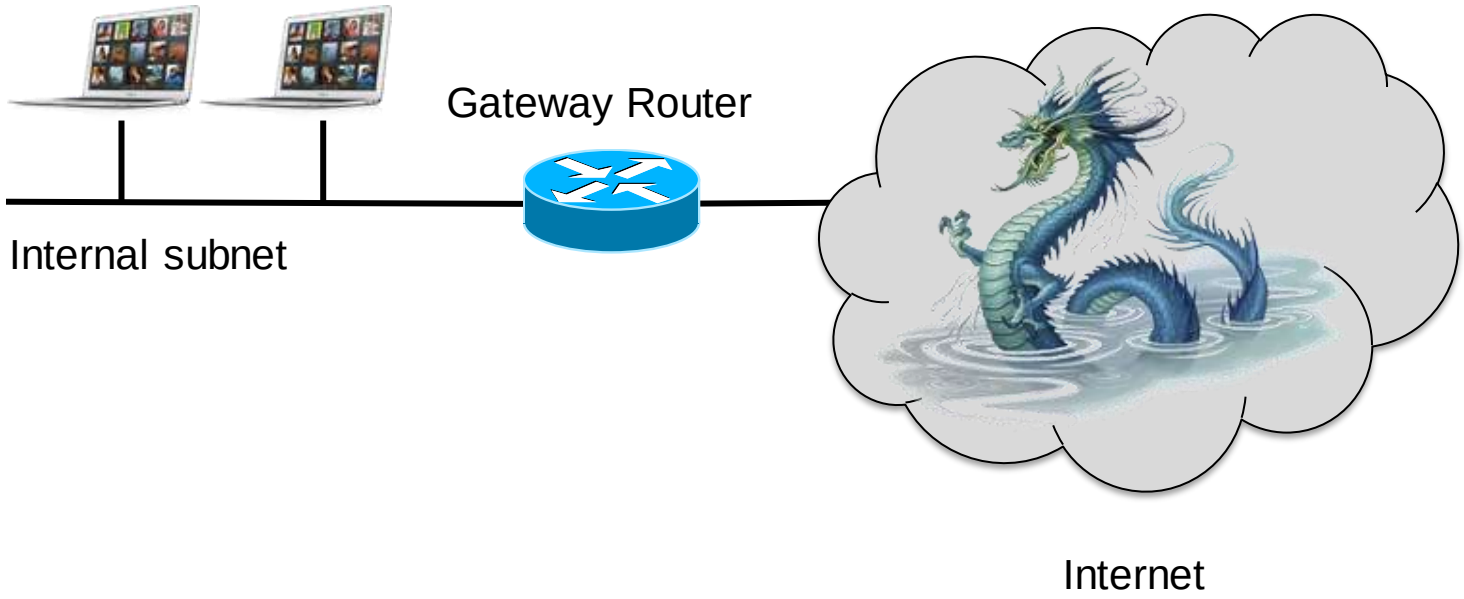
Problems with TLS

- Client authentication Problem
  - Client authentication is almost never used
    - Generating keys & obtaining certificates is not an easy process
    - Any site can request the certificate: user will be unaware anonymity is lost
    - Moving private keys around can be difficult (what about public systems?)
  - We usually rely on other authentication mechanisms (usually user name and password)

Firewalls

Network Security Goals

- Confidentiality: sensitive data & systems not accessible
- Integrity: data not modified during transmission
- Availability: systems should remain accessible



Firewall

- Separate your local network from the Internet
  - Protect the border between trusted internal networks and the untrusted Internet

- Approaches
  - Packet filters
  - Application proxies
  - Intrusion detection / intrusion protection systems

Screening router

- Border router (gateway router)
  - Router between the internal network(s) and external network(s)
  - Any traffic between internal & external networks passes through the border router

Instead of just routing the packet, decide *whether* to route it

- Screening router = Packet filter
  Allow or deny packets based on
  - Incoming interface, outgoing interface
  - Source IP address, destination IP address
  - Source TCP/UDP port, destination TCP/UDP port, ICMP command
  - Protocol (e.g., TCP, UDP, ICMP, IGMP, RSVP, etc.)

Filter chaining

- An IP packet entering a router is matched against a set of rules: access control list (ACL) or chain

- Each rule contains criteria and an action
  - Criteria: packet screening rule
  - Actions
    - *Accept* – and stop processing additional rules
    - *Drop* – discard the packet and stop processing additional rules
    - *Reject* – and send an error to the sender (ICMP Destination Unreachable)
  - Also
    - *Route* – rereoute packets
    - *Nat* – perform network address translation
    - *Log* – record the activity

Filter structure is vendor specific

Examples

- Windows
  - *Allow*, *Block*
  - Options such as
    - Discard all traffic except packets allowed by filters *(default deny)*
    - Pass through all traffic except packets prohibited by filters *(default allow)*
- OpenBSD
  - *Pass* (allow), *Block*
- Linux nftables (netfilter)
  - Chain types: *filter, route, nat*
  - Chain control
    - *Return* – stop traversing a chain
    - *Jump* – jump to another chain (*goto* = same but no return)

Network Ingress Filtering: incoming packets

Basic firewalling principle

Never have a direct inbound connection from the originating host from the Internet to an internal host – all traffic must flow through a firewall and be inspected

- Determine which services you want to expose to the Internet
  - e.g., HTTP & HTTPS: TCP ports 80 and 443
- Create a list of services and allow only those inbound ports and protocols to the machines hosting the services.
- Default Deny model - by default, "deny all"
  - Anything not specifically permitted is dropped
  - May want to log denies to identify who is attempting access

Network Ingress Filtering

- Disallow IP source address spoofing
  - Restrict forged traffic (RFC 2827)
- At the ISP
  - Filter upstream traffic - prohibit an attacker from sending traffic from forged IP addresses
  - Attacker must use a valid, reachable source address
- Disallow incoming/outgoing traffic from private, non-routable IP addresses
  - Helps with DDoS attacks such as SYN flooding from lots of invalid addresses

```
access-list 199 deny ip 192.168.0.0 0.0.255.255 any log
access-list 199 deny ip 224.0.0.0 0.0.0.255 any log
                    ....
access-list 199 permit ip any any
```

Network Egress Filtering (outbound)

- Usually we don't worry about outbound traffic.
  - *Communication from a higher security network (internal) to a lower security network (Internet) is usually fine*

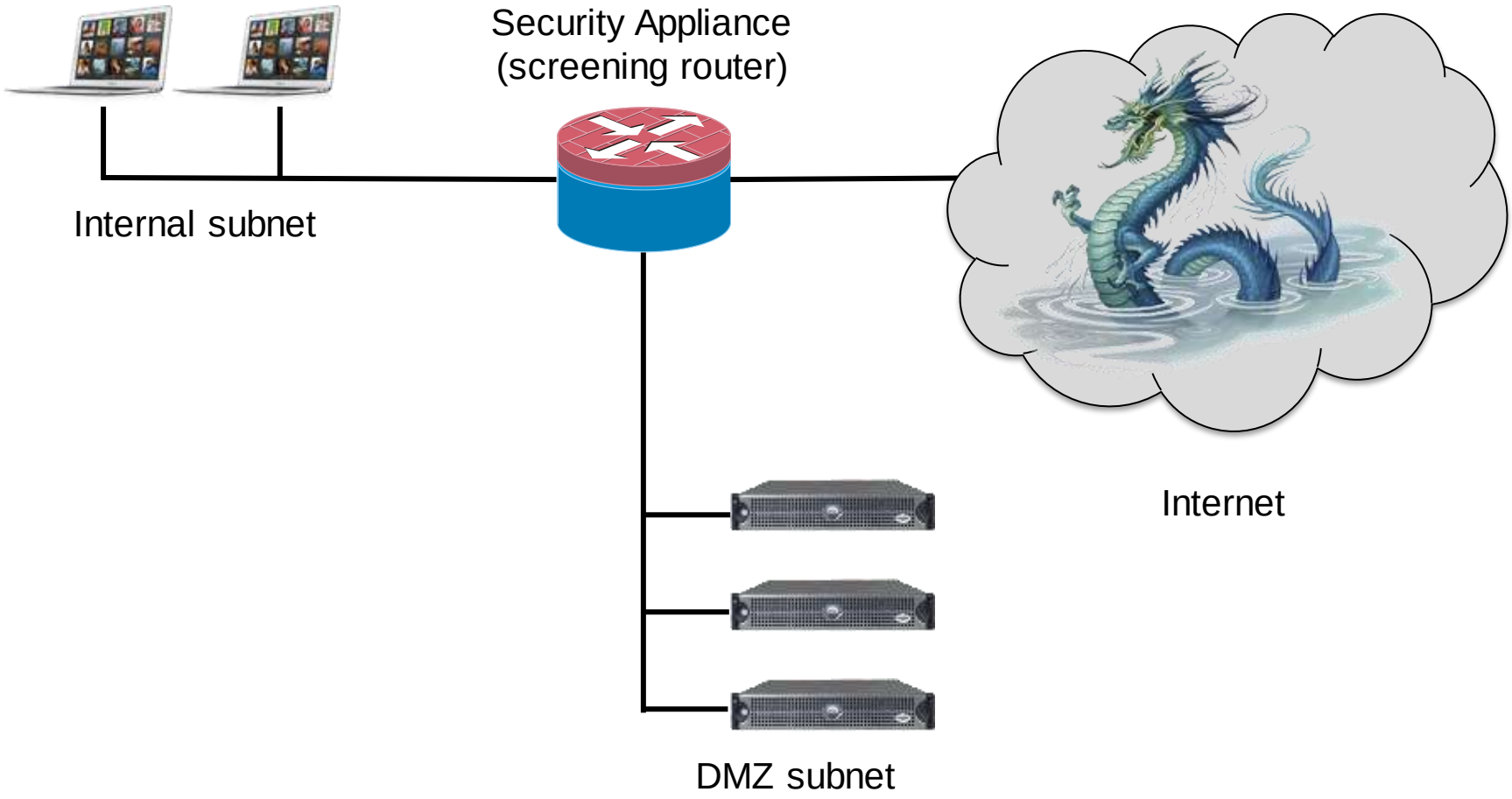
- Why might we want to restrict it?
  - Consider: if a web server is compromised & all outbound traffic is allowed, it can connect to an external server and download more malicious code
    ... or launch a DoS attack on the internal network

  - Also, log which servers are trying to access external addresses

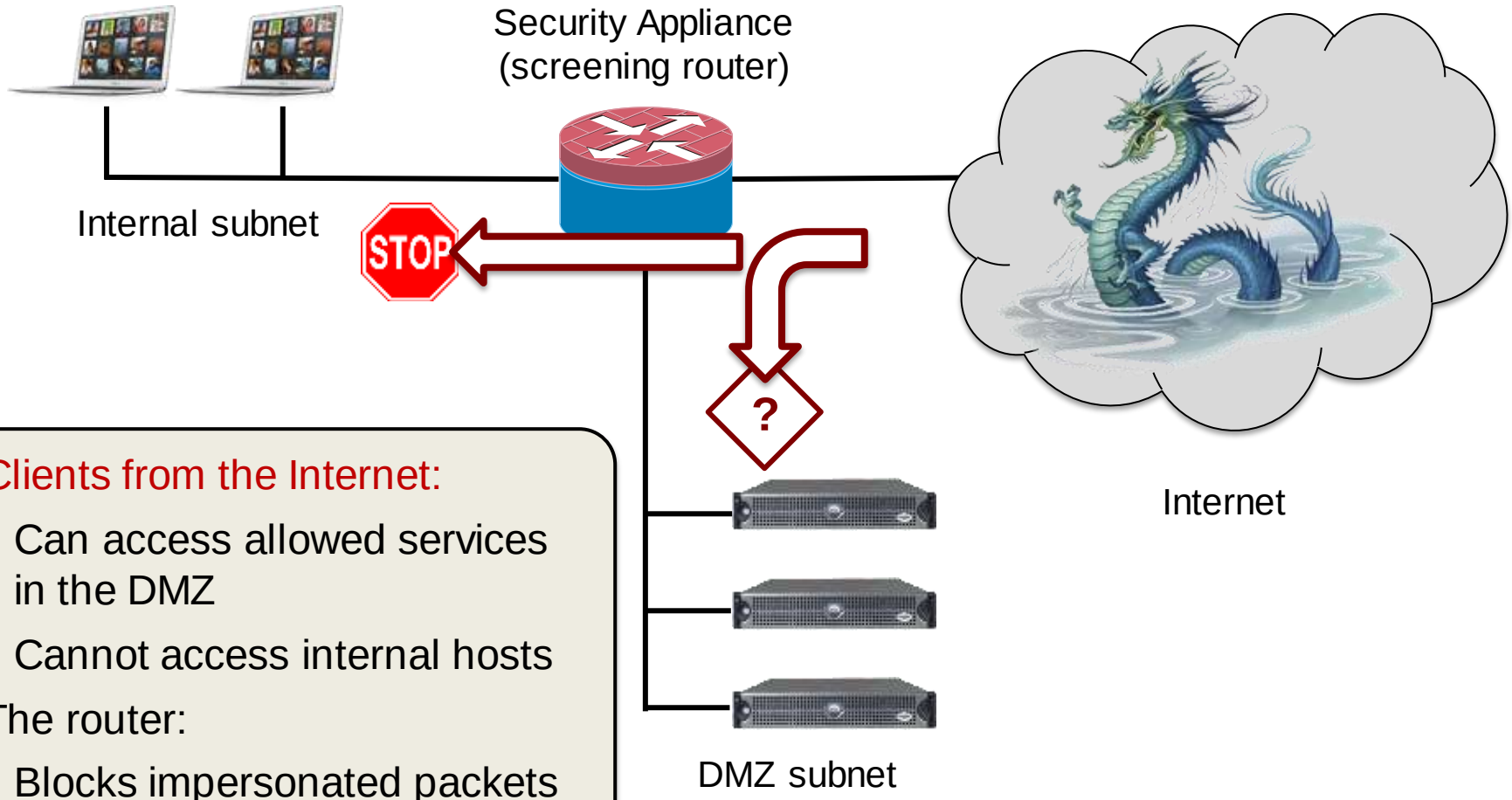
Stateful Inspection

- Retain state information about a stream of related packets
- Examples
  - TCP connection tracking
    - Disallow TCP data packets unless a connection is set up
  - ICMP echo-reply
    - Allow ICMP echo-reply only if a corresponding echo request was sent.
  - Related traffic
    - Identify & allow traffic that is related to a connection
    - Example: related ports in FTP

Network Design: DMZ



Network Design: DMZ



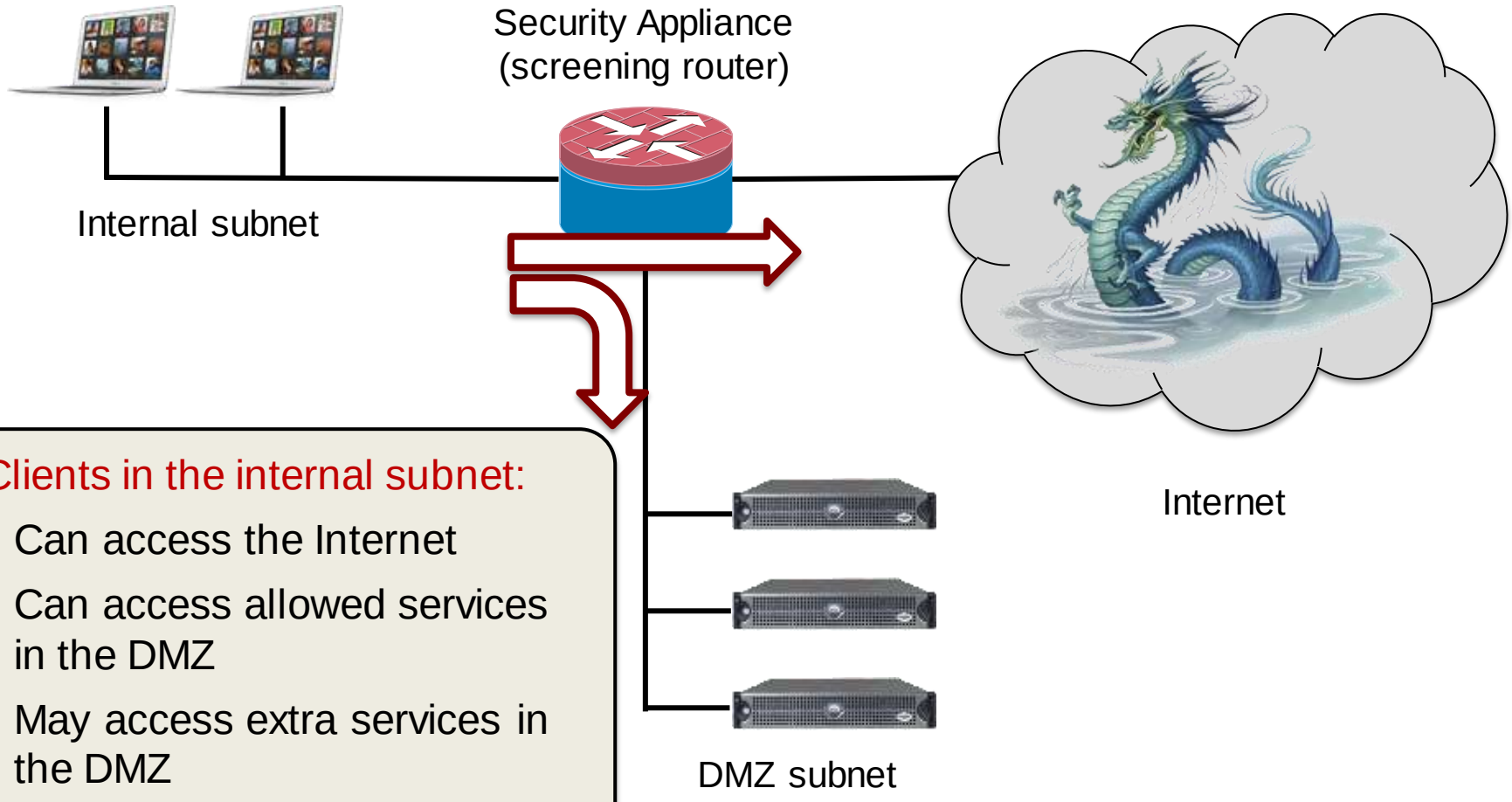
Clients from the Internet:

- Can access allowed services in the DMZ
- Cannot access internal hosts

The router:

- Blocks impersonated packets

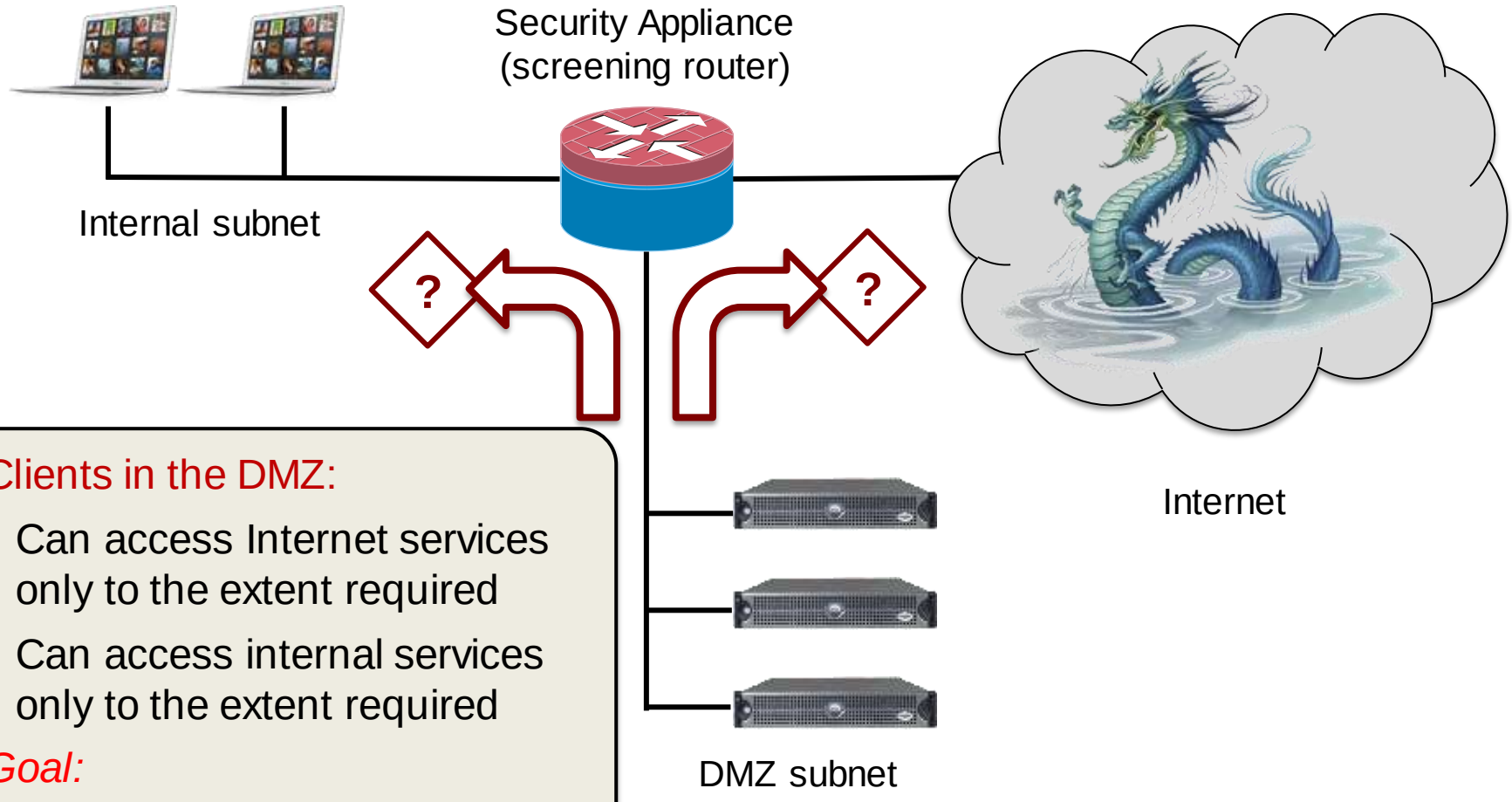
Network Design: DMZ



Clients in the internal subnet:

- Can access the Internet
- Can access allowed services in the DMZ
- May access extra services in the DMZ

Network Design: DMZ



Clients in the DMZ:

- Can access Internet services only to the extent required
- Can access internal services only to the extent required

Goal:
Limit possible damage if DMZ machines are compromised

Network Address Translation

- Most organizations use private IP addresses
- External traffic goes through a NAT router
  - Network Address Translation
- NAT is an implicit firewall (sort of)
  - Arbitrary hosts and services on them (ports) cannot be accessed unless
    - They are specifically mapped to a specific host/port by the administrator
    - Internal services have initiated outgoing traffic
      - Return traffic from the same address/port will be accepted

Application-Layer Filtering

- Firewalls don't work well when everything's a web service
- Deep packet inspection
  - Look beyond layer 3 & 4 headers
  - Need to know something about application protocols & formats
- Example
  - URL filtering
    - Normal source/destination host/port filtering + URL pattern/keywords, rewrite/truncate rules, protocol content filters
    - Detect ActiveX and Java applets; configure specific applets as trusted
      - Remove others from the HTML code
  - Keyword detection
    - Prevent classified material from leaving the organization
    - Prevent banned content from leaving or entering an organization

IDS/IPS

- Intrusion Detection/Prevention Systems
  - Identify threats and attacks

- Types of IDS
  - Protocol-based
  - Signature-based
    - We know what is bad; anything else is good
  - Anomaly-based
    - We know what is good; anything else is bad

Protocol-Based IDS

- Reject packets that do not follow a prescribed protocol
- Permit return traffic as a function of incoming traffic
- Define traffic of interest (filter), filter on traffic-specific protocol/patterns
- Examples
  - DNS inspection: prevent spoofing DNS replies: make sure they match IDs of sent DNS requests
  - SMTP inspection: restrict SMTP command set (and command count, arguments, addresses)
  - FTP inspection: restrict FTP command set (and file sizes and file names)

Signature-based IDS

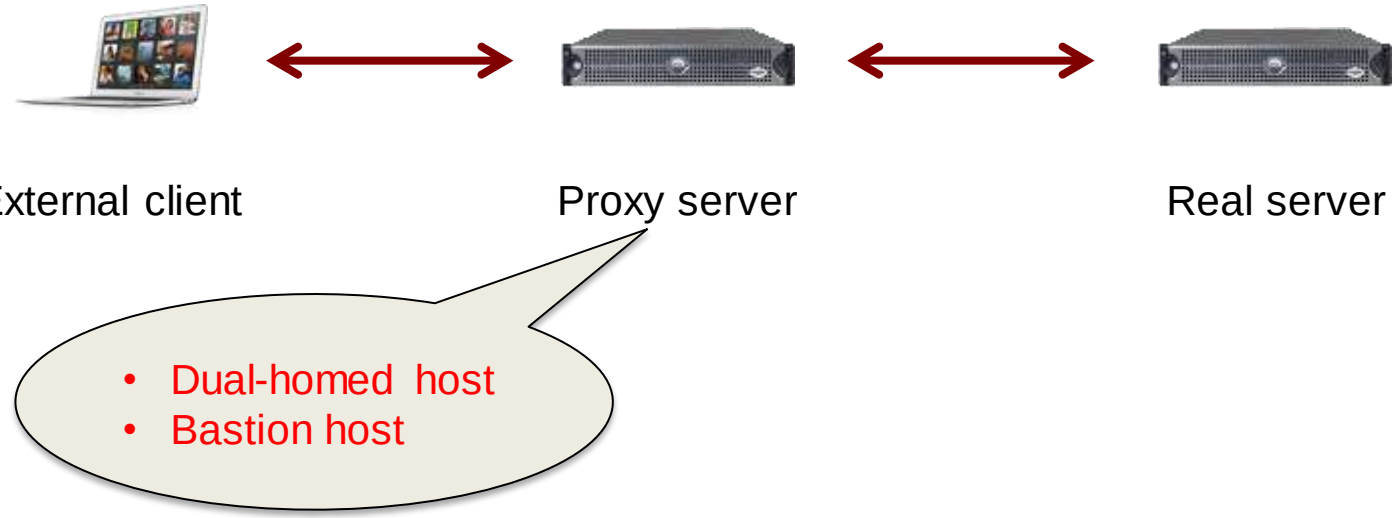
- Don't search for protocol violations but for exploits in programming
- Match patterns of known “bad” behavior
  - Viruses
  - Malformed URLs
  - Buffer overflow code

Anomaly-based IDS

- Search for statistical deviations from normal behavior
  - Measure baseline behavior first
- Examples:
  - Port scanning
  - Imbalance in protocol distribution
  - Imbalance in service access

Application proxies

- Proxy servers
  - Intermediaries between clients and servers
  - Stateful inspection and protocol validation



Deperimiterization

- Boundaries & access between internal & external systems are harder to identify
  - Mobile systems
  - Cloud-based computing
  - USB flash memory
  - Web-based applications

Host-based firewalls

- Run on the user's systems, not as dedicated firewalls
- Manage network-facing effects of malware
  - Allow only approved applications to send or receive data over the network
- Problem
  - If malware gets elevated privileges, it can reconfigure or disable the firewall
- Personal IDS
  - E.g., fail2ban on Linux
    - Scan log files to detect & ban suspicious IP addresses
    - High number of failed logins, probes, URLs that try to target exploits

Intrusion detection & prevention problems

- There's a lot of stuff going on
  - People visit random websites with varying frequencies
  - Software accesses varying services
  - Buggy software may create bad packets
  - How do you detect what is hostile?
- Attack rates is miniscule … compared to legitimate traffic
  - Even a small % of false positives can be annoying and hide true threats
- Environments are dynamic
  - Content from CDNs or other large server farms has a broad range of IP addresses
  - Malicious actors can coexist with legitimate ones

Intrusion detection & prevention problems

- Encrypted traffic cannot be easily inspected
  - Just because you visit a web site using HTTPS doesn't mean the site is secure … or hasn't been compromised
- Packet inspection is limiting
  - You may need to reconstruct sessions, which is time consuming
- Threats & services change
  - Rules have to be updated

Summary

Firewall (screening router)	1st generation packet filter that filters packets between networks. Blocks/accepts traffic based on IP addresses, ports, protocols
Stateful inspection firewall	Like a screening router but also takes into account TCP connection state and information from previous connections (e.g., related ports for TCP)
Application proxy	Gateway between two networks for a specific application. Prevents direct connections to the application from outside the network. Responsible for validating the protocol.
IDS/IPS	Can usually do what a stateful inspection firewall does + examine application-layer data for protocol attacks or malicious content
Host-based firewall	Typically screening router with per-application awareness. Sometimes includes anti-virus software for application-layer signature checking
Host-based IPS	Typically allows real-time blocking of remote hosts performing suspicious operations (port scanning, ssh logins)

DDoS

DDoS: Distributed Denial of Service

- Compromise machines (create a botnet)
  - Use *amplification* techniques to generate a lot of traffic for targets
    - Exploit services that generate a lot of traffic to a small query
    - DNS amplification:
      Small UDP query with forged source address results in large response
- Some targets were too huge to hurt with traffic
  - Amazon, Google, sites using CDNs such as Akamai
- Vast quantities of compromised systems reduce need for amplification
  - Create a botnet of millions of systems

Dealing with DDoS

Really difficult in general

- Bandwidth management routers
  - Either in data center or ISP
  - Limit outbound or inbound traffic on a per-IP basis
- Detect DNS attack and set null routing
  - Traffic to attacked DNS goes nowhere
- Egress filtering by ISPs
  - Attempt to find malicious hosts participating in DDoS or sending spam
- Identify incoming attackers & block traffic at firewall
  - Difficult with a truly distributed DDoS attack

The end