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CO331 – Network and Web Security

7. Network Security

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Course web page: http://www.doc.ic.ac.uk/~maffeis/331

WiFi hotspot

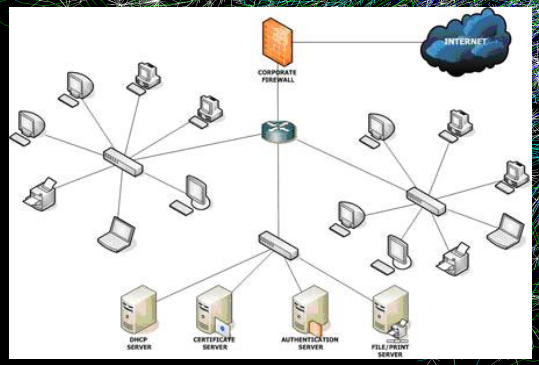
Home LAN

Internet

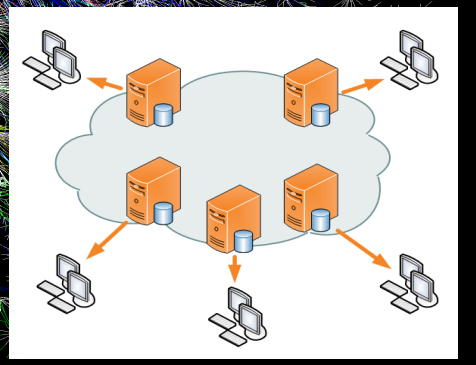
/ˈɪntənɛt/

noun

a global computer network providing a variety of information and communication facilities, consisting of interconnected networks using standardized communication protocols.



Corporate network



Content Delivery Network

Network addresses

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- *Hosts* are the machines connected to the network
- Each internet host needs an IP address, such as 155.198.140.14
- Network services are multiplexed through the same IP address using *ports*
  - 155.198.140.14**:80**
  - Common services **tend** to be hosted on standard ports
    - SSH: 22, DNS: 53, HTTP: 80, HTTPS: 443
    - We shall see that this does not always hold in practice
- One machine can have multiple IPs
  - Over time: connect at home, at work, on the go
  - At the same time
    - Client with wireless and Ethernet connections
    - *Dual-homed host* (firewall, gateway) connecting two different networks
- Multiple machines may share the same IP
  - Home router connecting desktop, laptop, iPhone
  - Port- or name-based virtual hosting of websites
- *Packet* (or *datagram*): message that is sent as a single unit on the network
  - Typically composed of *headers* + *payload*

Network intermediaries

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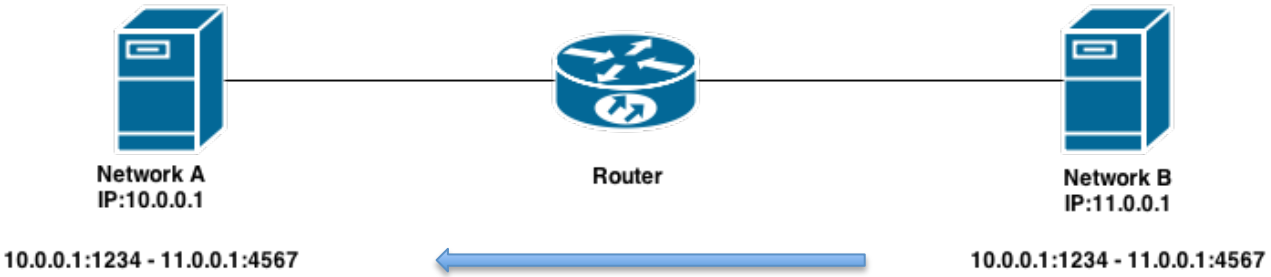
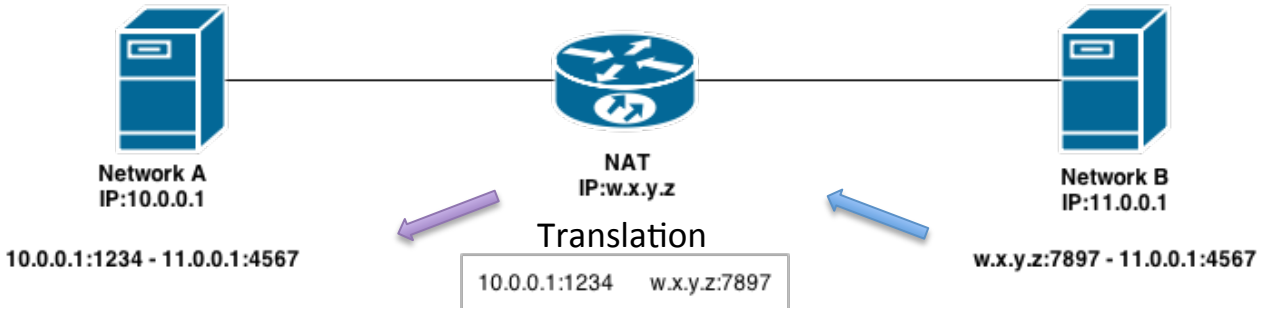
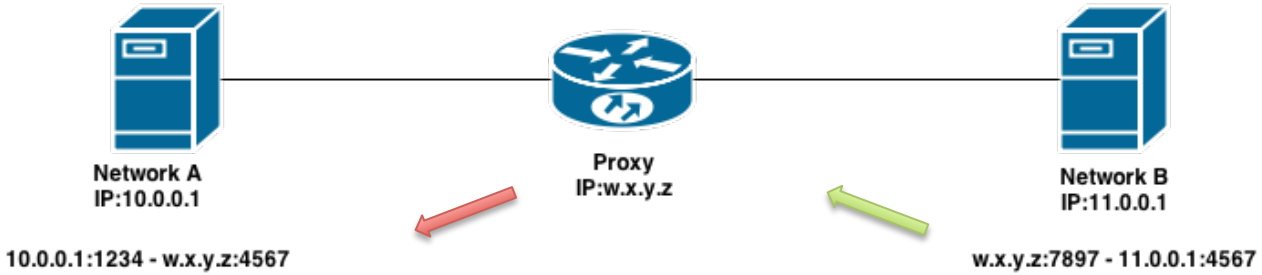
- Router
  - Connects two different networks
  - Does not modify packet addresses



- Network Address Translator (NAT)
  - Exposes a local network via the ports of 1 IP address
  - Modifies packet's IP addresses to effect the mapping



- Proxy
  - A and B communicate to proxy, not directly to each other
  - There are 2 independent packets



Network capabilities

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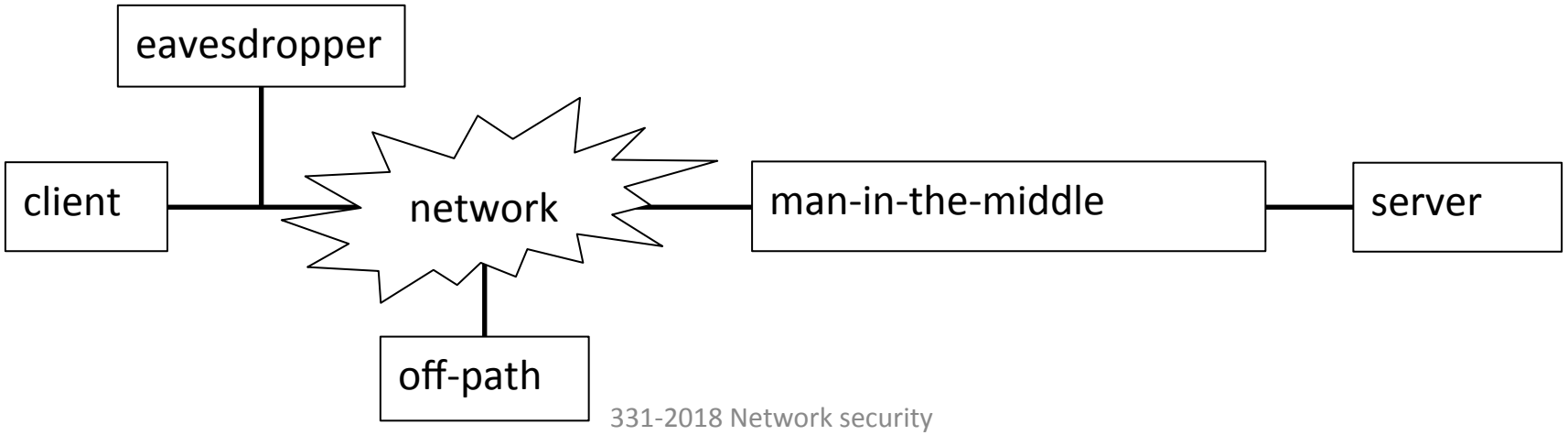
- Participant
  - Capabilities: send and receive legitimate packets that respect the protocol
  - Examples: web browser, web application
- Eavesdropper
  - Capabilities: read packets sent to others, cannot (or will not) participate
  - Examples: wiretapper, sniffer on a broadcast network (WiFi)
- Off-path
  - Capabilities: participate; create arbitrary packets
  - Examples: machine connected to WiFi, ethernet
- Man in the middle (MITM)
  - Capabilities: participate; read, modify, create or delete packets
  - Example: proxy, ISP, router, WiFi access point



Layers and protocols

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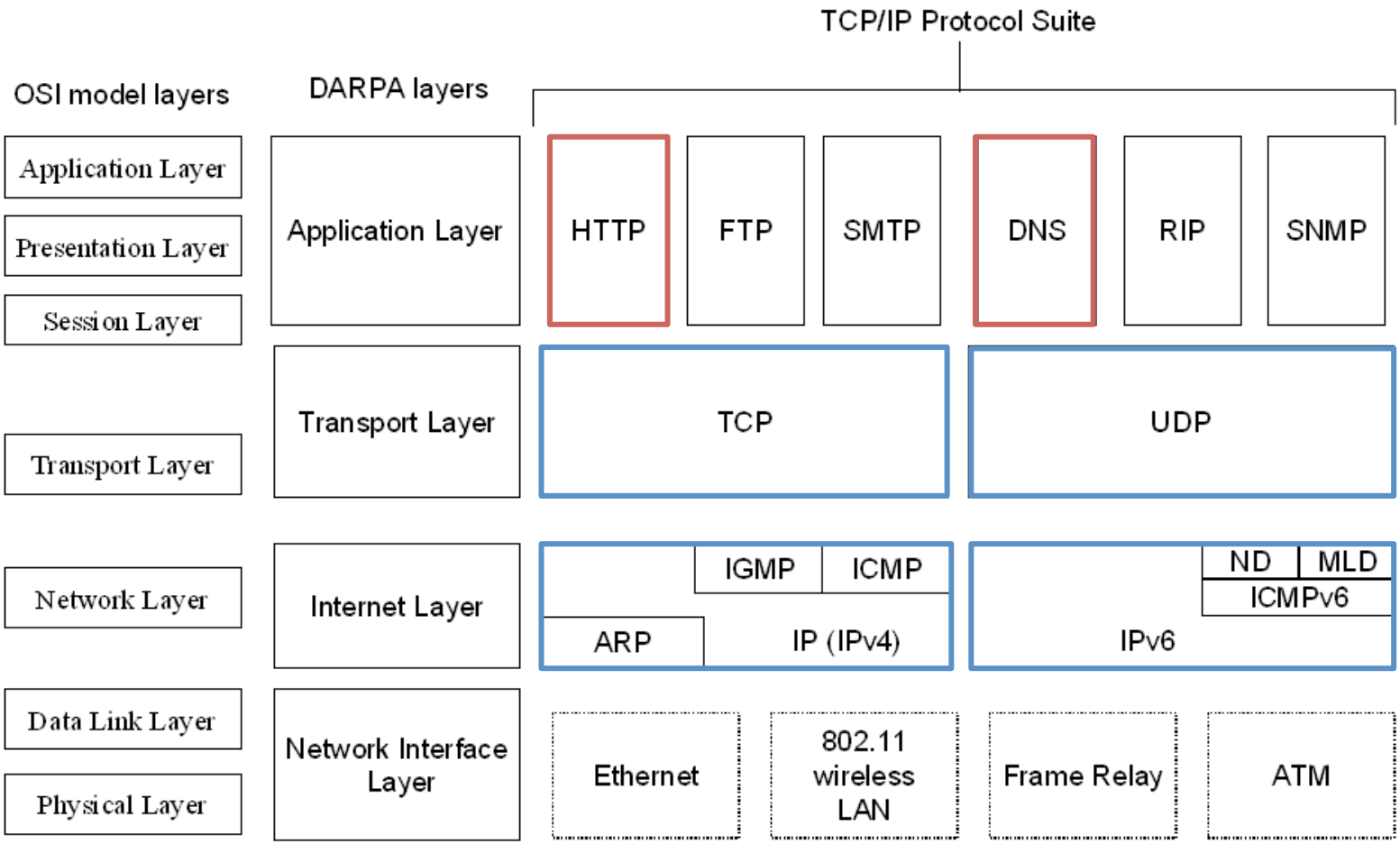

Datagram encapsulation

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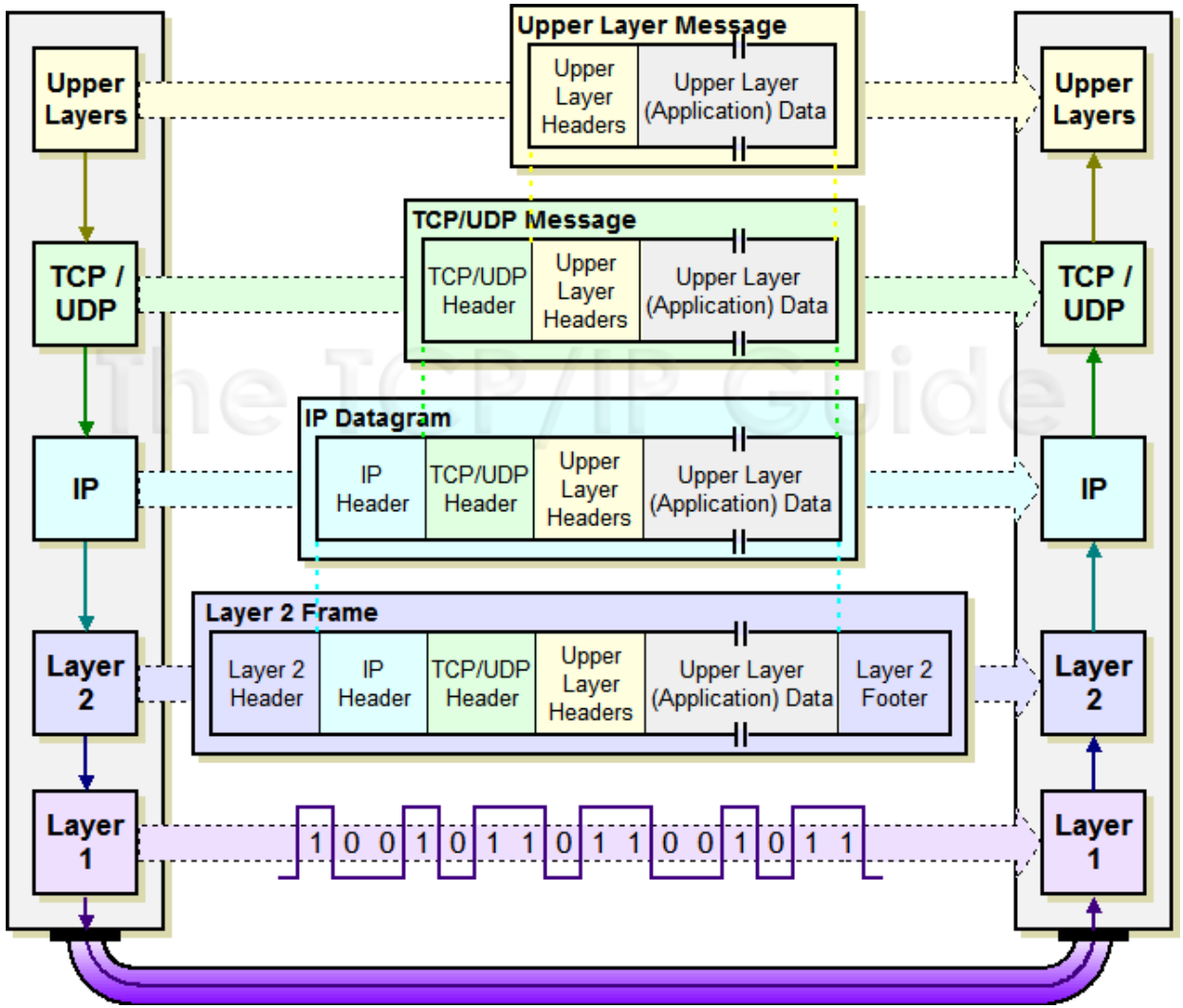

Local Area Network

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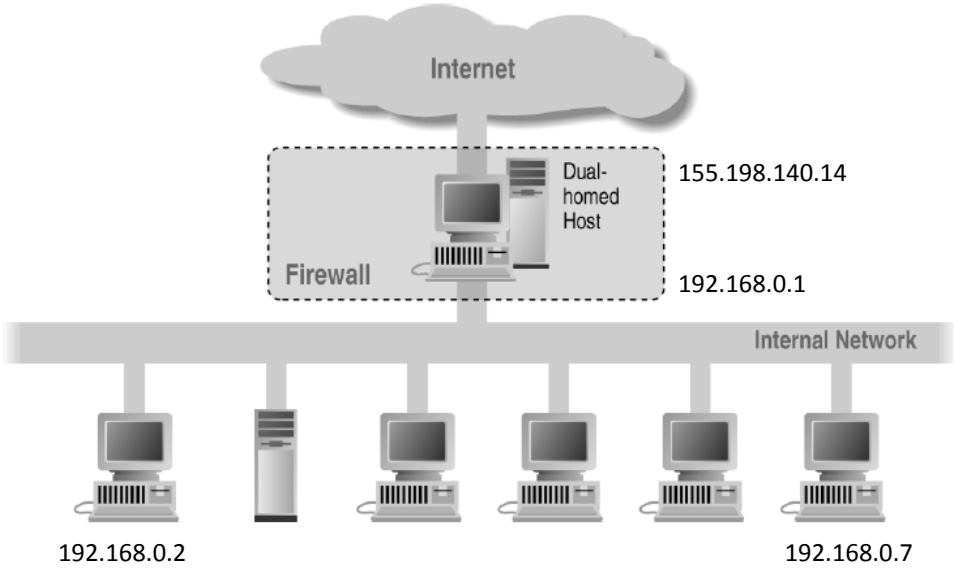
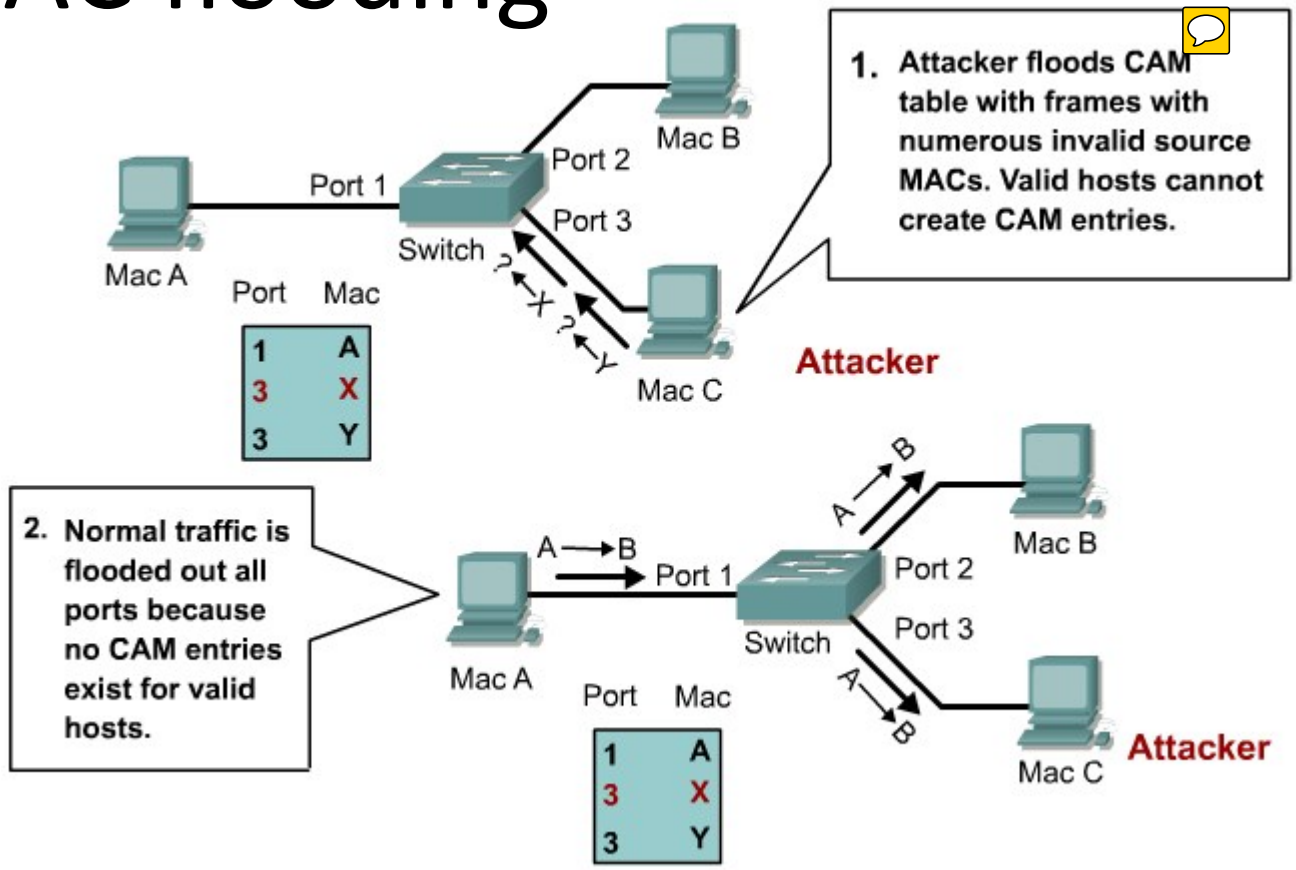
- Local Area Network (LAN)
  - Typically based on a broadcast medium, such as cable (Ethernet) or wireless (WiFi)
  - The network interface of each host has a Media Access Control (MAC) address
  - The Address Resolution Protocol (ARP) assigns IP addresses to MAC addresses
    - IP range 192.168.0-255.0-255 is reserved for private networks
  - The Dynamic Host Configuration Protocol (DHCP) tells new hosts their IP and other configuration information
- LAN relies on broadcast medium
  - Conflict resolution requirements prescribe a minimum packet size
  - If padding data is not initialized this may lead to data disclosure
  - Similar to the OpenSSL *Heartbleed* vulnerability



MAC flooding



- Network switches cache Port-MAC associations
- Attacker forces switch to broadcast traffic, so he can sniff packets
- Typical countermeasures
  - "Port security": limit ability to flood caches
  - Keep track of authorised MAC addresses in the system

ARP poisoning

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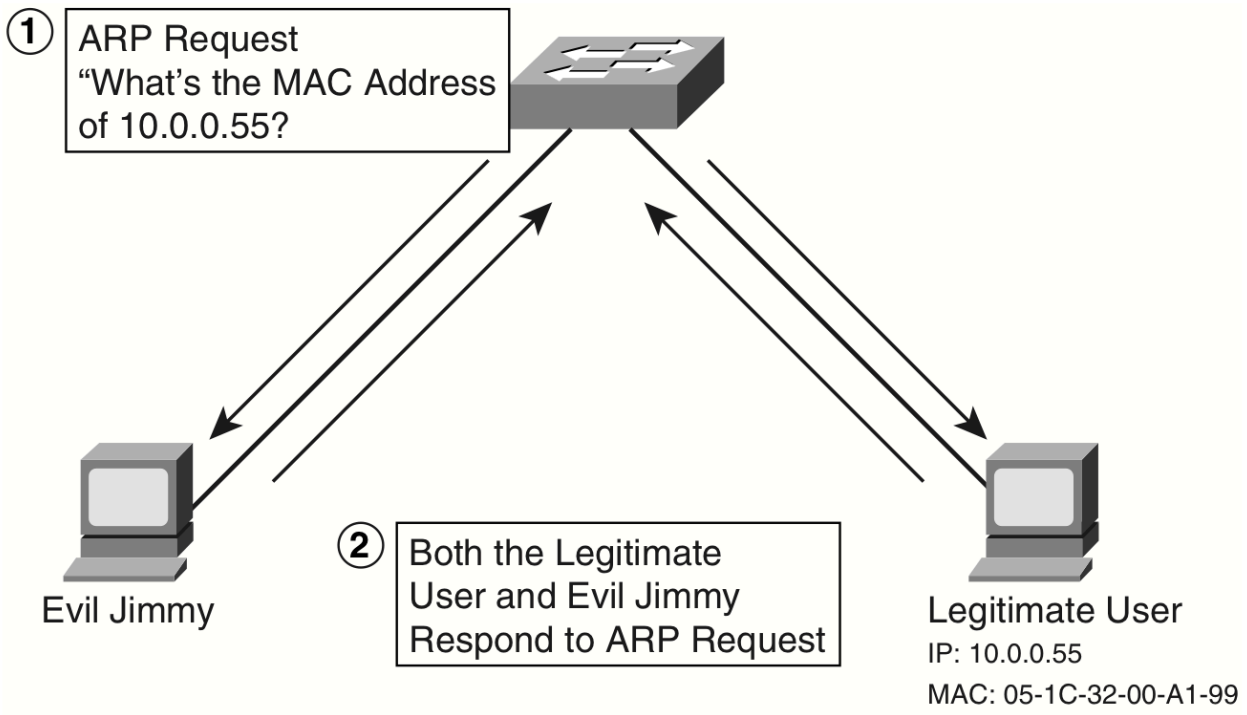
- MAC is easy to spoof: feature to deal with conflicting hardware
  - Attacker can evade MAC-based filtering and access control
  - Off-path attacker spoofing router becomes MITM!
- ARP poisoning
  - Switch needs to find MAC corresponding to an IP
  - Attacker spoofs MAC of victim and replies, like victim does
  - Message is forwarded to both ports that replied (including Evil Jimmy's)
  - Typical countermeasure: static ARP rules or spoofed ARP message detection



Internet Protocol

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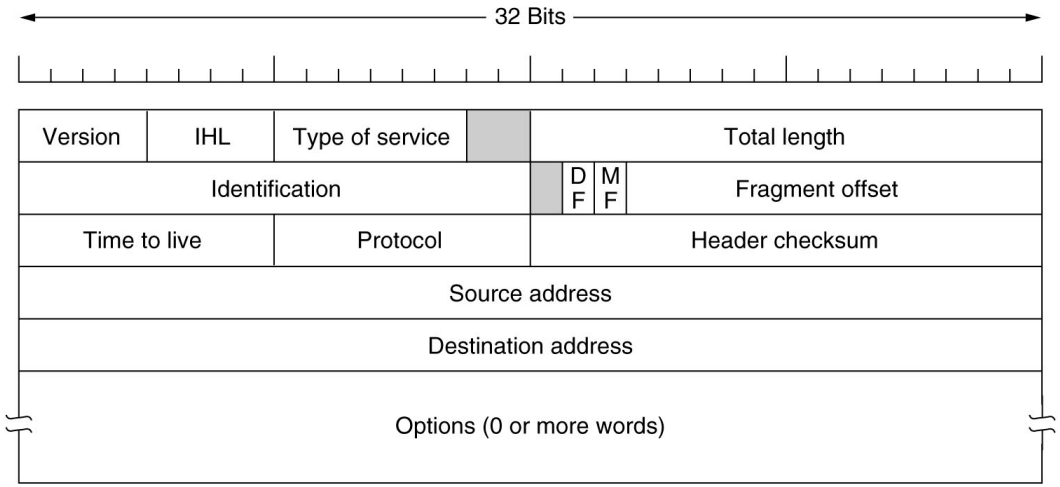
- The IP protocol delivers packets between *Source* and *Destination* hosts
- Structure of IP addresses is hierarchical and guides routing
- Protocol is “best effort”: may drop or reorder packets
- IP packet can be fragmented when it transits on networks with smaller packet sizes
  - **D**on’t **F**ragment, **M**ore **F**ragments flags indicate fragment type
  - *Fragment offset* gives position of fragment in original packet
  - *Identification* differentiates fragments for different packets
  - Various OSs treat duplicate IP fragments in different ways: used for OS fingerprinting
- *Time to live* (TTL) is used to discard packets that take too many steps to reach destination
  - TTL is decremented at each step (“hop”) in the network until it reaches 0
  - At 0, packet is discarded and ICMP error message is sent to source



Traceroute

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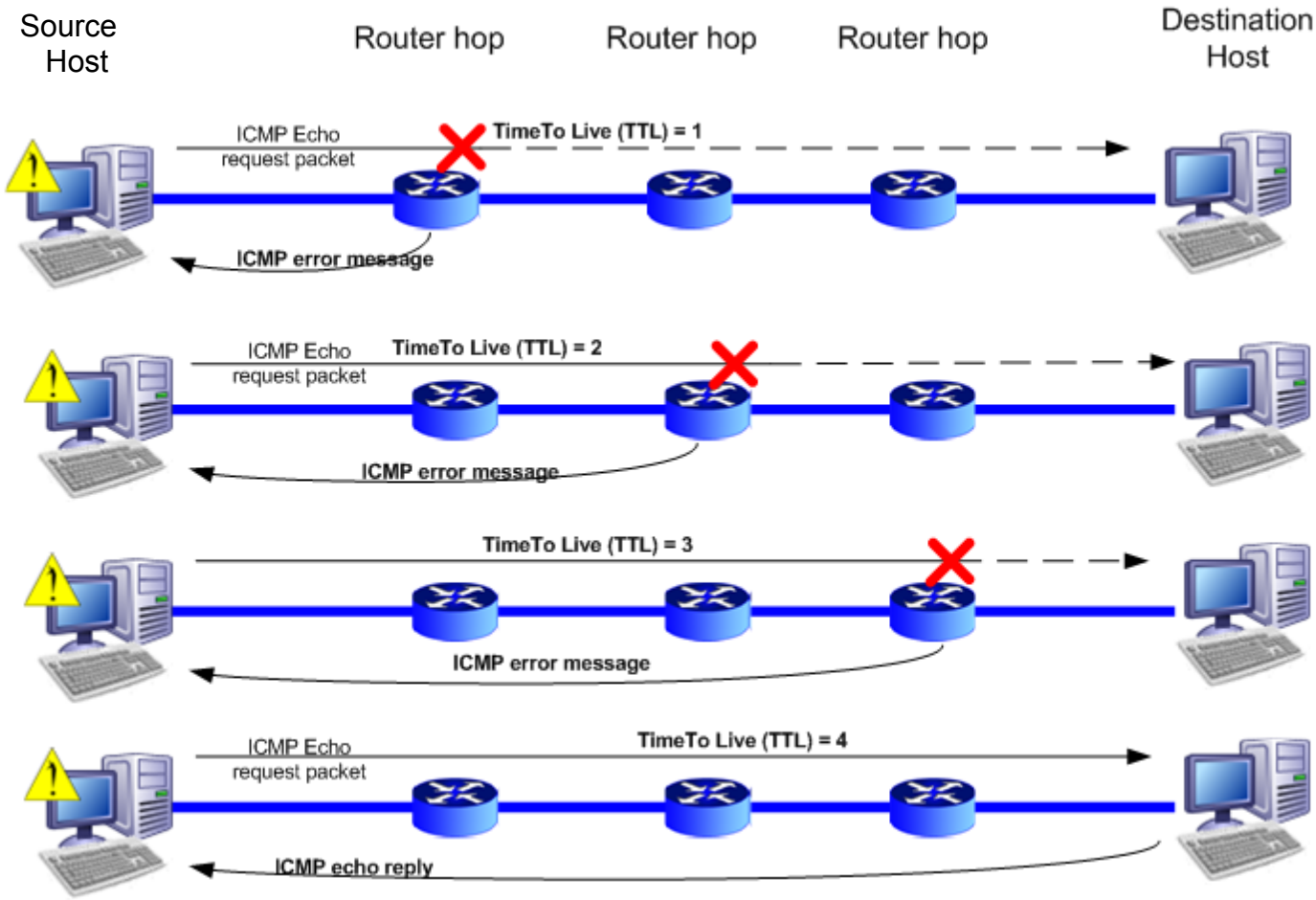
- Traceroute algorithm uses TTL to identify hosts/routers on path to target
  - Send packets increasing TTL (1, then 2, then 3, …) until destination is reached
  - Each ICMP error message should be from a host on the path to the destination



IP security

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- The source IP is not authenticated and easy to spoof
  - Off-path attacker can send packets with target IP as source
    - The target will receive response
    - Used for attacks including idle scanning, DDoS
  - Hard to trace back malware infections
- Packets travel through untrusted hosts
  - MITM attacker can directly read packets and modify payload
- *IPsec* adds security to IP protocol
  - Authentication Header (AH)
    - Authentication and integrity of whole packet
      - Does not interoperate with NAT
    - Allows packet inspection, not blocked by firewalls
  - Encapsulating Security Payload (ESP)
    - Confidentiality of payload
    - Optional authentication
  - Transport mode: protects the IP payload only
  - Tunnel mode: protects also the IP header
  - Limitations
    - Hard to configure correctly
    - Hard to connect to the application layer
  - Used mostly in tunnel mode, for VPNs

IPsec in AH Transport mode

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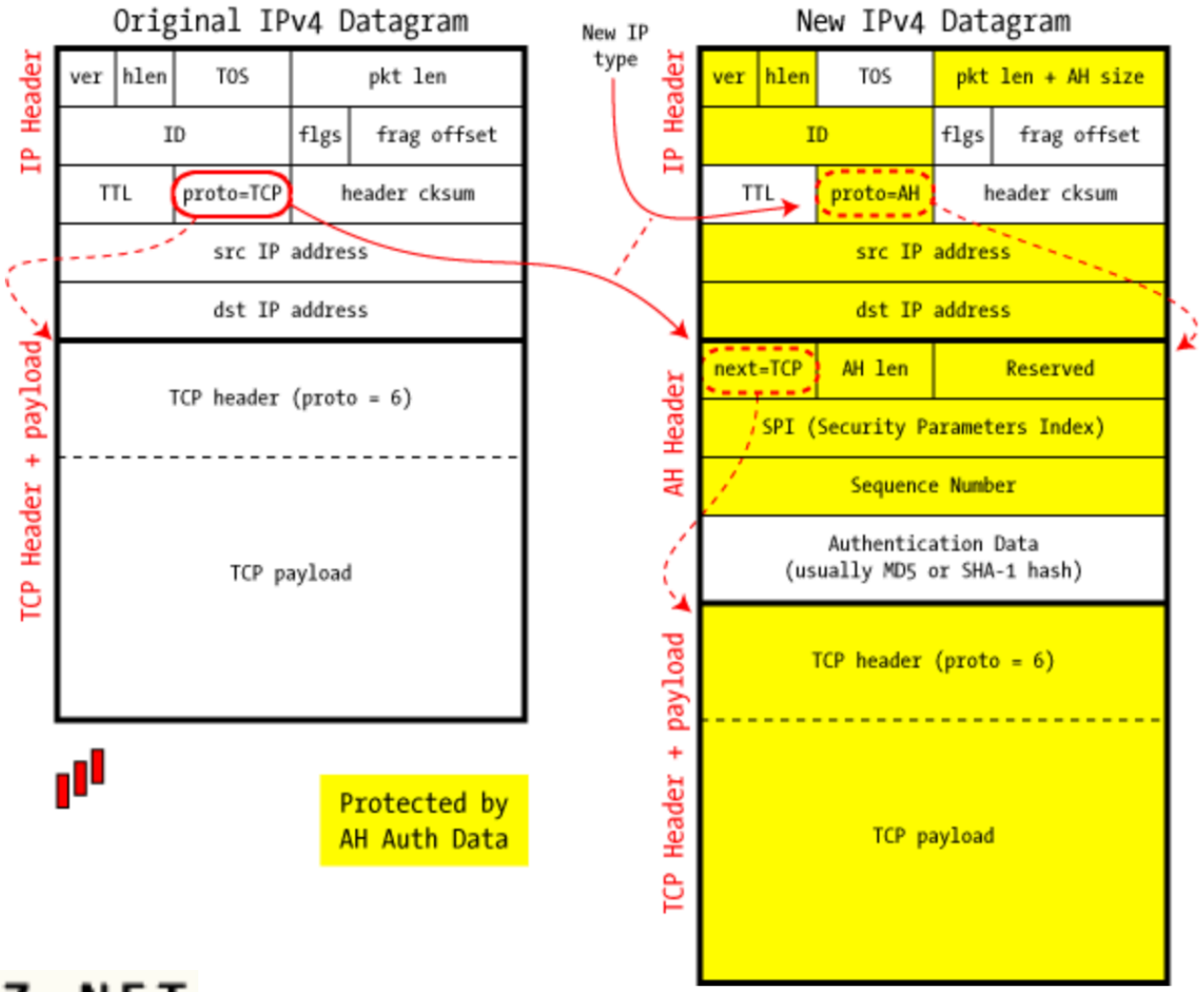

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IPsec in ESP Transport mode

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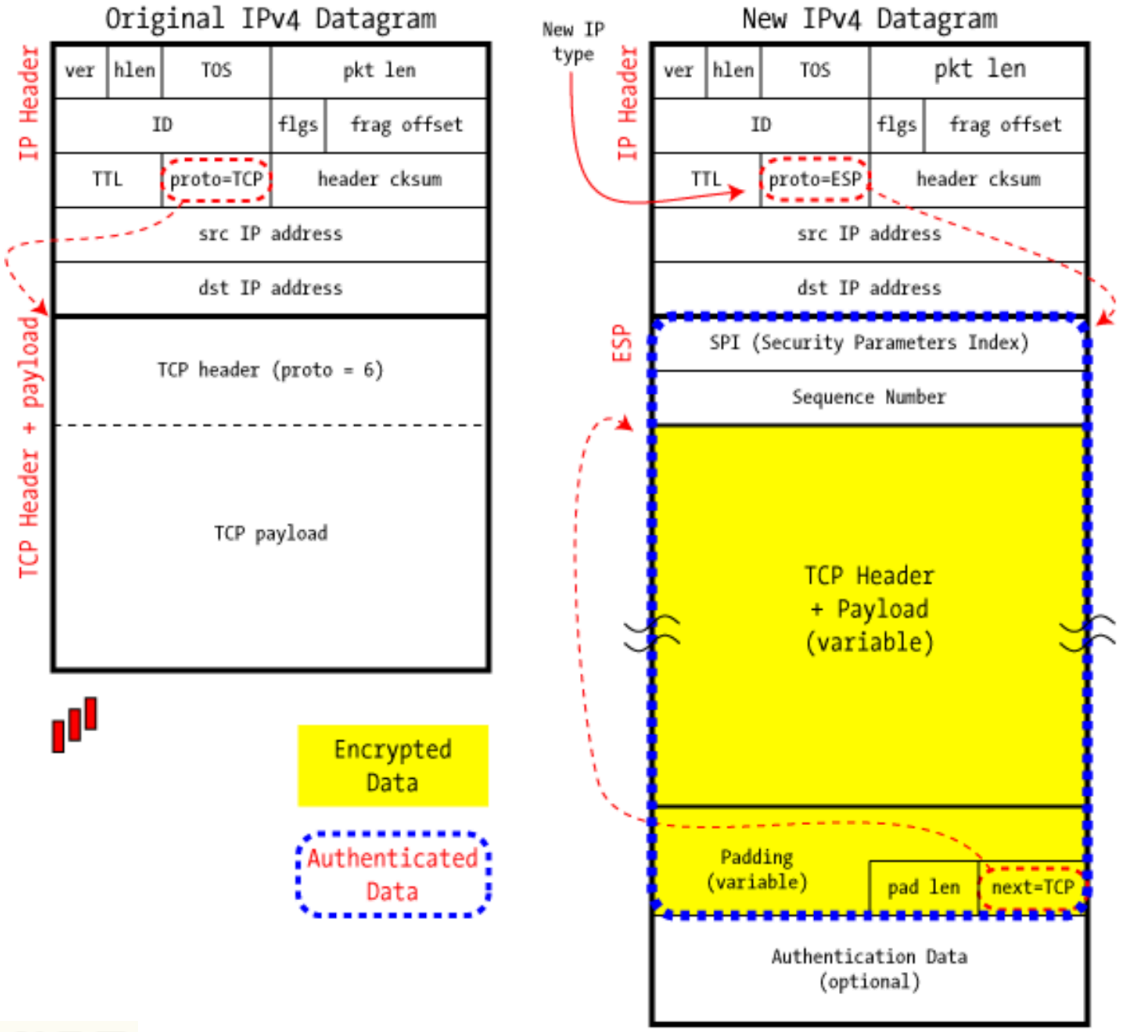

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IPsec in ESP Tunnel mode

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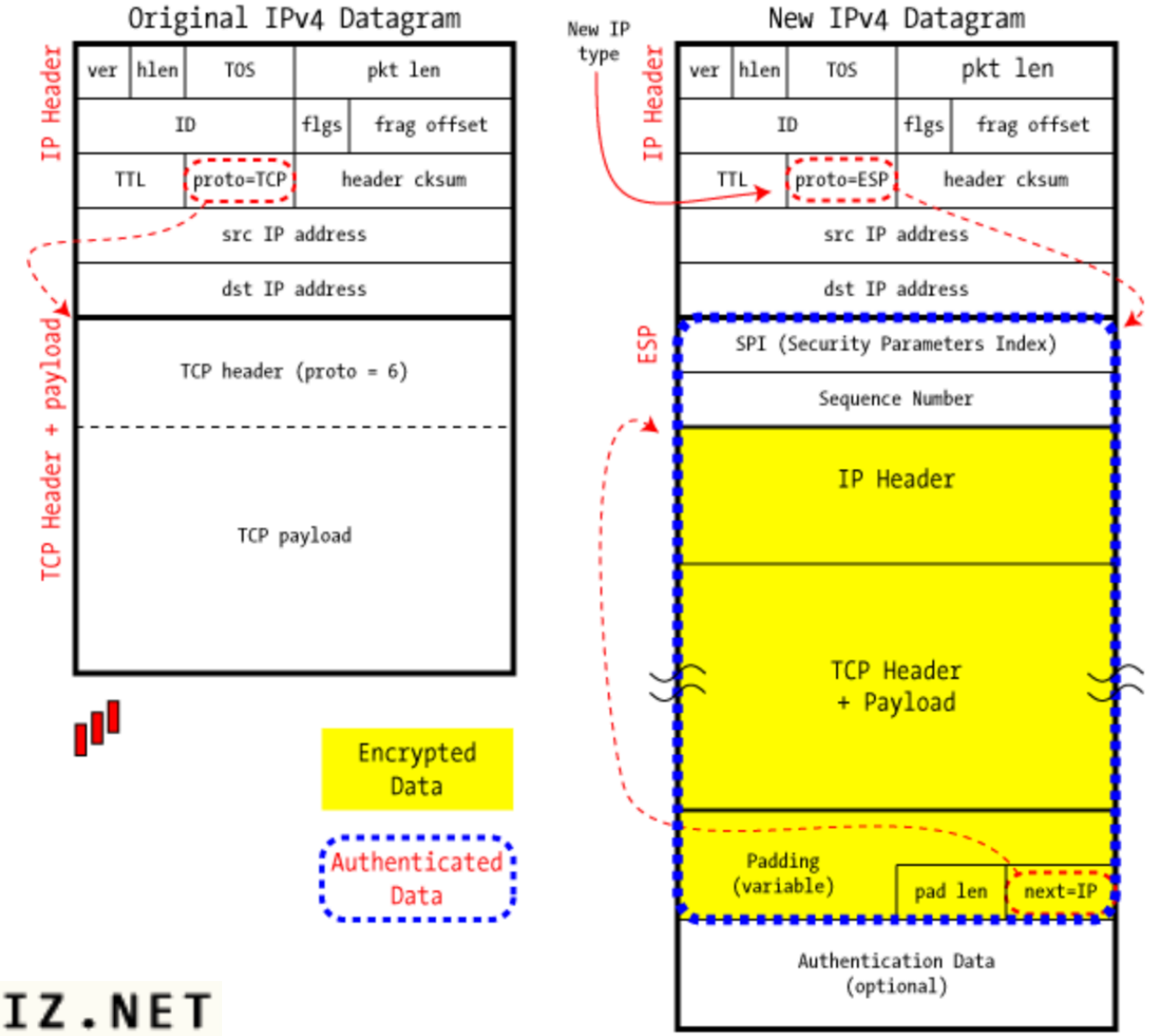

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IPv6

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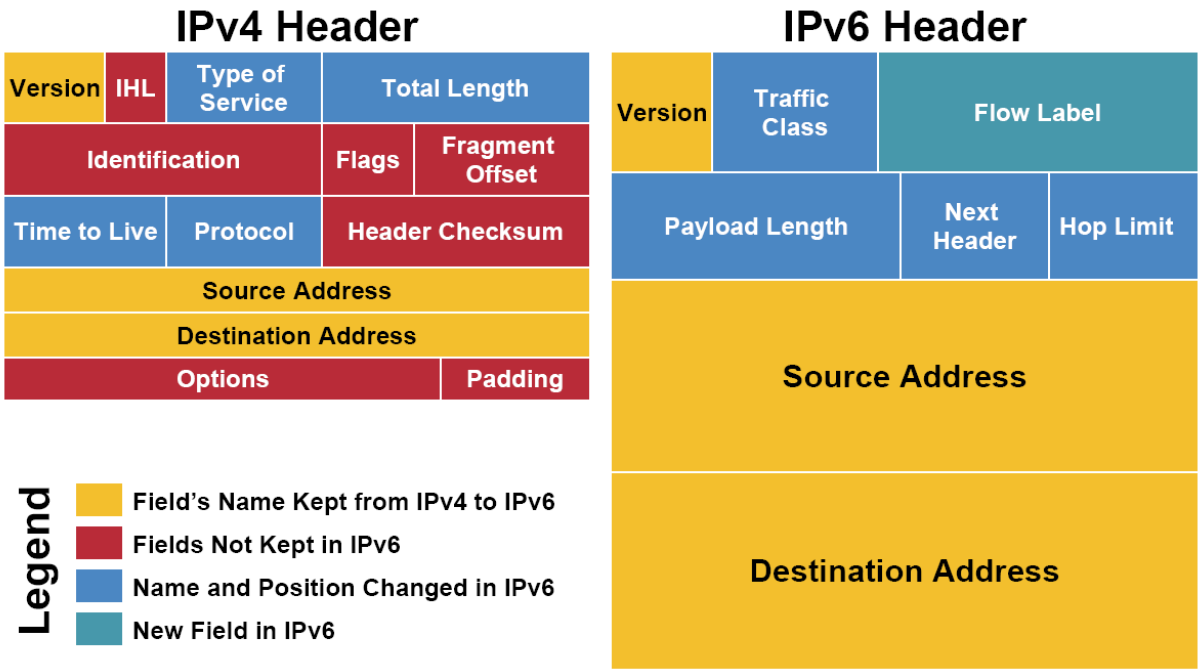
- IPv4: 155.198.140.14 is 32 bits (AFRINIC running out of space by mid 2018?)
- IPv6: 2001:0000:3238:DFE1:EA06:88FF:FECB:AF19 is 128 bits (more than enough!)
- Comparison with IPv4
  - Address space is large enough that there is no more need for NAT
  - Fewer headers, enables better routing
- IPv6 includes IPsec natively
  - Will work more efficiently (packet size) and protect more (headers)
  - Up to the network rather than application layer to use IPsec, so applications should not rely on it



Transmission Control Protocol

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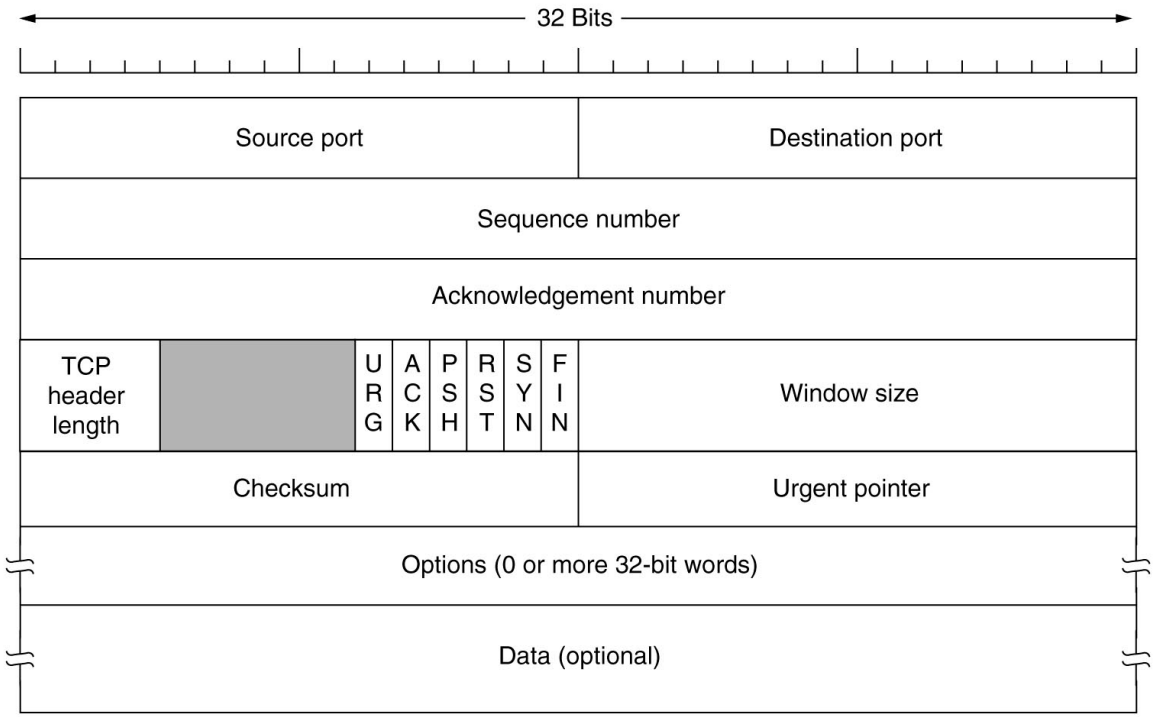
- TCP establishes a reliable connection to a service on the target destination port
  - Source port is chosen at random by OS, to receive responses
  - TCP adds sequence numbers and re-requests lost packets
  - Everything is delivered to the application, and in the right order
- TCP is the channel used to send HTTP data



TCP security issues

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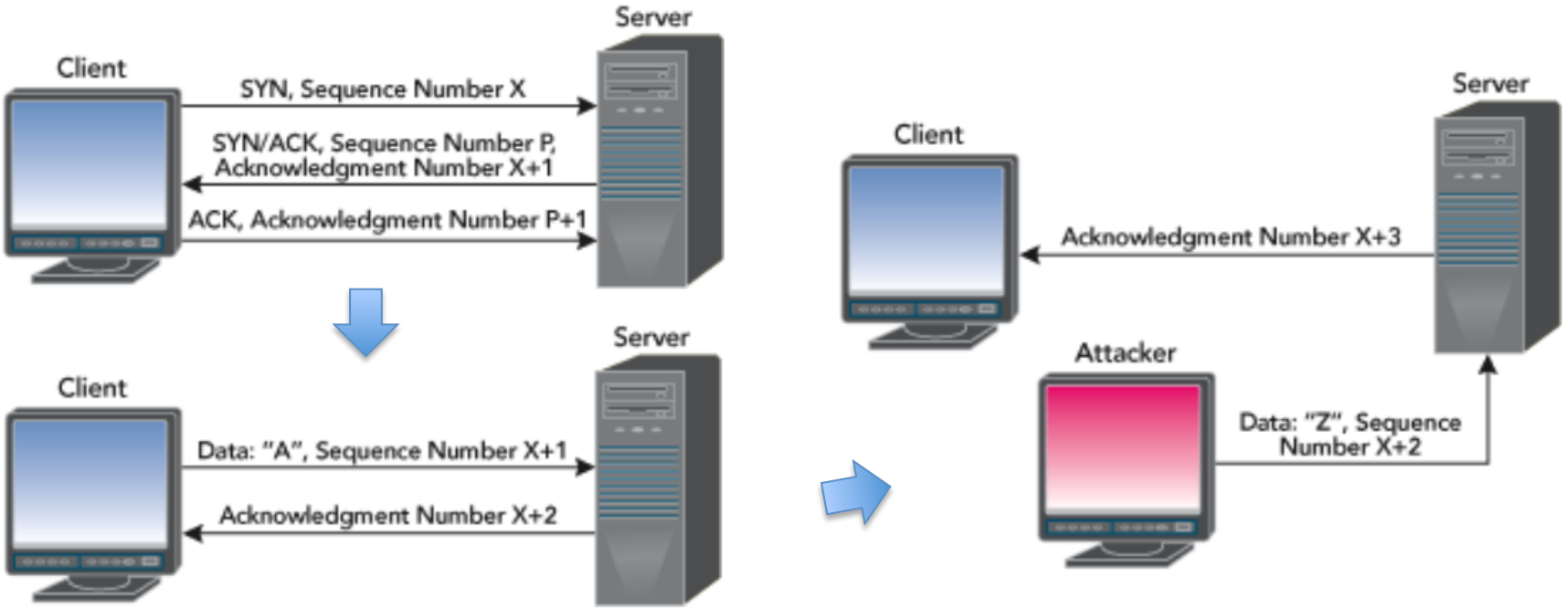
- TCP state easily accessible
- Sequence numbers are predictable: previous number + bytes exchanged
- MITM attacker can read current sequence number and inject new packets
  - TCP session hijacking
- Off-path attacker can try and guess the right sequence number
  - Blind spoofing attack
  - See recommended reading: *Off-Path Hacking*
- Typical countermeasures
  - Time-delay, and discard race-condition packers
  - Use IDS, HTTPS



Port scanning

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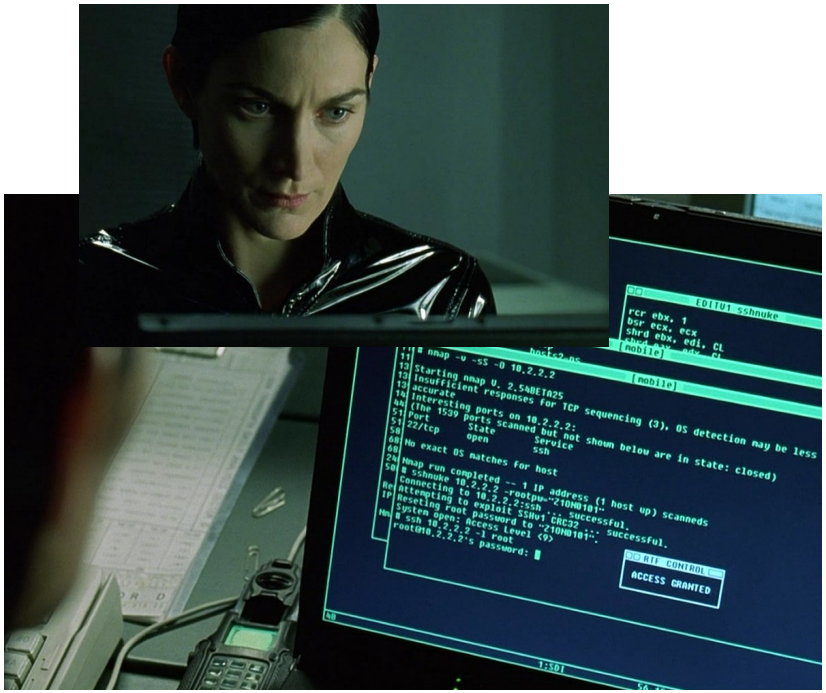
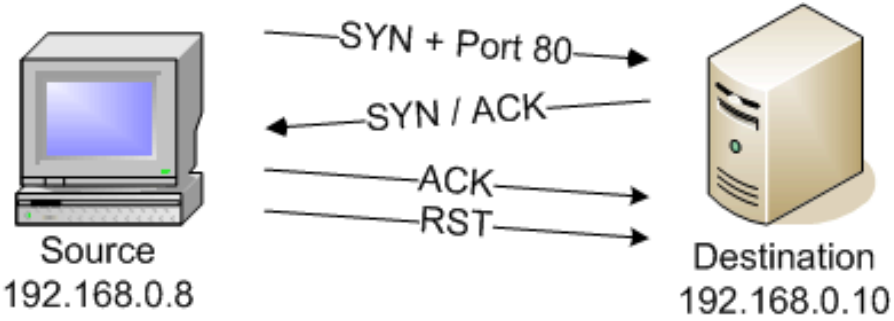
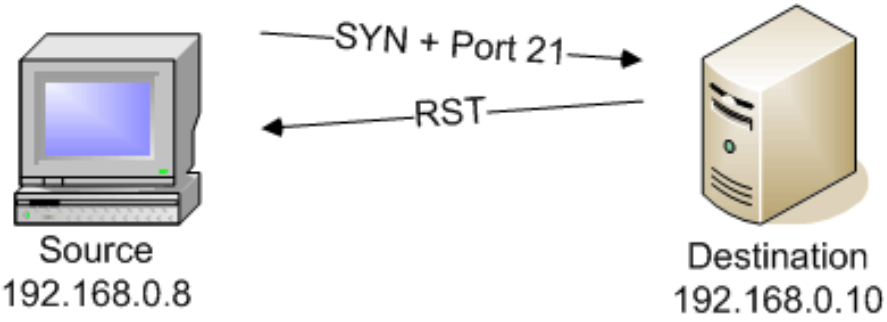
- (Unauthorised) port scanning **is a crime**
  - We will practice safely in the lab with Nmap
- Different services/protocols require different kind of scans
- Examples
  - TCP `connect()` scan (below)
  - TCP idle scan (next slide)



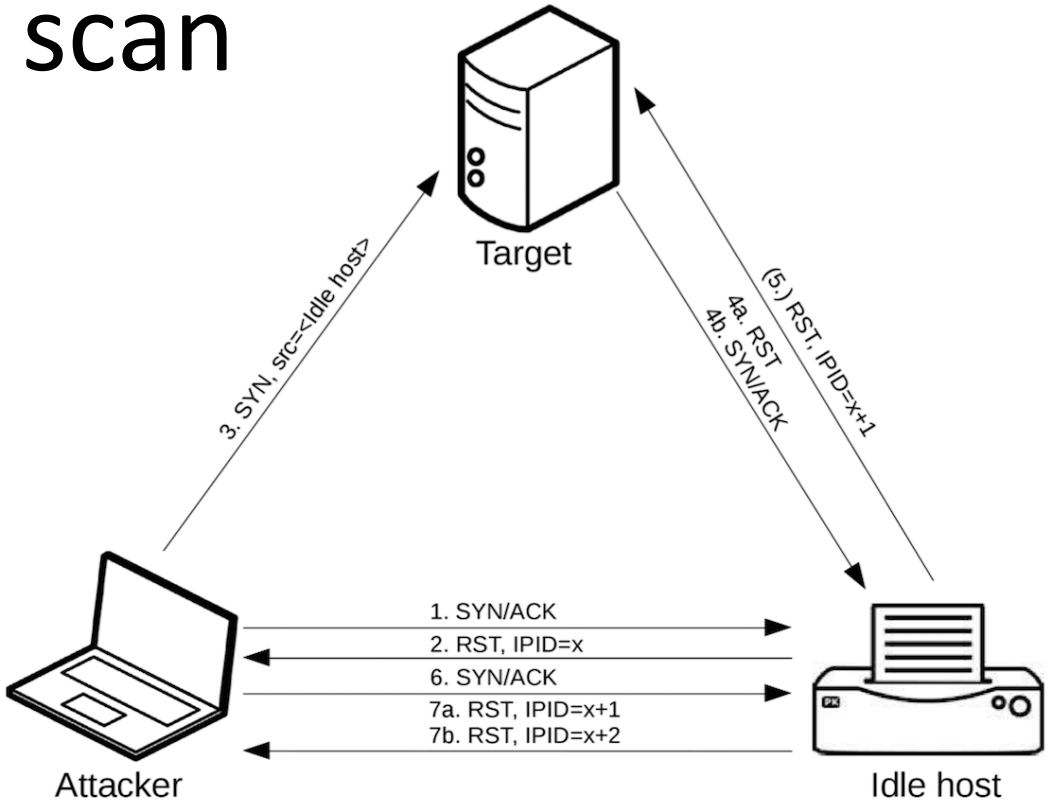
a) HTTP port is open



b) FTP port is closed



TCP idle scan



0. Identify an idle host (printer, ftp server, …)
1. & 2. Check available IPID on idle host
3. Spoof source IP when connecting to target
4. Idle host receives scan result it is not waiting for
5. 4a (closed): no response; 4b (open): RST packet and IPID increment
6. & 7. Check new available IPID on idle host

User Datagram Protocol

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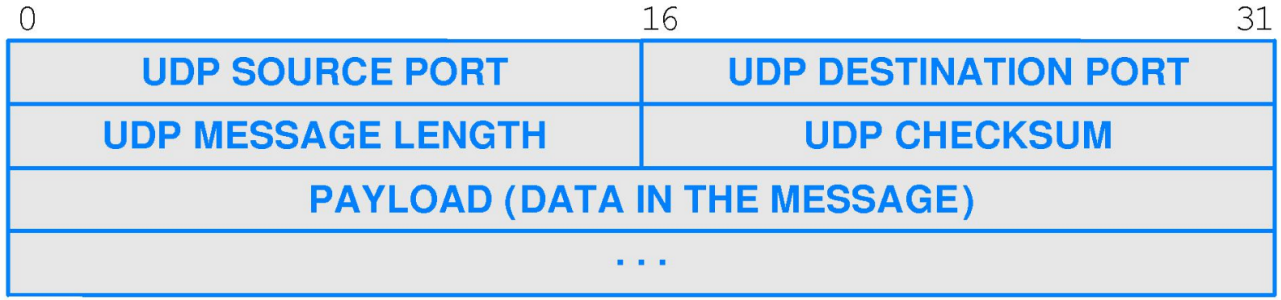
- *Connectionless protocol*
  - Low overhead, low latency: faster than TCP
  - Can be used for broadcasting, multicasting packets
  - Up to the application layer to make sense of a stream of UDP packets
    - No guarantee data reaches destination: routers may drop UDP packets if there's a conflict
    - No integrity: checksum is optional
    - Packets may be received in different order than they are sent, receiver may also get duplicates
- Usage
  - Streaming media: voice and video
    - WebRTC (RTP) can use UDP or TCP
  - Network management: SNMP, DHCP, DNS
  - Applications that need low-level control on network packets



UDP scans

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- Many different protocols may be run on top of UDP
- Send generic UDP header with no payload to target ports
- If you receive a UDP response, the port is **open**
- If you receive an ICMP error the port is **closed** or **filtered** by a firewall
- If you timeout without a response
  - The port may be **open** and host a service that drops ill-formed packets
  - The port may be **filtered** by a firewall
  - Probe the port again using UDP packets with protocol-specific payloads
- UPD services are harder to scan
  - More time consuming
    - Timeouts for lack of response
    - May take several attempts to resolve **open|filtered** ports
  - Less precise
    - Some UDP custom protocols simply can't be probed

Key TCP/IP threats

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- Host and port scanning
  - Used by hackers during active information gathering
  - They will try to hide the requests within the normal variance of network traffic
- Port sweep
  - One attacker looks for a specific service on many machines
  - More sensitive than port scanning: likely that service is vulnerable (0-day, unpatched)
- Malicious traffic
  - Targeted attacks via network connections
  - Exploitation of networking stack implementation
  - Exfiltration of data
- Distributed Denial of Service (DDoS)
  - Flood a target with extremely high volume of network traffic
  - Attacker can use a botnet
    - Achieve large volume
    - Diversify behaviour to avoid detection
    - Spread attack traffic to preventing takedown

Port knocking

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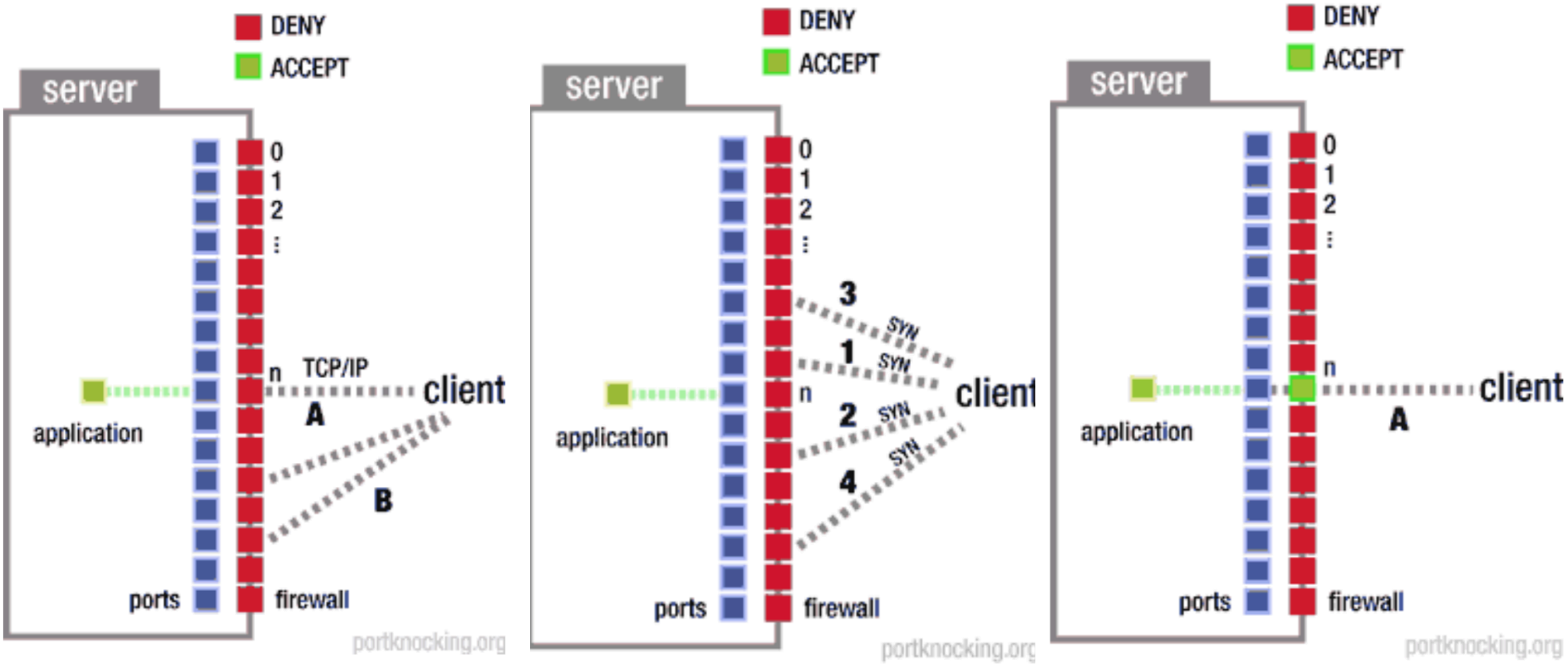
- Technique to hide a service from port scanning
  1. Sequential or random scan only finds closed ports
  2. Client shares a secret with server that identifies specific ports to probe in a fixed order (3,1,2,4); server replies to last probe (4) with random port (n) where the service will be provided
  3. Client connect to service on the random port
- Can be used legitimately, or to hide backdoors



Network defenses

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- Firewalls
  - Open source examples: `iptables` (Linux), `pf` (OpenBSD, OSX)
  - Beyond packet filtering, firewalls can keep state, inspect application-layer packets
  - Can protect individual machine from port scanning, malicious traffic
  - Needs kernel-level operations: critical to defend from compromise
  - No help against DDoS or port sweep
- Intrusion Detection Systems
  - Free/open source examples: Snort, Bro
  - Dedicated hardware that inspects network traffic (on- or off-path)
    - Signature based
    - Anomaly detection based (also machine learning techniques)
  - Can detect host and port scanning, port sweep
  - Can filter malicious traffic but must be fast (hence miss attacks)
  - Can rate-limit connections to mitigate DDOS
    - But the source IP is easy to spoof: risk of blocking too many IPs
- Variants: IPS, egress filters, etc..

IDS evasion

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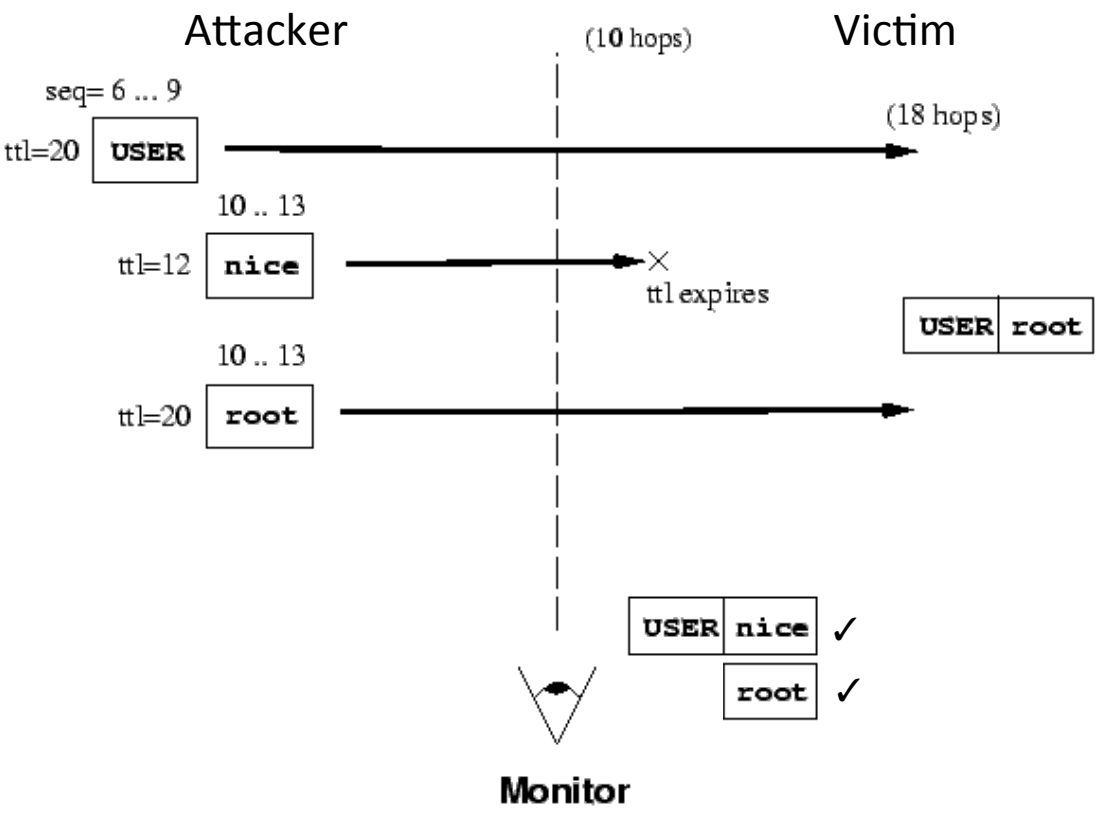
Example of attack against IDS using IP fragmentation:

1. Fragment a suspicious IP packet in 2
2. Traceroute to determine distance to IDS and target
3. Send frag 1 to reach target
4. Send innocuous replacement of frag 2 so that it's seen by the IDS but expires before reaching the target
5. IDS decides that communication is safe
6. Send malicious frag 2 so that it reaches the target
7. IDS does not interpret message from (6) as related to the one in (3)



(*A System for Detecting Network Intruders in Real-Time*, V. Paxson)