Computer Security

10. Network Security

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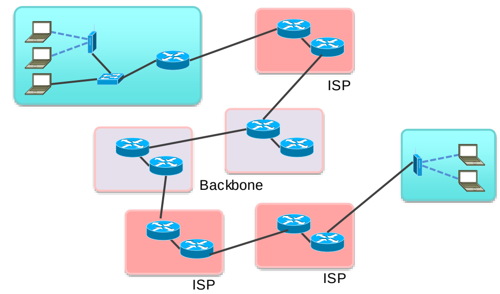
The Internet

Packet switching: store-and-forward routing across multiple physical networks
... across multiple organizations



The Internet: Key Design Principles

1. Support interconnection of networks
   – No changes needed to the underlying physical network
   – IP is a *logical network*

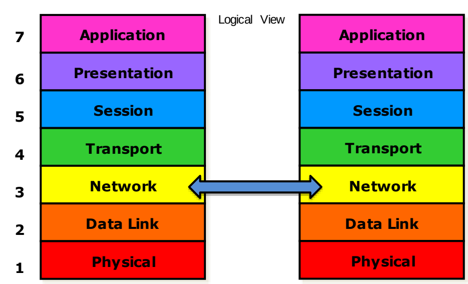
2. Assume unreliable communication
   – If a packet does not get to the destination, software on the receiver will have to detect it and the sender will have to retransmit it

3. Routers connect networks
   – Store & forward delivery

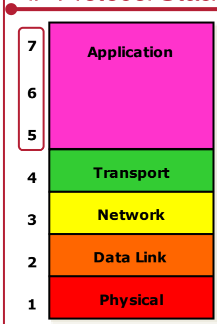
4. No global (centralized) control of the network

Protocol layers

Protocol layers communicate with their counterparts
Low-level attacks can affect higher levels



IP Protocol Stack



SMTP, IMAP, HTTP, FTP, ...

BGP, DNS, NTP

TCP, UDP

IP

Ethernet MAC, 802.11, ARP

Internet protocol stack

Data Link Layer

Data Link Layer (Layer 2)

Layer 2 generally has weak security

- MAC Attacks – CAM overflow
- VLAN Hopping
- ARP cache poisoning
- DHCP spoofing

Link Layer: CAM overflow

Layer 2: Ethernet Switches

TP-Link Switch
- 8 1-GbE ports

Cisco Nexus 9516 Switch
- 1/10/40 GbE
- 21-rack-unit chassis
- Up to 576 1/10 Gb ports

Ethernet MAC addresses

- Ethernet frames are delivered based on their 48-bit MAC address
  - Top 24 bits: manufacturer code assigned by IEEE
  - Bottom 24 bits: assigned by manufacturer
  - `ff:ff:ff:ff:ff:ff` = broadcast address
- Ethernet MAC address ≠ IP address

How does an Ethernet switch work?

- A switch contains a switch table (MAC address table)
  - Contains entries for known MAC addresses & their interface
- Forwarding & filtering: a frame arrives for some destination address *D*
  - Look up *D* in the switch table to find the interface
  - If found & the interface is the same as the one the frame arrived on
    - Discard the frame (**filter**)
  - If found & *D* is on a different interface
    - **Forward** the frame to that interface: queue if necessary
  - If not found
    - **Forward** to ALL interfaces

The switch table

A switch is self-learning

- Switch table (MAC address → interface): initially empty
- Whenever a frame is received, associate the interface with the source MAC address in the frame
- Delete switch table entries if they have not been used for some time

Switches have to be fast: can't waste time doing lookups
- They use CAM – Content Addressable Memory
- Fixed size table

CAM overflow attack

- Exploit size limit of CAM-based switch table
- Send bogus Ethernet frames with random source MAC addresses
  - Each new address will displace an entry in the switch table
  - *macof* tool: ~100 lines of perl
- With the CAM table full, legitimate traffic will be broadcast to all links
  - A host on any port can now see all traffic
  - CAM overflow attack turns a switch into a hub
- Countermeasures: port security
  - Some managed switches let you limit # of addresses per switch port

dsniff: collection of tools for network auditing and penetration testing
https://monkey.org/~dugsong/dsniff/

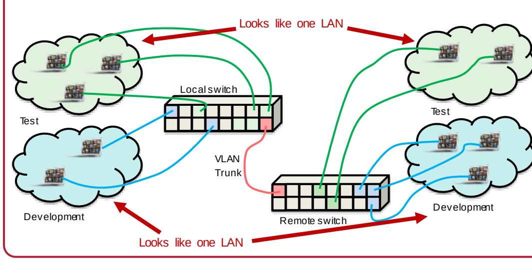
Link Layer: VLANs & VLAN hopping

VLANs

- A switch + cables creates a local area network (LAN)
- We use LANs to
  - Isolate broadcast traffic from other groups of systems
  - Isolate users into groups
  - What if users move? What if switches are inefficiently used?
- Virtual Local Area Networks (VLANs)
  - Create multiple virtual LANs over one physical switch infrastructure
  - Network manager can assign a switch's ports to a specific VLAN
  - Each VLAN is a separate broadcast domain

VLAN Trunking

VLANs across multiple locations/switches
- VLAN Trunking: a single connection between two VLAN-enabled switches carries all traffic for all VLANs

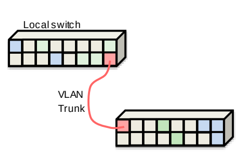


VLAN Hopping Attack

- VLAN trunk carries traffic for *all* VLANs
- Extended Ethernet frame format
  - 802.1Q for frames on an Ethernet trunk = Ethernet frame + VLAN tag
  - Sending switch adds VLAN tag for traffic on the trunk
  - Receiving switch removes VLAN tag and sends traffic to appropriate VLAN ports based on VLAN ID

Attack: **switch spoofing**

Devices can spoof themselves to look like a switch with a trunk connection and become a member of all VLANs



Avoiding VLAN Hopping

- Disable unused ports & assign them to an unused VLAN
- Disable auto-trunking
- Explicitly configure trunking on switch ports that are used for trunks

ARP Cache Poisoning

Find MAC address given an IP address

- We need to send a datagram to an IP address
- It is encapsulated in an Ethernet frame and a MAC address

MAC destination	MAC source	type	IP header	IP data	CRC

- How do we know what MAC address to use?

Address Resolution Protocol (ARP)

- ARP table
  - Kernel table mapping IP addresses & corresponding MAC addresses
  - OS uses this to fill in the MAC header given an IP destination address
  - *What if the IP address we want is not in the cache?*
- ARP Messages
  - A host creates an ARP query packet & broadcasts it on the LAN
    - Ethernet broadcast MAC address: `ff:ff:ff:ff:ff:ff`
  - All adapters receive it
    - If an adapter's IP address matches the address in the query, it responds
    - Response is sent to the MAC address of the sender

HW Protocol (ethernet)	Protocol type (e.g., IPv4)	MAC addr length	query/ response	sender MAC addr	sender IP addr	target MAC addr	target IP addr

ARP packet structure

see the **arp** command on Linux/BSD/Windows/OS X

ARP Cache Poisoning

- Network hosts cache any ARP replies they see … even if they did not originate them … on the chance that they might have to use that IP address
- Any client is allowed to send an *unsolicited* ARP reply
  - Called a gratuitous ARP
- ARP replies will overwrite older entries in the ARP table … even if they did not expire
- An attacker can create fake ARP replies
  - Containing the attacker's MAC address and the target's IP address
  - This will direct any traffic meant for the target to the attacker
  - Enables man-in-the-middle or denial of service attacks

See *Ettercap* – a multipurpose sniffer/interceptor/logger https://github.com/Ettercap/ettercap

Defenses against ARP cache poisoning

- Ignore replies that are not associated with requests
  - But you have to hope that the reply you get is a legitimate one
- Use static ARP entries
  - But can be an administrative nightmare
- Enable Dynamic ARP Inspection
  - Validates ARP packets against DHCP Snooping database information or static ARP entries

DHCP Server Spoofing

DHCP

- Computer joins a network – needs to be configured
  - *Broadcasts* a *DHCP Discover* message
- A DHCP server picks up this requests and sends back a response
  - IP address
  - Subnet mask
  - Default router (gateway)
  - DNS servers
  - Lease time
- Spoof responses that would be sent by a valid DHCP server

DHCP Spoofing

- Anybody can pretend to be a DHCP server
  - Spoof responses that would be sent by a valid DHCP server
  - Provide:
    - False gateway address
    - False DNS server address
- Attacker can now direct traffic from the client to go anywhere
- The real server may reply too
  - If the attacker responds first, he wins
  - Can delay or disable the real server: denial of service attack

Defenses

- Some switches (Cisco, Juniper) support **DHCP snooping**
  - Switch ports can be configured as "trusted" or "untrusted"
  - Only specific machines are allowed to send DHCP responses
  - The switch will use DHCP data to track client behavior
    - Ensure hosts use only the IP address assigned to them
    - Ensure hosts do not fake ARP responses

Network Layer (IP)

Network Layer: IP

- Responsible for end-to-end delivery of packets
- No guarantees on message ordering or delivery
- Key functions
  - Routing
    - Each host knows the address of one or more connected routers (gateways)
    - The router knows how to route to other networks
  - Fragmentation & reassembly
    - An IP fragment may be split if the MTU size on a network is too small
    - Reassembled at its final destination
  - Error reporting
    - ICMP messages sent back to the sender (e.g., if packet is dropped)
  - Time-to-live
    - Hop count avoids infinite loops; packet dropped when TTL = 0

Source IP address

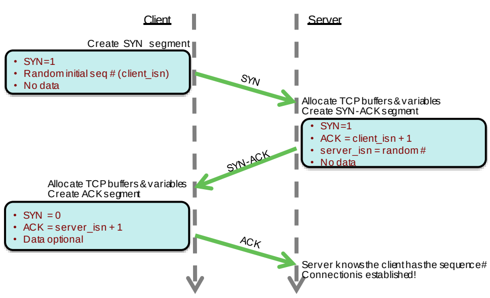
- No source IP address authentication
- Clients are supposed to use their own source IP address
  - Can override with raw sockets
  - Error responses will be sent to the forged source IP address
- Enables
  - Anonymous DoS attacks
  - DDoS attacks
    - Sent lots of packets from many places that will cause routers to generate ICMP responses
    - All responses go to the forged source address

Transport Layer (UDP, TCP)

TCP & UDP

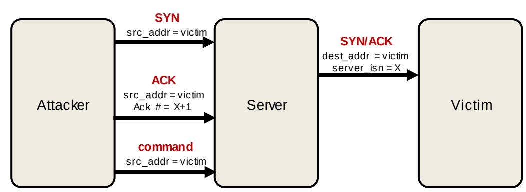
- UDP: User Datagram Protocol
  - Stateless, connectionless & unreliable
  - Anyone can send forged UDP messages
- TCP
  - Stateful, connection-oriented & reliable
  - Every packet contains a sequence number (byte offset)
    - Receiver assembles packets into correct order
    - Sends acknowledgements
    - Missing packets are retransmitted

TCP connection setup: three-way handshake



Why random initial sequence numbers

- If predictable, an attacker can create a TCP session on behalf of a forged source IP address



- Random numbers make this attack harder – especially if the attacker cannot sniff the network

Denial of service: SYN Flooding

An OS will allocate only a finite # of TCP buffers

- SYN Flooding attack
  - Send lots of SYN segments but never complete the handshake
  - The OS will not be able to accept connections until those time out
- SYN Cookies: Dealing with SYN flooding attacks
  - Do not allocate buffers & state when a SYN segment is received
  - Create initial sequence # =
    hash(src_addr, dest_addr, src_port, dest_port, SECRET)
  - When an ACK comes back, validate the ACK #
    Compute the hash as before & add 1
  - If valid, then allocate resources necessary for the connection & socket

Denial of service: Reset

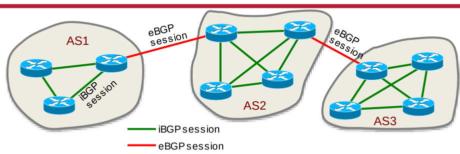
- Attacker can send a RESET (RST) packet to an open socket
- If the server sequence number is correct then the connection will close
- Sequence numbers are 32 bits
  - Chance of success is $1/2^{32} \approx 1$ in 4 billion
  - But many systems allow for a large range of sequence numbers
  - Attacker can send a flood of RST packets until the connection is broken

Routing Protocols

Routing protocols

- OSPF: Open Shortest Path First
  - Interior Gateway Protocol (IGP) within an autonomous system (AS)
  - Uses a **link state routing algorithm** (Dijkstra's shortest path)
- BGP: Border Gateway Protocol
  - Exterior Gateway Protocol (EGP) between autonomous systems (AS)
  - Exchanges routing and reachability information
  - **Distance vector routing protocol**

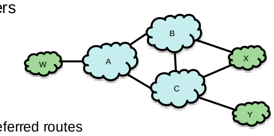
BGP sessions maintained via TCP links



- Pairs of routers exchange information via semi-permanent TCP connections
  - One connection for each link between gateway routers
    - External BGP (eBGP) session
  - Also BGP TCP connections between routers *inside* an AS
    - Internal BGP (iBGP) session

Route selection

- A, B, C: transit ASes – ISPs & backbone
- W, X, Y: stub ASes – customers



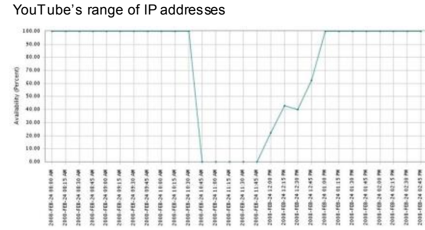
BGP route selection
- Policies allow selection of preferred routes
- Otherwise, pick the route with the shortest path
- If there's a tie, choose the shortest path with the closest router

Security problems with BGP

- Route advertisements are not authenticated
  - Anyone can inject advertisements for arbitrary routes
  - Information will propagate throughout the Internet
  - Can be used for DoS or eavesdropping
- (Partial) Solutions
  - **RPKI** (Resource Public Key Infrastructure) framework — See RFC 6480
    - Each AS obtains an X.509 certificate from the Regional Internet Registry (RIR)
    - AS admin creates a Route Origin Authorization (ROA)
      - Associates the set of prefixes managed by that AS
    - ROA is signed by the AS's private key
    - Advertisements without a valid, signed ROA are ignored
  - **BGPsec** — Still a draft standard
    - Integral part of BGP protocol
    - Each hop in the AS path is protected with a signature

Pakistan's attack on YouTube in 2008

- YouTube service was cut off the global web for over an hour
- Pakistan Telecom received a censorship order from the telecommunications ministry to block YouTube
  - The company sent spoofed BGP messages claiming to be the best route for YouTube's range of IP addresses



Pakistan's attack on YouTube in 2008

- Pakistan Telecom sent BGP advertisements that it was the correct route for 256 addresses in YouTube's 208.65.153.0 network
  - Advertise a /24 network
- That is a more specific destination that YouTube's broadcast, which covered 1024 addresses
  - YouTube advertised a /22 network
- Within minutes, all YouTube traffic started to flow to Pakistan
- YouTube immediately tried countermeasures
  - Narrowed its broadcast to 256 addresses … but too late
  - Then tried an even more specific group: 64 addresses
    - Advertise a /26 network ⇒ priority over /24 routes
    - Routes for more specific addresses overrule more general ones
  - Route updates finally fixed after 2 hours

Domain Name System

Domain Name System

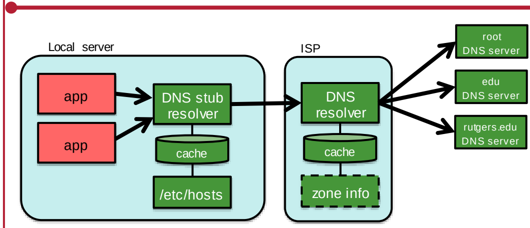
- Hierarchical service to map domain names to IP addresses
- How do you find the DNS Server for rutgers.edu?
  - That's what the domain registry keeps track of
  - When you register a domain,
    - You supply the addresses of at least two DNS servers that can answer queries for your zone
    - You give this to the domain registrar, who updates the database at the domain registry
- So how do you find the right DNS server?
  - Start at the root

Root name servers

- The root name servers provide lists of authoritative name servers for top-level domains
- 13 root name servers
  - A.ROOT-SERVERS.NET, B.ROOT-SERVERS.NET, …
  - Each has redundancy (via *anycast* routing or load balancing)
    - Each server is really a set of machines

Download the latest list at http://www.internic.net/domain/named.root

DNS Resolvers in action



Local stub resolver:
- check local cache
- check local hosts file
- send request to external resolver

E.g., on Linux: resolver is configured via the /etc/resolv.conf file

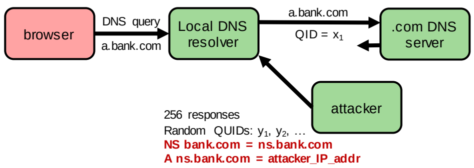
External resolver
- Running at ISP, Google Public DNS, OpenDNS, etc.

DNS Vulnerabilites

- We trust the host-address mapping
  - This is the basis for some security policies
    - Browser same-origin policy, URL address bar
- Each DNS query contains a Query ID (QID)
  - Response must have a matching QID
- Responses can be intercepted & modified
  - Malicious responses can direct messages to different hosts
- Solution: DNSsec
  - Secure extension to DNS that provide authenticated requests & responses
  - Few use it

DNS Cache Poisoning

JavaScript on a website may launch a DNS attacker



If there is some j such that $x_1 = y_j$ then the response is cached
All future DNS queries for anything at bank.com will go to attacker_IP_addr
If it doesn't work … try again with b.bank.com

Defenses against DNS cache poisoning

- Randomize source port #
  - Attack will take several hours instead of a few minutes
- Issue double DNS queries
  - Attacker will have to guess the Query ID twice (32 bits)

DNS Rebinding

- Attacker
  - Registers a domain (attacker.com)
  - Sets up a DNS server
  - DNS server responds with very short TTL values – response won't be cached
- Client (browser)
  - Script on page causes access to malicious domain
  - Attacker's DNS server responds with IP address of a server hosting malicious client-side code
  - Malicious client-side code makes additional references to the domain
    - Permitted under **same-origin policy**
      - A browser permits scripts in one page to access data in another only if both pages have the same origin & protocol
    - The script causes the browser to issue a new DNS request
    - Attacker replies with a new IP address (e.g., a target somewhere else on the Internet)

Defending against DNS rebinding

- Force minimum TTL values
  - This may affect some legitimate dynamic DNS services
- DNS pinning: refuse to switch IP address
  - This is similar to forcing minimum TTL values
- Make sure DNS responses don't contain private IP addresses
- Server-side defense
  - Reject HTTP requests with unrecognized Host headers
  - Authenticate users

The end

