CSE 433S: Introduction to Computer Security

Lecture 1: Security Fundamentals and Network Security through the Lens of Attackers

Washington University in St. Louis

Security Concepts

What is security?

- Keeping something (information, system in some case) secure against stealing & changing & destroying & forging
- Traditionally provided by physical (e.g., cabinets with locks) and administrative means (e.g., personal screening procedures)

Why is security hard ?

- Security game is hard, because we have a negative goal
- Secure means nobody can break our system
  - Who is nobody ?
  - What weapons do they have ?

Three Elements of Security

Achieve some ***goal*** against some ***adversary***

- System Goal / Security Service / Policy
- Threat models
- Mechanism

Security Goal / Services / Policy

- Confidentiality
  - Information can only be accessed by authorized entity
- Integrity
  - Information has not been tampered with
- Availability
  - Information is available to the authorized entities

Other policy goals

- Authenticity
- Accountability
- Non-repudiation
- Attack surface
- Vulnerability
- Exploitation

Policy went wrong – Sarah Palin yahoo account

Img src: wikipedia

Threat models

- Who are the attackers
- What are the attackers capable of?

Threat models go wrong

Img src: Wikipedia.org

Threat models go wrong

Img src: amazon.com

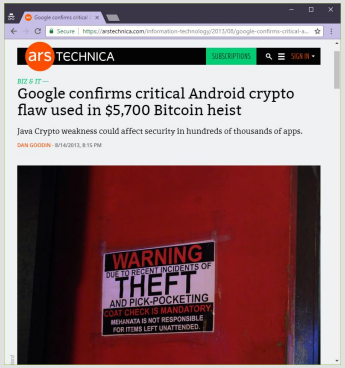
Is this code secure

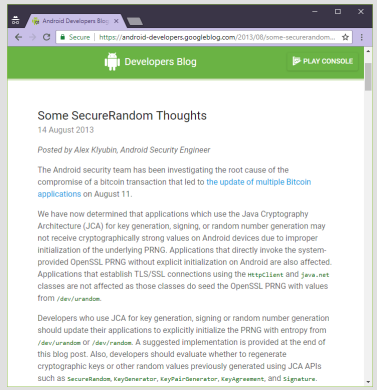

```
main (char * i){
  char s[128];
  memset(s,0,128);
  strncpy(s, i, 127);
  printf("%s",s);
}
```

Mechanism

- What is the system composed of ?
  - Software
  - Hardware
  - Design
  - Implementation

Mechanisms go wrong
When random is no longer random



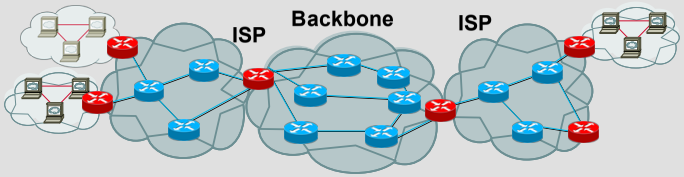


Why are things so broken

- Faulty design
- Buggy Specification
- Implementation Errors
- Side-channel leaks
- Misconfiguration
- Gullible users
- Weak Passwords
- Malicious Insiders
- Physical security Failures
- Reliance on third party software
- Malicious software

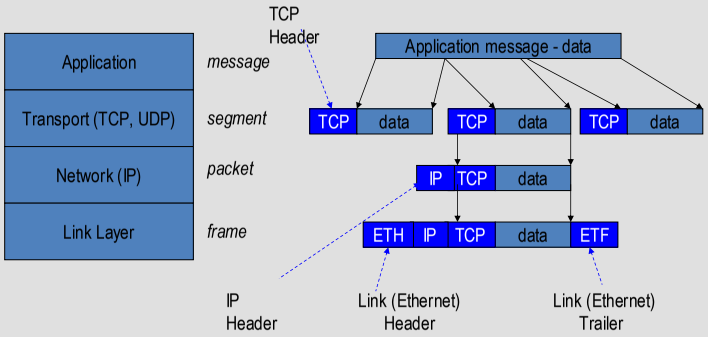
Network 101

Internet Infrastructure

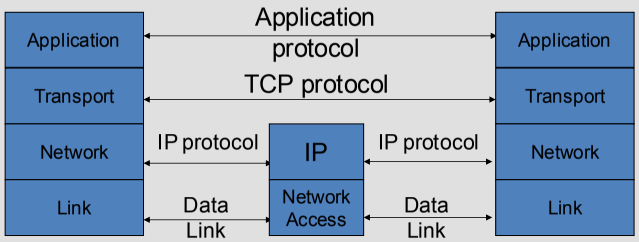


- Local and interdomain routing
  - TCP/IP for routing and messaging
  - BGP for routing announcements
- Domain Name System
  - Find IP address from symbolic name (cse.wustl.edu)

Data Formats



TCP Protocol Stack



Types of Addresses in Internet

- Media Access Control (MAC) addresses in the network access layer
  - Associated w/ network interface card (NIC)
  - 00-50-56-C0-00-01
- IP addresses for the network layer
  - IPv4(32 bit) vs IPv6(128 bit)
  - 128.1.1.3 vs fe80::fc38:6673:f04d:b37b%4
- IP addresses + ports for the transport layer
  - E.g., 10.0.0.2:8080
- Domain names for the application/human layer
  - E.g., www.wustl.edu

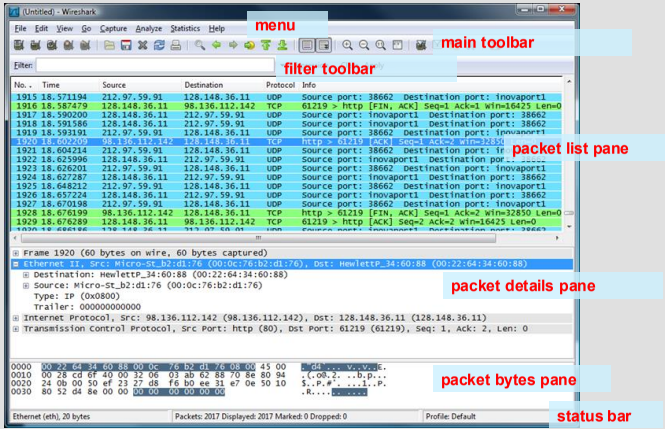
Routing and Translation of Addresses (All of them are attack surfaces)

- Translation between IP addresses and MAC addresses
  - Address Resolution Protocol (ARP) for IPv4
  - Neighbor Discovery Protocol (NDP) for IPv6
- Routing with IP addresses
  - TCP, UDP for connections, IP for routing packets
  - Border Gateway Protocol for routing table updates
- Translation between IP addresses and domain names
  - Domain Name System (DNS)

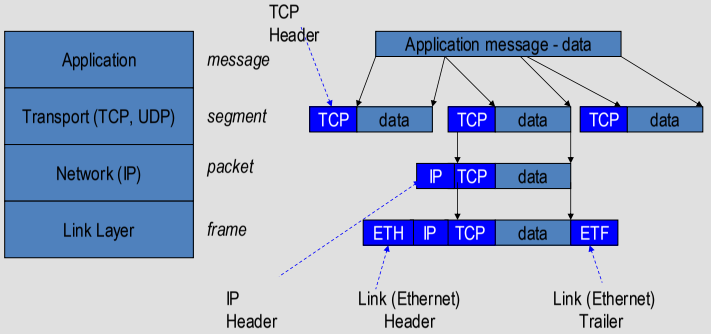
Network Monitoring Tool: Wireshark

- Wireshark is a packet sniffer and protocol analyzer
  - Captures and analyzes frames
  - Supports plugins
- Usually required to run with administrator privileges
- Setting the network interface in promiscuous mode captures traffic across the entire LAN segment and not just frames addressed to the machine
- Freely available on www.wireshark.org

Wireshark GUI



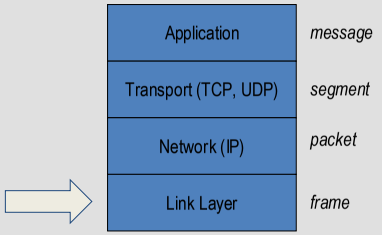
Layer Summary



In Class Discussion

- Given the network communication tool you just developed
- How do you attack it?
  - Threat model, target mechanism, properties to violate
  - What assumptions did you violate
- How do you defend it?
  - Threat model, protection mechanism, properties to protect

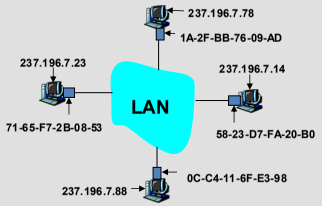
Examining the Link Layer



Routing 101

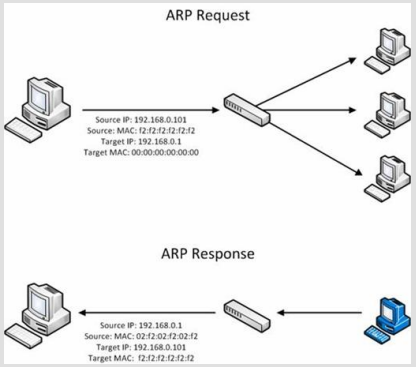
- When a packet arrives at the destination subnet, MAC address is used to deliver the packet

ARP: Address Resolution Protocol



- Each IP node (Host, Router) on LAN has ARP table
- ARP Table: IP/MAC address mappings for some LAN nodes
  < IP address; MAC address; TTL>
  - TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

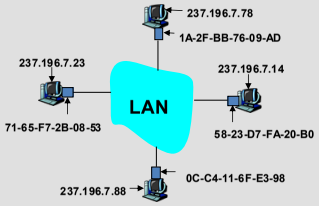
ARP: Address Resolution Protocol

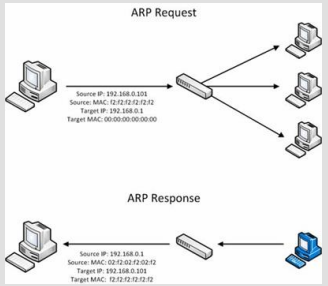


http://www.windowsecurity.com

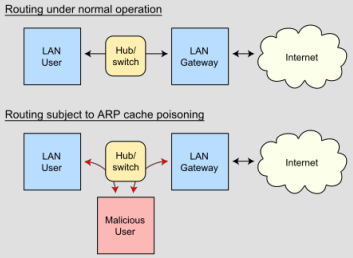
Discussion

What can go wrong during the IP-to-MAC translation?
- Hint: Try exploiting the ARP request/responses





Problem: Lack of Source Authentication - ARP Spoofing (ARP Poisoning)

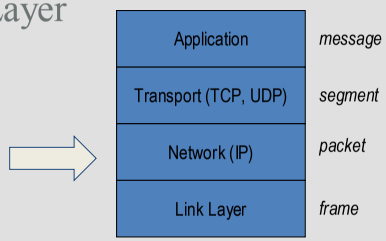


- Send fake or 'spoofed', ARP messages to an Ethernet LAN.
  - To have other machines associate IP addresses with the attacker's MAC
- Legitimate use
  - Implementing redundancy and fault tolerance

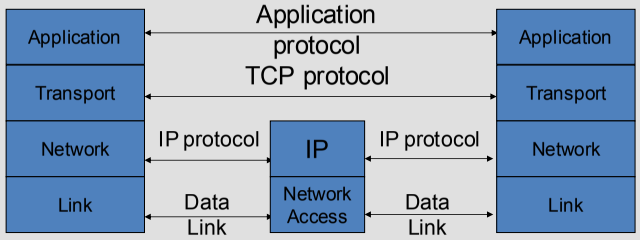
ARP Spoofing (Poisoning) Defense

- Prevention
  - Static ARP table
  - DHCP Certification (use access control to ensure that hosts only use the IP addresses assigned to them, and that only authorized DHCP servers are accessible)
- Detection
  - Arpwatch (sending email when updates occur)

Examining the Network Layer

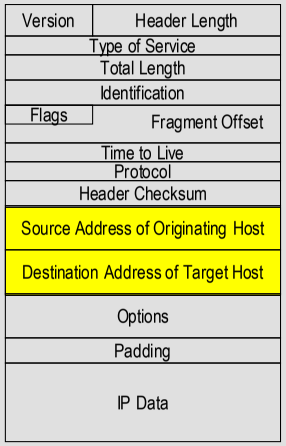


TCP Protocol Stack

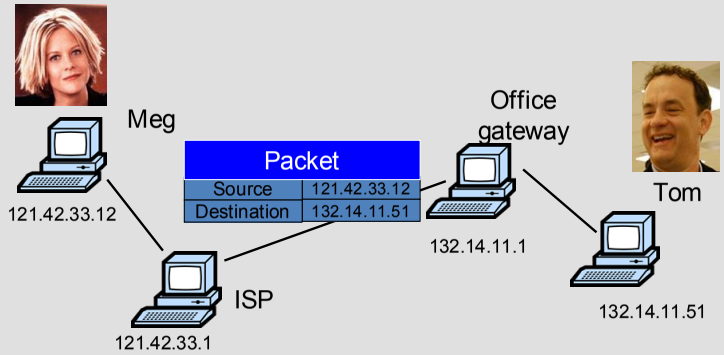


Internet Protocol (IP)

- Connectionless
  - Unreliable
  - Best effort
- Notes:
  - src and dest **ports** not parts of IP hdr



IP Routing

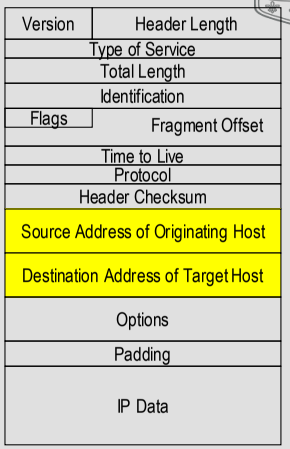


- Typical route uses several hops
- IP : no ordering or delivery guarantees

Discussion

What can go wrong during IP routing?
- Hint: How can we direct *all* packets to the victim?

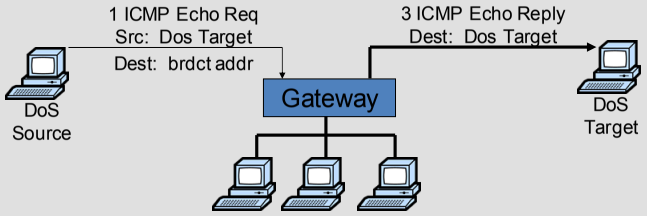
What can we do to prevent the attacks?



Problem: Lack of Source IP Authentication

- Client is trusted to embed correct source IP
  - Easy to override using raw sockets
  - **Libnet**: a library for formatting raw packets with arbitrary IP headers
  - **Scapy**: a python library for packet crafting
- Anyone who owns their machine can send packets with arbitrary source IP
  - … response will be sent back to forged source IP
- Implications:
  - Anonymous DoS attacks (e.g. smurf amplification)
  - Anonymous infection attacks (e.g. slammer worm)

Implication: Smurf Amplification DoS attack

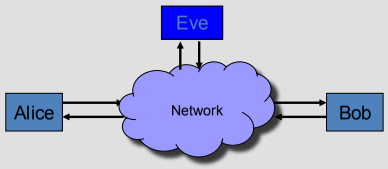


- Send ping request to broadcast addr (ICMP Echo Req)
- Lots of responses:
  - Every host on target network generates a ping reply (ICMP Echo Reply) to victim

Prevention: Reject external packets to broadcast address

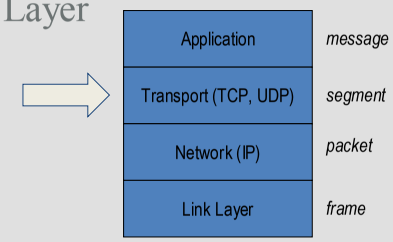
Problem: Lack of Confidentiality Protection - Packet Sniffing

- Promiscuous Network Interface Card reads all packets
  - Read all unencrypted data (e.g., “ngrep”)
  - FTP, Telnet send passwords in clear!

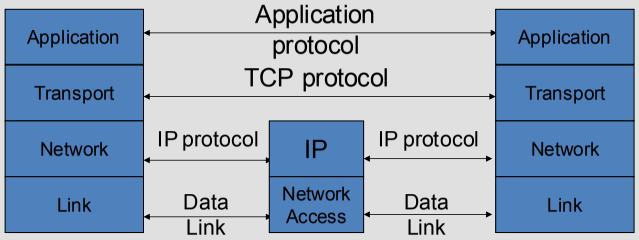


Prevention: Encryption (IPSEC, TLS)

Examining the Transport Layer

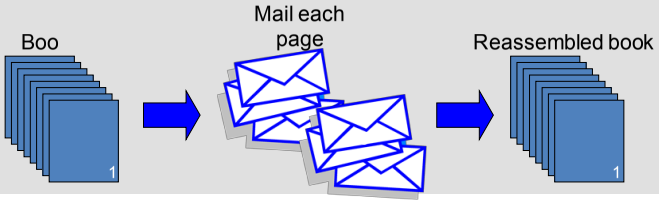


TCP Protocol Stack

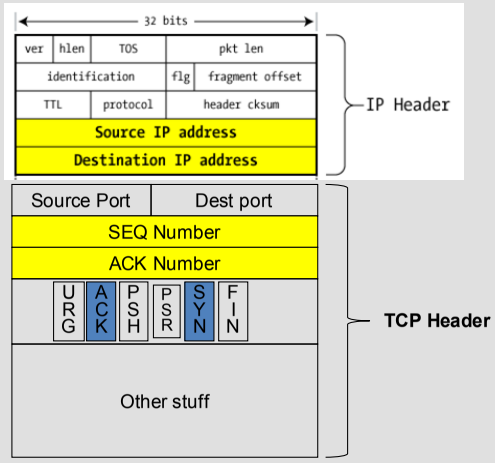


Transmission Control Protocol (TCP)

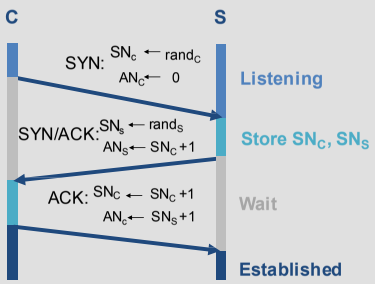
- Connection-oriented, preserves order
  - Sender
    - Break data into packets
    - Attach packet numbers
  - Receiver
    - Acknowledge receipt; lost packets are resent
    - Reassemble packets in correct order



TCP Header (protocol=6)



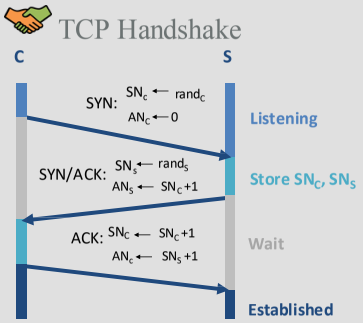
TCP Handshake



Discussion

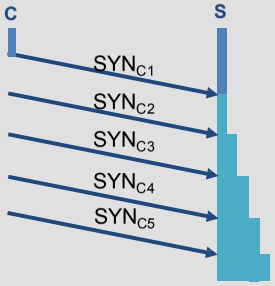
What can go wrong during the handshake?
- Hint: "Don't leave me hanging!"

Problem 2. Denial of Service (DoS) vulnerabilities (e.g. TCP SYN Flood)



Problem: Low Rate TCP SYN Flood

Single machine:
- SYN Packets with random source IP addresses
- Fills up backlog queue on server
- No further connections possible



Problem: Low Rate TCP SYN Flood

A classic SYN flood example

MS Blaster worm (2003)
- Infected machines at noon on Aug 16th:
  - SYN flood on port 80 to windowsupdate.com 50
  - SYN packets every second
    - each packet is 40 bytes
  - Spoofed source IP: a.b.X.Y where X,Y random

MS Solution
- New name: windowsupdate.microsoft.com

TCP SYN Flood Defense

Can you think of any defense mechanisms?
- Hint: If only I have good memory…

Non-solution:

- Increase backlog queue size or decrease timeout

Correct Solution:

- SYN Cookies: remove state from server
- Small performance overhead

SYN COOKIES

Idea: use secret key and data in packet to `generate server SN`

Server responds to Client with SYN-ACK cookie:

- T = 5-bit counter incremented every 64 secs.
- $L = MAC_{key}$ (SAddr, SPort, DAddr, DPort, SN_C, T) [24 bits]
- key: picked at random during boot
- $SN_S = (T \,.\, mss \,.\, L)$ (|L| = 24 bits)
- Server does not save state

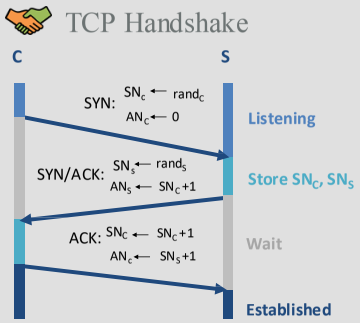
Honest client responds with ACK ($AN=SN_S+1$, $SN=SN_C+1$):

- Server allocates space for socket only if valid SN_S

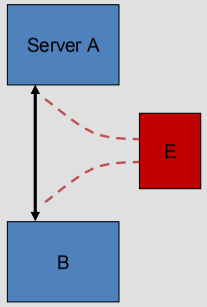
Discussion

What else can go wrong during the handshake?
- If the seq numbers (SN) are not random…

Problem 3. TCP state easily obtained by eavesdropping
- Enables spoofing and session hijacking



Problem: Hijacking Existing TCP Connection



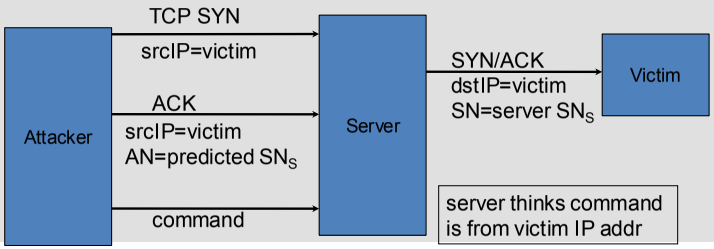
- A, B trusted connection
  - Send packets with **predictable** seq numbers
- E impersonates B to A
  - *DoS B's queue*
  - Sends packets to A that resemble B's transmission
  - E cannot receive, but may execute commands on A

Attack can be blocked if E is outside firewall.

Random Initial Sequence Numbers

Suppose initial seq. numbers (SN_C , SN_S) are predictable:

- Attacker can create TCP session on behalf of forged source IP
- Breaks IP-based authentication (e.g. SPF, /etc/hosts)
  - Random seq. num. do not prevent attack, but make it harder



Risks from Session Hijacking

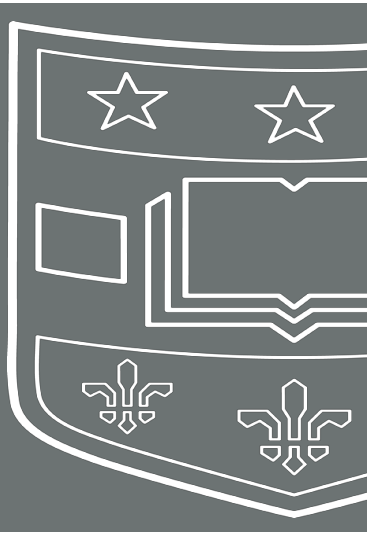
- Inject data into an unencrypted server-to-server traffic, such as an e-mail exchange, DNS zone transfers, etc.
- Inject data into an unencrypted client-to-server traffic, such as FTP file downloads, HTTP responses.
- Spoof IP addresses, which are often used for preliminary checks on firewalls or at the service level.
- Carry out MITM attacks on weak cryptographic protocols.
  - often result in warnings to users that get ignored
- Denial of service attacks, such as resetting the connection.

Let's take a look at how it is used

- https://youtu.be/KIWOYkicnlw?t=19m41s

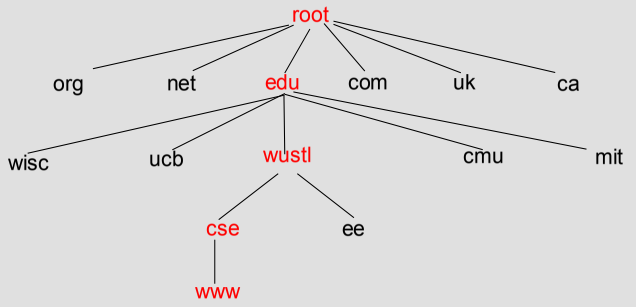
Don't do this on a public network!

Domain Name System

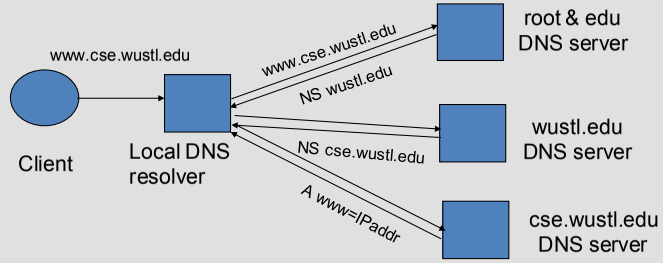


Domain Name System (DNS)

- Hierarchical Name Space



DNS Lookup Example

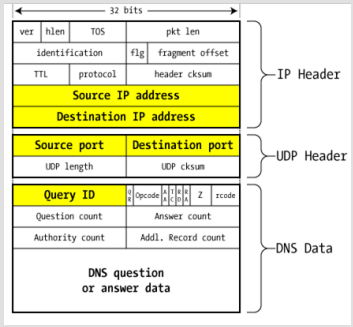


DNS record types (partial list):

- NS: name server (points to other server)
- A: address record (contains IP address)
- MX: address in charge of handling email
- TXT: generic text (e.g. used to distribute site public keys (DKIM)

DNS Packet

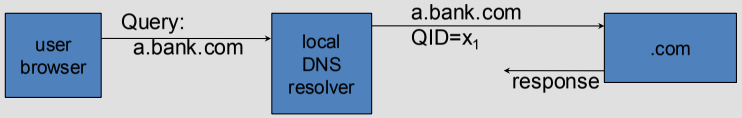
- Query ID:
  - 16 bit random value
  - Links response to query



(from Steve Friedl)

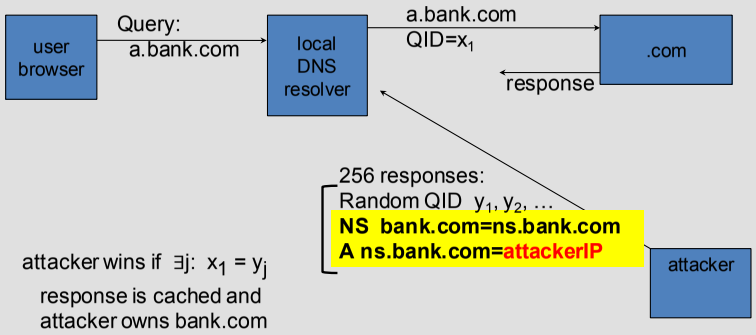
Discussion

How can the attacker hijack this DNS Lookup session?



DNS Cache Poisoning (a la Kaminsky'08)

- Victim machine visits attacker's web site, downloads Javascript



DNS Vulnerabilities

- Users/hosts trust the host-address mapping provided by DNS:
  - Used as basis for many security policies:
    Browser same origin policy, URL address bar
- Obvious problems
  - Interception of requests or compromise of DNS servers can result in incorrect or malicious responses
    - e.g. malicious access point in a Cafe
  - Solution – authenticated requests/responses
    - Provided by DNSsec … but few use DNSsec

Summary of Threats

- Confidentiality
  - Packet sniffing
- Integrity
  - ARP poisoning
  - UDP spoofing
  - TCP Session hijacking
  - DNS poisoning
- Availability
  - Denial of service attacks
- Common
  - Address translation poisoning attacks (DNS, ARP)
  - Packet Spoofing

Competition

- **Objective:** Destroy other teams' flags
- **Rules:**
  - No physical attack
  - No permanent denial of service
  - No self-replicating or self-propagating malware
  - No attacks against other team's computing infrastructure
  - No attacks against instructor's computing infrastructure
- **Local Network:** Tenda_6CB460, pwd: fillquest448