CSci 4271W
Development of Secure Software Systems
Day 23: Networks and protocols

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## Outline



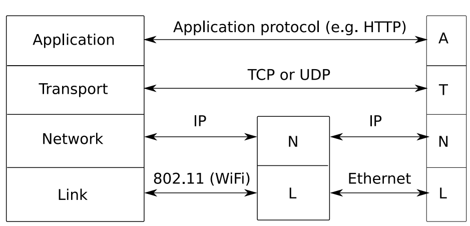
## The Internet

- A bunch of computer networks voluntarily interconnected
- Capitalized because there's really only one
- No centralized network-level management
  - But technical collaboration, DNS, etc.

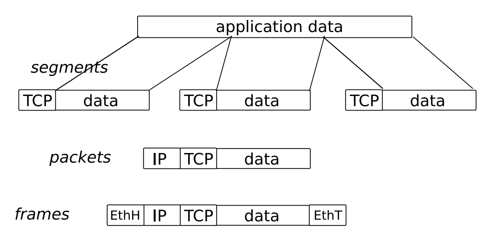
## Layered model (OSI)

7. Application (HTTP)
6. Presentation (MIME?)
5. Session (SSL?)
4. Transport (TCP)
3. Network (IP)
2. Data-link (PPP)
1. Physical (10BASE-T)

## Layered model: TCP/IP




## Packet wrapping




## IP(v4) addressing

- Interfaces (hosts or routers) identified by 32-bit addresses
  - Written as four decimal bytes, e.g. 192.168.10.2
- First $k$ bits identify network, $32 - k$ host within network
  - Can't (anymore) tell $k$ from the bits
- We'll run out any year now

## IP and ICMP

- Internet Protocol (IP) forwards individual packets
- Packets have source and destination addresses, other options
- Automatic fragmentation (usually avoided)
- ICMP (I Control Message P) adds errors, ping packets, etc.

## UDP

- User Datagram Protocol: thin wrapper around IP
- Adds source and destination port numbers (each 16-bit)
- Still connectionless, unreliable
- OK for some small messages

## TCP

- Transmission Control Protocol: provides reliable bidirectional stream abstraction
- Packets have sequence numbers, acknowledged in order
- Missed packets resent later

## Flow and congestion control

- Flow control: match speed to slowest link
  - "Window" limits number of packets sent but not ACKed
- Congestion control: avoid traffic jams
  - Lost packets signal congestion
  - Additive increase, multiplicative decrease of rate

## Routing

- Where do I send this packet next?
  - Table from address ranges to next hops
- Core Internet routers need big tables
- Maintained by complex, insecure, cooperative protocols
  - Internet-level algorithm: BGP (Border Gateway Protocol)

## Below IP: ARP

- Address Resolution Protocol maps IP addresses to lower-level address
  - E.g., 48-bit Ethernet MAC address
- Based on local-network broadcast packets
- Complex Ethernets also need their own routing (but called switches)

## DNS

- Domain Name System: map more memorable and stable string names to IP addresses
- Hierarchically administered namespace
  - Like Unix paths, but backwards
- `.edu` server delegates to `.umn.edu` server, etc.

## DNS caching and reverse DNS

- To be practical, DNS requires caching
  - Of positive and negative results
- But, cache lifetime limited for freshness
- Also, reverse IP to name mapping
  - Based on special top-level domain, IP address written backwards

## Classic application: remote login

- Killer app of early Internet: access supercomputers at another university
- Telnet: works cross-OS
  - Send character stream, run regular login program
- rlogin: BSD Unix
  - Can authenticate based on trusting computer connection comes from
  - (Also rsh, rcp)

## Outline

- Brief introduction to networking
- Announcements intermission
- Some classic network attacks
- Cryptographic protocols
- Key distribution and PKI
- SSH

## Project 1 second submission postponed

- New due date: Friday April 22nd
- Not as long as it might feel because of the midterm

## Problem set 2 coming today

- Will be posted in the noon hour
- Covers OS, web security, and crypto
  - Suggest taking a look before the midterm
- Due Wednesday, April 27th

## Midterm one week from today

- Tuesday, April 19th in class
- Open book, open notes, no electronics
- Topics up through last Thursday's lecture

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## Packet sniffing

- Watch other people's traffic as it goes by on network
- Easiest on:
  - Old-style broadcast (thin, "hub") Ethernet
  - Wireless
- Or if you own the router

## Forging packet sources

- Source IP address not involved in routing, often not checked
- Change it to something else!
- Might already be enough to fool a naive UDP protocol

## TCP spoofing

- Forging source address only lets you talk, not listen
- Old attack: wait until connection established, then DoS one participant and send packets in their place
- Frustrated by making TCP initial sequence numbers unpredictable
  - But see Oakland'12, WOOT'12 for fancier attacks, keyword "off-path"

## ARP spoofing

- Impersonate other hosts on local network level
- Typical ARP implementations stateless, don't mind changes
- Now you get victim's traffic, can read, modify, resend

## rlogin and reverse DNS

- rlogin uses reverse DNS to see if originating host is on whitelist
- How can you attack this mechanism with an honest source IP address?

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- Remember, ownership of reverse-DNS is by IP address

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## A couple more security goals

- Non-repudiation: principal cannot later deny having made a commitment
  - I.e., consider proving fact to a third party
- Forward secrecy: recovering later information does not reveal past information
  - Motivates using Diffie-Hellman to generate fresh keys for each session

## Abstract protocols

- Outline of what information is communicated in messages
  - Omit most details of encoding, naming, sizes, choice of ciphers, etc.
- Describes honest operation
  - But must be secure against adversarial participants
- Seemingly simple, but many subtle problems

## Protocol notation

$A \to B : N_B, \{T_0, B, N_B\}_{K_B}$

- $A \to B$: message sent from Alice intended for Bob
- $B$ (after :): Bob's name
- $\{\cdots\}_K$: encryption with key $K$

## Example: simple authentication

$A \to B : A, \{A, N\}_{K_A}$

- E.g., Alice is key fob, Bob is garage door
- Alice proves she possesses the pre-shared key $K_A$
  - Without revealing it directly
- Using encryption for authenticity and binding, not secrecy

## Nonce

$A \to B : A, \{A, N\}_{K_A}$

- $N$ is a *nonce*: a value chosen to make a message unique
- Best practice: pseudorandom
- In constrained systems, might be a counter or device-unique serial number

## Replay attacks

- A nonce is needed to prevent a verbatim replay of a previous message
- Garage door difficulty: remembering previous nonces
  - Particularly: lunchtime/roommate/valet scenario
- Or, door chooses the nonce: *challenge-response* authentication

## Middleperson attacks

- Older name: man-in-the-middle attack, MITM
- Adversary impersonates Alice to Bob and vice-versa, relays messages
- Powerful position for both eavesdropping and modification
- No easy fix if Alice and Bob aren't already related

## Chess grandmaster problem

- Variant or dual of middleperson
- Adversary forwards messages to simulate capabilities with his own identity
- How to win at correspondence chess
- Anderson's MiG-in-the-middle

## Anti-pattern: "oracle"

- Any way a legitimate protocol service can give a capability to an adversary
- Can exist whenever a party decrypts, signs, etc.
- "Padding oracle" was an instance of this at the implementation level

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## Public key authenticity

- Public keys don't need to be secret, but they must be right
- Wrong key $\to$ can't stop middleperson
- So we still have a pretty hard distribution problem

## Symmetric key servers

- Users share keys with server, server distributes session keys
- Symmetric key-exchange protocols, or channels
- Standard: Kerberos
- Drawback: central point of trust

## Certificates

- A name and a public key, signed by someone else
  - $C_A = \text{Sign}_S(A, K_A)$
- Basic unit of transitive trust
- Commonly use a complex standard "X.509"

## Certificate authorities

- "CA" for short: entities who sign certificates
- Simplest model: one central CA
- Works for a single organization, not the whole world

## Web of trust

- Pioneered in PGP for email encryption
- Everyone is potentially a CA: trust people you know
- Works best with security-motivated users
  - Ever attended a key signing party?

## CA hierarchies

- Organize CAs in a tree
- Distributed, but centralized (like DNS)
- Check by follow a path to the root
- Best practice: sub CAs are limited in what they certify

## PKI for authorization

- Enterprise PKI can link up with permissions
- One approach: PKI maps key to name, ACL maps name to permissions
- Often better: link key with permissions directly, name is a comment

## The revocation problem

- How can we make certs "go away" when needed?
- Impossible without being online somehow

1. Short expiration times
2. Certificate revocation lists
3. Certificate status checking

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## Short history of SSH

- Started out as freeware by Tatu Ylönen in 1995
- Original version commercialized
- Fully open-source OpenSSH from OpenBSD
- Protocol redesigned and standardized for "SSH 2"

## OpenSSH t-shirt


## SSH host keys

- Every SSH server has a public/private keypair
- Ideally, never changes once SSH is installed
- Early generation a classic entropy problem
  - Especially embedded systems, VMs

## Authentication methods

- Password, encrypted over channel
- `.shosts`: like `.rhosts`, but using client host key
- User-specific keypair
  - Public half on server, private on client
- Plugins for Kerberos, PAM modules, etc.

## Old crypto vulnerabilities

- 1.x had only CRC for integrity
  - Worst case: when used with RC4
- Injection attacks still possible with CBC
  - CRC compensation attack
- For least-insecure 1.x-compatibility, attack detector
- Alas, detector had integer overflow worse than original attack

## Newer crypto vulnerabilities

- IV chaining: IV based on last message ciphertext
  - Allows chosen plaintext attacks
  - Better proposal: separate, random IVs
- Some tricky attacks still left
  - Send byte-by-byte, watch for errors
  - Of arguable exploitability due to abort
- Now migrating to CTR mode

## SSH over SSH

- SSH to machine 1, from there to machine 2
  - Common in these days of NATs
- Better: have machine 1 forward an encrypted connection

1. No need to trust 1 for secrecy
2. Timing attacks against password typing

## SSH (non-)PKI

- When you connect to a host freshly, a mild note
- When the host key has changed, a large warning

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now
(man-in-the-middle attack)!
It is also possible that a host key has just been changed.
```