Overview

- What is network security?

- Communications channel vulnerabilities
  - End-to-end cryptography

- System software vulnerabilities
  - Perimeter defenses

- Protocol vulnerabilities
  - Deliberate Misinformation
Network Security?

- What properties do we want?
  - Confidentiality, Integrity, Authenticity
  - Access control
  - Availability
  - Non-repudiation?
  - Consistency?
  - Privacy?

- What is challenging about the network environment?
  - Exposure/sharing
  - Anonymity
  - Fragility
Approaches at 10,000 ft

- Physical security
  - Tackle the problem of sharing directly
- “Security through obscurity”
  - Hope no-one will find out what you’re doing!
- Throw math at the problem
  - Cryptography

- Why is security difficult?
  - It’s a negative goal: can you be sure there are no flaws?
  - Often assumptions turn out to be invalid
Taxonomy of attacks

- Vulnerability
  - Design
  - Implementation
  - Configuration

- Means of exploitation
  - Interception
  - Interruption
  - Modification
  - Fabrication

- Result
  - Increased access
  - Disclosure of information
  - Corruption of information
  - Denial-of-service
  - Resource theft

Example: IIS Unicode Buffer overflow
Communications channel vulnerabilities

- **Confidentiality**
  - Attacker can intercept messages (passwords, data)
  - Easy on local network; harder at a distance

- **Integrity**
  - Attacker can change messages unbeknownst to sender/receiver
  - Marginally harder attack – must intercept or stop forwarding of legitimate messages

- **Authenticity**
  - Attacker can “pretend” to be a user illegitimately
  - Easy
Basic Encryption for Confidentiality

- Cryptographer chooses functions $E$, $D$ and keys $K^E$, $K^D$
  - Solving $D(C, x) = M$ should be hard without $x$
- Cryptanalyst try to “break” the system
  - Depends on what is known: $E$ and $D$, $M$ and $C$?
Symmetric Key Functions (DES, IDEA, AES)

- \( K^E, K^D = K; E(M,K) = \{M\}^K, D(\{M\}^K,K) = M \)
- Key must be communicated to both parties, but must be secret to everyone else (key distribution problem)
- Encryption/decryption fast and have equivalent cost
- Also called secret-key or shared-key cryptography

Plaintext

Encrypt with secret key

Ciphertext

Decrypt with secret key

Plaintext
Asymmetric Key Functions (RSA)

- **K^E** = secret key (SK) \( K^D = \text{public key (PK)} \)
  - \( E(M,SK) = \{M\}^{SK}, D(\{M\}^{SK},PK) = M \)
  - \( E(M,PK) = \{M\}^{PK}, D(\{M\}^{PK},SK) = M \)
- DES 100 times faster than RSA in software
  - Typically, PK/SK used to exchange symmetric key, which is used for the conversation
  - PK can be exchanged “in the clear” (issues?)
**Integrity (MD5, SHA)**

- Verify that a message has not been modified
  - Much stronger than checksum (difference?)

- Message digest/ characteristic function/ one-way hash:
  - $H(M) = h$
  - $h, H \neq M$ (inversion resistance) [also called one-way]
  - $M \neq M', \text{s.t. } H(M) = H(M')$ (collision resistance)
  - Additional mechanism to prevent attacker from also modifying hash
    - encrypt $h$, or
    - $h = H(M,K)$, $K$ is a secret key known by both sender and receiver
Authenticity
Symmetric (secret) keys

- Three-way handshake for mutual authentication
  - Client and server share secrets, e.g., login password

Client

Server

Client Id, $E(x, CHK)$

$E(x + 1, SHK), E(y, SHK)$

$E(y + 1, CHK)$

$E(SK, SHK)$

Client authenticates server here

Session key exchanged

Server authenticates client here
Authenticity
Asymmetric (public) keys

- Notice that we reversed the role of the keys (and the math just works out) so only one party can send the message but anyone can check it’s authenticity.
Digital signatures

- Encryption can be expensive, e.g., RSA 1Kbps
- To speed up, let’s just encrypt the message digest/hash instead!
- Absolutely critical that hash is “cryptographically strong”
  - Inversion resistance, collision resistance
  - Related to size of hash
Example: SSL

- Transport layer secure channel

- Connection setup
  - Negotiate encryption algorithm
  - Server provides SSL certificate
    - Certification Authority (CA), CA signature, principal, principals public key and timeout
  - Client validates certificate (digital signature) using well-known public-key for CA
    - If valid, can use principal’s public key to negotiate session key

- Symmetric session key used to encrypt channel

- Who is trying to establish trust with whom here?
System-level vulnerabilities

- How often is security break caused by breaking crypto?
  - Why/where is strength/weakness of crypto important?
- Implementation bugs principal technical source of host compromises
  - Buffer overflow
  - Unchecked parameters
  - Randomness assumptions
  - Race condition

- Ideally: patch/fix all the hosts so no vulnerabilities can be exploited
Perimeter defenses

- Key ideas:
  - Too hard to secure/patch/fix each individual system
  - Install “watchdog” system at perimeter of network to protect all hosts inside
  - Model: internal machines are trusted, external machines are untrusted

- Network address translation
  - Multiplex internal address space on small number of public IP addresses; internal hosts can’t be addressed directly from the outside

- Firewalls
  - Limit access to end hosts (only those hosts/services that must be made public can be accessed from the outside)

- Intrusion detection systems
  - Detect attempts to break into hosts or exploit system vulnerabilities
Typical Firewall Topology

- Internet
- DMZ (De-Militarized Zone)
  - Web server, email server, web proxy, etc
- Intranet

The diagram shows a typical network topology with firewalls separating the Internet, DMZ, and Intranet.
Types of Firewalls

- **Proxy**
  - End host connects to proxy and asks it to perform actions on its behalf
    - Policy determines if action is secure or insecure
  - Transport level relays (SOCKS)
    - Ask proxy to create, accept TCP (or UDP) connection
    - Cannot secure against insecure application
  - Application level relays (e.g. HTTP, FTP, telnet, etc.)
    - Ask proxy to perform application action (e.g. HTTP Get, FTP transfer)
    - Can use application action to determine security
  - Requires applications to be modified to use the proxy
  - Considered to be the most secure since it has most information to make decision
Types of Firewalls

- Packet filters
  - Set of filters and associated actions that are used on a packet by packet basis
  - Filters specify fields, masks and values to match against packet contents, input and output interface
  - Actions are typically **forward** or **discard** (yes or no)
  - Such systems have difficulty with things like fragments and a variety of attacks
  - Typically a difficult balance between the access given and the ability to run applications
    » E.g. FTP often needs inbound connections on arbitrary port numbers – either make it difficult to use FTP or limit its use
Types of Firewalls

- **Stateful packet filters**
  - Allocate state for each flow (i.e. each TCP session)
  - Typically allow richer parsing of each packet (variable length fields, application headers, etc.)
  - Actions can include the addition of new rules and the creation of state to process future packets
    - Often have to parse application payload to determine “intent” and determine security considerations
  - Rules can be based on packet contents and state created by past packets
  - Provides many of the security benefits of proxies but without having to modify applications
Network Intrusion Detection Systems

- Deployed in similar manner to firewalls
  - Frequently not “in-line” (i.e., if IDS fails, traffic continues)
- Observe all packets and check for intrusion attempts
  - Signature detection (e.g., any HTTP packets with “rm –rf” them)
  - Anomaly detection (e.g., unusual sized requests to port 79)
- Issues
  - False negatives, False positives
  - Evading detection
  - Overhead (can be overwhelmed)
  - Still expensive to respond
Example: Evading a NIDS

Internet

Firewall

NIDS

Router

Target

Packet stream seen at NIDS from attack

rm  TTL=2
ail  TTL=1
*.*  TTL=2

NIDS sees “rmail *.*”
Target sees “rm *.*”
Protecting against evasion

- **Traffic normalization**
  - Overwrite packets to make them consistent
  - E.g. all packets get same ttl

- **Active Mapping**
  - NIDS measures per destination characteristics and adjust analysis accordingly
  - E.g. how far each host is from NIDS
Protocol vulnerabilities

- Even if two endpoints have authenticity, integrity, & confidentiality that doesn’t mean they will behave
  - Where does trust work as a security mechanism?

- Examples
  - Routing protocols
  - TCP congestion control
Routing attacks

- **Problem**: Attacker may advertise bogus routes
  - Claim to originate network/host
  - Intercept packets then re-route to true destination
  - May also cause denial-of-service

- **Solutions**
  - Policy about which routes you believe (don’t accept routes for own network); have well-known neighbors
  - Authentication of routing protocol sessions
  - Open research problem to handle this problem efficiently…
TCP Congestion Control with a Misbehaving Receiver [Savage+99]

- Simple Question
  - Can a TCP client influence how fast a TCP server sends it data?
- Simple Answer: Yes!

- Outline:
  - Why this matters
  - The attacks
  - Some countermeasures
The tragedy of the commons

- Internet bandwidth is a shared resource
  - Stability depends on voluntary end-to-end congestion control
  - If an individual host has both the incentive and ability to cheat then the entire system fails

- TCP senders (i.e. content servers)
  - Clearly have ability to cheat (send too fast)
  - Not strong incentive to cheat; own the whole commons
    - Few senders, each high volume, diverse receivers

- TCP receivers (i.e. Web browsers)
  - Clearly have incentive to steal bandwidth
  - Not obvious they have ability
Sources of vulnerability

- ACKs *mean* things that they don’t *prove*
  - I was sent in response to a data packet
  - That data packet has been received
  - I have received all the data up to X-1
  - I have (still) not yet received data X

- Sender assumes things that aren’t necessarily true
  - At most one ACK generated per data packet
  - Every ACK acknowledges a full-sized packet
Vulnerability 1: Bytes vs. Segments

- TCP: reliable byte stream w/ cumulative ACKs
- Cwnd limits unacknowledged data
- TCP begins a session in slow start:

  *During slow start, TCP increments cwnd by at most MSS bytes [one full sized packet] for each ACK received that acknowledges new data.*
(1) **ACK Division**

- Send $M$ ACKs for one pkt
- Exponential growth factor proportional to $M!$
- Preserves end-to-end semantics

**Diagram:**

- **Sender**
  - Data: 1:1461
  - ACK 487
  - ACK 973
  - ACK 1461
- **Receiver**
  - RTT
  - Data: 1461:2921
  - Data: 2921:4381
  - Data: 4381:5841
  - Data: 5841:7301

May 27, 2003
Example

Page fetch from CNN.com

Sequence Number (bytes) vs. Time (sec)

- Modified Client
- Normal Client
Vulnerability 2: Fast Retransmit and Recovery

- Receive out-of-order segment => send duplicate ACK

- Sender receives 3 duplicate ACKs => fast retransmits, enters fast recovery
  - Cwnd = cwnd/2 + 3*SMSS
  - On a duplicate ACK, cwnd += SMSS

- Each additional duplicate ACK is taken as evidence that a data packet has left the network and therefore cwnd is increased
(2) **DupACK Spoofing**

- Send extra duplicate ACKs
- Sender sends one pkt for each duplicate ACK
- Preserves end-to-end semantics
Vulnerability 3: Freshness

- When sender receives a new ACK, it increases cwnd
- But how do you know the receiver got the data?

- Must recover at application layer
  - HTTP range request
  - FTP byte request
(3) Optimistic ACKing

- Send ACKs early
- Sender sends pkts in proportion to ACK rate
- Violates end-to-end semantics
- Lose reliability
Developing a solution

Not well suited to cryptographic methods

- Need to ensure validity of information, not authenticity or integrity
- Can’t enforce behavior at remote peer
- Solution: penalize misbehavior
- Drop connection
  - Artificially limit connection speed
Detecting misbehavior

- Eliminate sender assumptions
- Include extra “evidence” in ACK
  - Which data packet it was sent in response to
  - Proof of receipt and proof of freshness

- Mechanism: **cumulative nonce**
  - Sender puts a random # (nonce) in each pkt
  - Receiver echoes sum of nonces
  - Can be implemented probabilistically with a single bit
Cumulative nonce example

Sender

Data 1:1461 (5)

ACK 1461 (5)

Data 1461:2921 (3)

ACK 2921 (8)

ACK 4381 (12)

Data 2921:4381 (7)

Receiver

Optimistic ACK

Rejected, Invalid nonce
Summary

- Basic security
  - Cryptographic primitives and operations
  - Firewalls
  - Intrusion Detection

- Protocol vulnerabilities
Next time

- More security...
- Denial-of-Service
- Worms