Network Security Protocols and Defensive Mechanisms

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Acknowledgments: Lecture slides are from the Computer Security course thought by Dan Boneh and John Mitchell at Stanford University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.
Network security

◆ What is the network for?
◆ What properties might attackers destroy?
  ▪ Confidentiality: no information revealed to others
  ▪ Integrity: communication remains intact
  ▪ Availability: messages received in reasonable time
Network Attacker
Intercepts and controls network communication

- Confidentiality
- Integrity
- Availability
Plan for today

Protecting network connections
- Wireless access—802.11i/WPA2
- IPSEC

Perimeter network defenses
- Firewall
  - Packet filter (stateless, stateful), Application layer proxies
- Intrusion detection
  - Anomaly and misuse detection

Network infrastructure security
- BGP instability and S-BGP
- DNS rebinding and DNSSEC
Last lecture

Basic network protocols
- IP, TCP, UDP, BGP, DNS

Problems with them
- TCP/IP
  - No SRC authentication: can’t tell where packet is from
  - Packet sniffing
  - Connection spoofing, sequence numbers
- BGP: advertise bad routes or close good ones
- DNS: cache poisoning, rebinding
  - Web security mechanisms rely on DNS
Network Protocol Stack

- Application
- Transport
- Network
- Link

Application protocol

TCP protocol

IP protocol

Data Link

Network Access

IP

Network

Transport

Application

Link
Link-layer connectivity
802.11i Protocol

**Supplicant**
Auth/Assoc
802.1X UnBlocked
PTK/GTK

**Authenticator**
Auth/Assoc
802.1X UnBlocked
PTK/GTK

**Authentication Server (RADIUS)**
No Key

**Link Layer**

802.11 Association

EAP/802.1X/RADIUS Authentication

MSK

4-Way Handshake

Group Key Handshake

Data Communication
TCP/IP CONNECTIVITY

How can we isolate our conversation from attackers on the Internet?
Basic Layer 2-3 Security Problems

- Network packets pass by untrusted hosts
  - Eavesdropping, packet sniffing
  - Especially easy when attacker controls a machine close to victim

- TCP state can be easy to guess
  - Enables spoofing and session hijacking
Virtual Private Network (VPN)

Three different modes of use:
- Remote access client connections
- LAN-to-LAN internetworking
- Controlled access within an intranet

Several different protocols
- PPTP – Point-to-point tunneling protocol
- L2TP – Layer-2 tunneling protocol
- IPsec (Layer-3: network layer)
LAN (Trusted Network)

VPN-1 Pro

Internet

L2TP VPN
Microsoft Windows

IPSec VPN
Palm OS
Microsoft Pocket PC

Clientless VPN
via SSL

Microsoft Handheld PC
Apple Macintosh
Microsoft Windows
IPSEC

- Security extensions for IPv4 and IPv6
- IP Authentication Header (AH)
  - Authentication and integrity of payload and header
- IP Encapsulating Security Protocol (ESP)
  - Confidentiality of payload
- ESP with optional ICV (integrity check value)
  - Confidentiality, authentication and integrity of payload
Recall packet formats and layers

- Application
- Transport (TCP, UDP)
- Network (IP)
- Link Layer

1. Application message - data
2. TCP data
3. IP data
4. ETH data

- TCP Header
- IP Header
- Link (Ethernet) Header
- Link (Ethernet) Trailer
IPSec Transport Mode: IPSEC instead of IP header

http://www.tcpipguide.com/free/t_IPSecModesTransportandTunnel.htm
IPSEC Tunnel Mode
IPSec Tunnel Mode: IPSEC header + IP header
IKE subprotocol from IPSEC

Result: A and B share secret $g^{ab} \mod p$
Mobile IPv6 Architecture

- **Mobile Node (MN)**
- **Corresponding Node (CN)**
- **Home Agent (HA)**

- Direct connection via binding update
- Authentication is a requirement
- Early proposals weak
- RFC 6618 – use IPSec
Summary of first section

Protecting network connections

- **Wireless access**– 802.11i/WPA2
  - Several subprotocols provide encrypted link between user device and wireless access point

- **IPSEC**
  - Give external Internet connections equivalent security to local area network connections

- **Mobility**
  - Preserve network connections when a device moves to different physical portions of the network
Second topic of today's lecture

Perimeter defenses for local networks

- Firewall
  - Packet filter (stateless, stateful)
  - Application layer proxies
- Intrusion detection
  - Anomaly and misuse detection
LOCAL AREA NETWORK

How can we protect our local area network from attackers on the external Internet?
Basic Firewall Concept

Separate local area net from internet

All packets between LAN and internet routed through firewall
Screened Subnet Using Two Routers
Alternate 1: Dual-Homed Host
Alternate 2: Screened Host
Basic Packet Filtering

- Uses transport-layer information only
  - IP Source Address, Destination Address
  - Protocol (TCP, UDP, ICMP, etc)
  - TCP or UDP source & destination ports
  - TCP Flags (SYN, ACK, FIN, RST, PSH, etc)
  - ICMP message type

Examples
- DNS uses port 53
  - Block incoming port 53 packets except known trusted servers

Issues
- Stateful filtering
- Encapsulation: address translation, other complications
- Fragmentation
Source-Address Forgery
More about networking: port numbering

**TCP connection**
- Server port uses number less than 1024
- Client port uses number between 1024 and 16383

**Permanent assignment**
- Ports <1024 assigned permanently
  - 20, 21 for FTP
  - 23 for Telnet
  - 25 for server SMTP
  - 80 for HTTP

**Variable use**
- Ports >1024 must be available for client to make connection
- Limitation for stateless packet filtering
  - If client wants port 2048, firewall must allow incoming traffic
- Better: stateful filtering knows outgoing requests
  - Only allow incoming traffic on high port to a machine that has initiated an outgoing request on low port
Filtering Example: Inbound SMTP

Assume we want to block internal server from external attack

Can block external request to internal server based on port number
Filtering Example: Outbound SMTP

Assume we want to allow internal access to external server

Known low port out, arbitrary high port in
If firewall blocks incoming port 1357 traffic then connection fails
Stateful or Dynamic Packet Filtering

Assume we want to allow external UDP only if requested
Telnet

How can stateful filtering identify legitimate session?

1. Client opens channel to server; tells server its port number. The ACK bit is not set while establishing the connection but will be set on the remaining packets.

2. Server acknowledges.

Stateful filtering can use this pattern to identify legitimate sessions.
FTP

How can stateful filtering identify legitimate session?

1. Client opens command channel to server; tells server second port number

2. Server acknowledges

3. Server opens data channel to client’s second port

4. Client acknowledges

FTP Server

FTP Client

Data Channel

TCP ACK

“PORT 5151”

“OK”

DATA CHANNEL

5150 5151
Normal IP Fragmentation

Complication for firewalls

Flags and offset inside IP header indicate packet fragmentation
Abnormal Fragmentation

Low offset allows second packet to overwrite TCP header at receiving host
Packet Fragmentation Attack

Firewall configuration
- TCP port 23 is blocked but SMTP port 25 is allowed

First packet
- Fragmentation Offset = 0.
- DF bit = 0 : "May Fragment"
- MF bit = 1 : "More Fragments"
- Destination Port = 25. TCP port 25 is allowed, so firewall allows packet

Second packet
- Fragmentation Offset = 1: second packet overwrites all but first 8 bits of the first packet
- DF bit = 0 : "May Fragment"
- MF bit = 0 : "Last Fragment."
- Destination Port = 23. Normally be blocked, but sneaks by!

What happens
- Firewall ignores second packet “TCP header” because it is fragment of first
- At host, packet reassembled and received at port 23
TCP Protocol Stack

Application protocol

TCP protocol

IP protocol

Data Link
Proxying Firewall

- Application-level proxies
  - Tailored to http, ftp, smtp, etc.
  - Some protocols easier to proxy than others

- Policy embedded in proxy programs
  - Proxies filter incoming, outgoing packets
  - Reconstruct application-layer messages
  - Can filter specific application-layer commands, etc.
    - Example: only allow specific ftp commands
    - Other examples: ?

- Several network locations – see next slides
Firewall with application proxies

Daemon spawns proxy when communication detected ...
Application-level proxies

- Enforce policy for specific protocols
  - E.g., Virus scanning for SMTP
    - Need to understand MIME, encoding, Zip archives
  - Flexible approach, but may introduce network delays

- “Batch” protocols are natural to proxy
  - SMTP (E-Mail)  NNTP (Net news)
  - DNS (Domain Name System)  NTP (Network Time Protocol)

- Must protect host running protocol stack
  - Disable all non-required services; keep it simple
  - Install/modify services you want
  - Run security audit to establish baseline
  - Be prepared for the system to be compromised
Web traffic scanning

- Intercept and proxy web traffic
  - Can be host-based
  - Usually at enterprise gateway
- Block known bad sites
- Block pages with known attacks
- Scan attachments
  - Virus, worm, malware, ...
Firewall references

Elizabeth D. Zwicky
Simon Cooper
D. Brent Chapman

William R. Cheswick
Steven M. Bellovin
Aviel D. Rubin
Dang... I knew we should've stormed the castle before it got trendy...
Intrusion detection

Many intrusion detection systems
- Network-based, host-based, or combination

Two basic models
- Misuse detection model
  - Maintain data on known attacks
  - Look for activity with corresponding signatures
- Anomaly detection model
  - Try to figure out what is “normal”
  - Report anomalous behavior

Fundamental problem: too many false alarms
Example: Snort

From: Rafeeq Ur Rehman, *Intrusion Detection Systems with Snort: Advanced IDS Techniques with Snort, Apache, MySQL, PHP, and ACID.*

http://www.snort.org/
Snort components

- **Packet Decoder**
  - input from Ethernet, SLIP, PPP...

- **Preprocessor:**
  - detect anomalies in packet headers
  - packet defragmentation
  - decode HTTP URI
  - reassemble TCP streams

- **Detection Engine:** applies rules to packets

- **Logging and Alerting System**

- **Output Modules:** alerts, log, other output
### Snort detection rules

**Rule header**

- **Action**
- **Protocol**
- **Address**
- **Port**
- **Direction**
- **Address**
- **Port**

**Rule options**

- Apply to all IP packets
- Source IP address
- Destination IP address
- Source port #
- Destination port
- Alert will be generated if criteria met
- Rule options

**Alert**

```plaintext
code
alert ip any any -> any any (msg: "IP Packet detected");
```

**Explanation**

The Snort detection rule is designed to alert on any IP packets that match the specified criteria. The rule is applied to all IP packets, and it checks for source and destination IP addresses and ports. If the criteria are met, an alert will be generated with the specified message.
Additional examples

```plaintext
alert tcp any any -> 192.168.1.0/24 111
(content:"|00 01 86 a5|"; msg: "mountd access");
```

```plaintext
alert tcp !192.168.1.0/24 any -> 192.168.1.0/24 111
(content: "|00 01 86 a5|"; msg: "external mountd access");
```

! = negation operator in address
content - match content in packet
192.168.1.0/24 - addr from 192.168.1.1 to 192.168.1.255

https://www.snort.org/documents/snort-users-manual
Snort challenges

- **Misuse detection – avoid known intrusions**
  - Database size continues to grow
    - Snort version 2.3.2 had 2,600 rules
  - Snort spends 80% of time doing string match

- **Anomaly detection – identify new attacks**
  - Probability of detection is low
Difficulties in anomaly detection

- Lack of training data
  - Lots of “normal” network, system call data
  - Little data containing realistic attacks, anomalies

- Data drift
  - Statistical methods detect changes in behavior
  - Attacker can attack gradually and incrementally

- Main characteristics not well understood
  - By many measures, attack may be within bounds of “normal” range of activities

- False identifications are very costly
  - Sys Admin spend many hours examining evidence
Perimeter defenses for local networks

- **Firewall**
  - Packet filter (stateless, stateful), Application layer proxies

- **Intrusion detection**
  - Anomaly and misuse detection
Last section of today’s lecture

Network infrastructure protocols
- BGP vulnerabilities and S-BGP
- DNS security, cache poisoning and rebinding attacks
INFRASTRUCTURE PROTOCOLS: BGP, DNS
BGP example

- Transit: 2 provides transit for 7
- Algorithm seems to work OK in practice
  - BGP is does not respond well to frequent node outages

Figure: D. Wetherall
BGP Security Issues

- BGP is used for all inter-ISP routing
- Benign configuration errors affect about 1% of all routing table entries at any time
- Highly vulnerable to human errors, malicious attacks
  - Actual routing policies can be very complicated
- MD5 MAC is rarely used, perhaps due to lack of automated key management, addresses only one class of attacks
S-BGP Design Overview

- **IPsec**: secure point-to-point router communication
- **Public Key Infrastructure**: authorization for all S-BGP entities
- **Attestations**: digitally-signed authorizations
  - Address: authorization to advertise specified address blocks
  - Route: Validation of UPDATEs based on a new path attribute, using PKI certificates and attestations
- **Repositories** for distribution of certificates, CRLs, and address attestations
- **Tools** for ISPs to manage address attestations, process certificates & CRLs, etc.
BGP example

Network diagram with nodes labeled 1, 2, 3, 4, 5, 6, 7, 8, and 7. The nodes are connected by arrows indicating relationships or connections between ASes (Autonomous Systems) and hosts. The diagram includes labels for AS, Host1, Host2, ... Hostn, and Address blocks.
Address Attestation

- Indicates that the final AS listed in the UPDATE is authorized by the owner of those address blocks
- Includes identification of:
  - owner’s certificate
  - AS to be advertising the address blocks
  - address blocks
  - expiration date
- Digitally signed by owner of the address blocks
- Used to protect BGP from erroneous UPDATEs (authenticated but misbehaving or misconfigured BGP speakers)
Route Attestation

Indicates that the speaker or its AS authorizes the listener’s AS to use the route in the UPDATE

Includes identification of:
- AS’s or BGP speaker’s certificate issued by owner of the AS
- the address blocks and the list of ASes in the UPDATE
- the neighbor
- expiration date

Digitally signed by owner of the AS (or BGP speaker) distributing the UPDATE, traceable to the IANA ...

Used to protect BGP from erroneous UPDATEs (authenticated but misbehaving or misconfigured BGP speakers)
Validating a Route

To validate a route from $AS_n$, $AS_{n+1}$ needs:

- address attestation from each organization owning an address block(s) in the NLRI
- address allocation certificate from each organization owning address blocks in the NLRI
- route attestation from every AS along the path ($AS_1$ to $AS_n$), where the route attestation for $AS_k$ specifies the NLRI and the path up to that point ($AS_1$ through $AS_{k+1}$)
- certificate for each AS or router along path ($AS_1$ to $AS_n$) to check signatures on the route attestations
- and, of course, all the relevant CRLs must have been checked
INFRASTRUCTURE PROTOCOLS: BGP, DNS
Recall: DNS Lookup

Query: "www.example.com A?"

<table>
<thead>
<tr>
<th>Reply</th>
<th>Resource Records in Reply</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>&quot;com. NS a.gtld.net&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;a.gtld.net A 192.5.6.30&quot;</td>
</tr>
<tr>
<td>5</td>
<td>&quot;example.com. NS a.iana.net&quot;</td>
</tr>
<tr>
<td></td>
<td>&quot;a.iana.net A 192.0.34.43&quot;</td>
</tr>
<tr>
<td>7</td>
<td>&quot;www.example.com A 1.2.3.4&quot;</td>
</tr>
<tr>
<td>8</td>
<td>&quot;www.example.com A 1.2.3.4&quot;</td>
</tr>
</tbody>
</table>

Local recursive resolver caches these for TTL specified by RR
DNS is Insecure

- Packets sent over UDP, < 512 bytes
- 16-bit TXID, UDP Src port are only “security”
- Resolver accepts packet if above match
- Packet from whom? Was it manipulated?

Cache poisoning
  - Attacker forges record at resolver
  - Forged record cached, attacks future lookups
  - Kaminsky (BH USA08)
**DNSSEC Goal**

“The Domain Name System (DNS) security extensions provide origin authentication and integrity assurance services for DNS data, including mechanisms for authenticated denial of existence of DNS data.”

-RFC 4033
DNSSEC

- Basically no change to packet format
  - Goal is security of DNS data, not channel security

- New Resource Records (RRs)
  - RRSIG: signature of RR by private zone key
  - DNSKEY: public zone key
  - DS: crypto digest of child zone key
  - NSEC / NSEC3 authenticated denial of existence

- Lookup referral chain (unsigned)

- Origin attestation chain (PKI) (signed)
  - Start at pre-configured trust anchors
    - DS/DNSKEY of zone (should include root)
  - DS → DNSKEY → DS forms a link
**DNSSEC Lookup**

Query: "www.example.com A?"

<table>
<thead>
<tr>
<th>Reply</th>
<th>RRs in DNS Reply</th>
<th>Added by DNSSEC</th>
</tr>
</thead>
</table>
| 3     | "com. NS a.gtld.net"  
"a.gtld.net A 192.5.6.30" | "com. DS"  
"RRSIG(DS) by ." |
| 5     | "example.com. NS a.iana.net"  
"a.iana.net A 192.0.34.43" | "com. DNSKEY"  
"RRSIG(DNSKEY) by com."  
"example.com. DS"  
"RRSIG(DS) by com." |
| 7     | "www.example.com A 1.2.3.4" | "example.com DNSKEY"  
"RRSIG(DNSKEY) by example.com."  
"RRSIG(A) by example.com." |
| 8     | "www.example.com A 1.2.3.4" | Last Hop? |
Authenticated Denial-of-Existence

- Most DNS lookups result in denial-of-existence
- NSEC (Next SECure)
  - Lists all extant RRs associated with an owner name
  - Easy zone enumeration
- NSEC3
  - Hashes owner names
    - Public salt to prevent pre-computed dictionaries
  - NSEC3 chain in hashed order
DNS Rebinding Attack

Read permitted: it’s the “same origin”

DNSSEC cannot stop this attack
DNS Rebinding Defenses

- Browser mitigation: DNS Pinning
  - Refuse to switch to a new IP
  - Interacts poorly with proxies, VPN, dynamic DNS, ...
  - Not consistently implemented in any browser

- Server-side defenses
  - Check Host header for unrecognized domains
  - Authenticate users with something other than IP

- Firewall defenses
  - External names can’t resolve to internal addresses
  - Protects browsers inside the organization
Summary of this section

Network infrastructure protocols
- BGP vulnerabilities and S-BGP
  - Security can be achieved by applying cryptography and basic network connection security to every step
  - Heavyweight solution, but illustrates the ways BGP can be vulnerable
- DNS security, rebinding attack
  - Domain-name security achieved by additional infrastructure
  - Most complicated part is addressing non-existence
Summary

Protecting network connections
  - Wireless security – 802.11i/WPA2
  - IPSEC

Perimeter network perimeter defenses
  - Firewall
    - Packet filter (stateless, stateful),
    - Application layer proxies
  - Intrusion detection
    - Anomaly and misuse detection

Network infrastructure security
  - BGP vulnerability and S-BGP
  - DNSSEC, DNS rebinding