

# CS 458 / 658

## Computer Security and Privacy

### Module 4 Network Security

Spring 2019

## Module outline

- 1 Network concepts
- 2 Threats in networks
- 3 Network security controls
- 4 Firewalls
- 5 Honeypots / honeynets
- 6 Intrusion detection systems

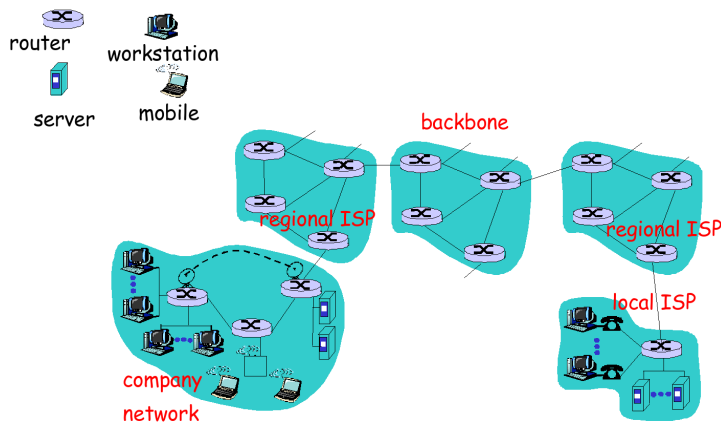
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# Architecture of the Internet



Slide adapted from "Computer Networking" by Kurose & Ross

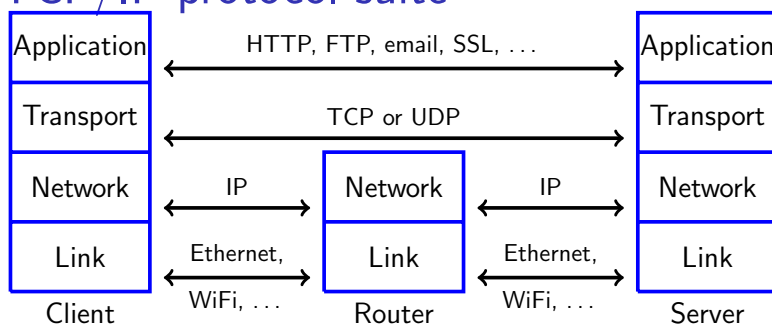
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## Characteristics of the Internet

- No single entity that controls the Internet
- Traffic from a source to a destination likely flows through nodes controlled by different entities
- End nodes cannot control through which nodes traffic flows
  - Worse, all traffic is split up into individual packets, and each packet could be routed along a different path
- Different types of nodes
  - Server, laptop, router, UNIX, Windows,...
- Different types of communication links
  - Wireless vs. wired
- TCP/IP suite of protocols
  - Packet format, routing of packets, dealing with packet loss,...

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## TCP/IP protocol suite



- Transport and network layer designed in the 1970s to connect local networks at different universities and research labs
- Participants knew and trusted each other
- Design addressed non-malicious errors (e.g., packet drops), but not malicious errors

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## Threats in networks

- Intelligence
- Attacks on confidentiality
- Impersonation and Spoofing
- Attacks on integrity
- Protocols failures
- Web site vulnerabilities
- Denial of service
- Botnets
- Threats in active/mobile code
- Script kiddies

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## Port scan

- To distinguish between multiple applications running on the same server, each application runs on a “port”
  - E.g., a Web server typically runs on port 80
- Attacker sends queries to ports on target machine and tries to identify whether and what kind of application is running on a port
- Identification based on loose-lipped applications or how exactly application implements a protocol

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## Port scan (cont.)

- Loose-lipped systems reveal (non-confidential) information that could facilitate an attack
  - Login application can reveal information about OS or whether a userid is valid
  - Web servers typically return version information
- Nmap tool can identify many applications
  - Useful not only to attackers, but also to system administrators
- Goal of attacker is to find application with remotely exploitable flaw
  - E.g., Apache web server prior to version 1.3.26 is known to be vulnerable to buffer overflow
  - Exploits for these flaws can be found on the Internet

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## Loose Lips

### Ashley Madison's Password Reset Form

Response for invalid email address

**Forgot Password?**

Please enter the email address used on your Ad Profile. Your log-in information will be sent to this email address.

Email Address

[Send](#)

Thank you for your forgotten password request. If that email address exists in our database, you will receive an email to that address shortly

For additional service or support, please [Contact Us](#).

If you are already a member and have accessed this page in error, [click here](#) to login.

Response for valid email address

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<http://www.troyhunt.com/2015/07/your-affairs-were-never-discrete-ashley.html>

4-11

## Intelligence

- Social Engineering
  - Attacker gathers sensitive information from person
  - Often, attacker pretends to be somebody within the person's organization who has a problem and exploits the person's willingness to help (or vice versa)
    - I forgot my password, I locked myself out, there's a problem with your Paypal account,...
- Dumpster diving
- Eavesdropping on oral communication
- Google
  - There's lots of information on the Internet that shouldn't be there
  - The right Google query will find it
- Victim's Facebook profile

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# Eavesdropping and wiretapping

- Owner of node can always monitor communication flowing through node
  - Eavesdropping or passive wiretapping
  - Active wiretapping involves modification or fabrication of communication
- Can also eavesdrop while communication is flowing across a link
  - Degree of vulnerability depends on type of communication medium
- Or when communication is accidentally sent to attacker's node
- It is prudent to **assume that your communication is wiretapped**

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# Communication media

- Copper cable
  - Inductance allows a physically close attacker to eavesdrop without making physical contact
  - Cutting cable and splicing in secondary cable is another option
- Optical fiber
  - No inductance, and signal loss by splicing is likely detectable
- Microwave/satellite communication
  - Signal path at receiver tends to be wide, so attacker close to receiver can eavesdrop
- All these attacks are feasible in practice, but require **physical expenses/effort**

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# Communication media (WiFi)

- WiFi
  - Can be **easily intercepted** by anyone with a WiFi-capable (mobile) device
    - Don't need additional hardware, which would cause suspicion
  - Maybe from kilometers away using a directed antenna
  - WiFi also raises other security problems
    - Physical barriers (walls) help against random devices being connected to a wired network, but are (nearly) useless in case of wireless network
    - Need authentication mechanism to defend against free riders

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# Misdelivered information

- Local Area Network (LAN)
  - Connects all computers within a company or a university
  - Technical reasons might cause a packet to be sent to multiple nodes, not only to the intended receiver
  - By default, a network card ignores wrongly delivered packets
  - An attacker can change this and use a **packet sniffer** to capture these packets
- Email
  - Wrongly addressed emails, inadvertent Reply-To-All

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# Impersonation

- Impersonate a person by stealing his/her password
  - Guessing attack
  - Exploit default passwords that have not been changed
  - Sniff password (or information about it) while it is being transmitted between two nodes
  - Social engineering
- Exploit trust relationships between machines/accounts
  - Rhosts/rlogin allows user A on machine X to specify that user B on machine Y can act as A on X without having to enter password
    - ssh has a similar mechanism
    - Attacker breaking into machine Y can exploit this
    - Or attacker might be able to masquerade as machine Y

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# Spoofing

- Object (node, person, URL, Web page, email, WiFi access point, ...) masquerades as another one
- URL spoofing
  - Exploit typos: [www.uwaterlo.ca](http://www.uwaterlo.ca)
  - Exploit ambiguities: [www.foobar.com](http://www.foobar.com) or [www.foo-bar.com](http://www.foo-bar.com)?
  - Exploit similarities: [www.paypa1.com](http://www.paypa1.com)
- Web page spoofing and URL spoofing are used in Phishing attacks
- “Evil Twin” attack for WiFi access points
- Spoofing is also used in session hijacking and man-in-the-middle attacks

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## Session hijacking

- TCP protocol sets up state at sender and receiver end nodes and uses this state while exchanging packets
  - e.g., sequence numbers for detecting lost packets
  - Attacker can hijack such a session and masquerade as one of the endpoints
- Web servers sometimes have client keep a little piece of data ("cookie") to re-identify client for future visits
  - Attacker can sniff or steal cookie and masquerade as client
- Man-in-the-middle attacks are similar; attacker becomes stealth intermediate node, not end node

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## Traffic analysis

- Sometimes, the mere existence of communication between two parties is sensitive and should be hidden
  - Whistleblowers, Military environments, or Two CEOs
- TCP/IP has each packet include unique addresses for the packet's sender and receiver end nodes, which makes traffic analysis easy
- Attacker can learn these addresses by sniffing packets
- June 2019: traffic to >70,000 routes in Europe were misdirected, maybe unintentionally, to China Telecom, for more than 2 hours.
- More on protecting yourself from this attack later

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## Integrity attacks

- Attacker can modify packets while they are being transmitted
  - Change payload of packet
  - Change address of sender or receiver end node
  - Replay previously seen packets
  - Delete or create packets
- Line noise, network congestion, or software errors could also cause these problems
  - TCP/IP will likely detect environmental problems, but fail in the presence of an active attacker
  - How in the case of TCP's checksumming mechanism?

## Integrity attacks (cont.)

- DNS cache poisoning
  - Domain Name System maps host names (www.uwaterloo.ca) to numerical addresses (129.97.128.40), as stored in packets
  - Attacker can create wrong mappings

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## Protocol failures

- TCP/IP assumes that all nodes implement protocols faithfully
- E.g., TCP includes a mechanism that asks a sender node to slow down if the network is congested
  - An attacker could just ignore these requests
- Some implementations do not check whether a packet is well formatted
  - E.g., the value in the packet's length field could be smaller than the packet's actual length, making buffer overflow possible
  - Potentially disastrous if all implementations are from the same vendor or based on the same code base

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## Protocol failures (cont.)

- Protocols can be very complex, behaviour in rare cases might not be (uniquely) defined
- Some protocols include broken security mechanisms
  - WEP (see later)

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## Web site vulnerabilities

- Web site defacements
- Accessing a URL has a web server return HTML code
  - Tells browser how to display web page and how to interact with web server
  - Attacker can examine this code and find vulnerabilities
- Attacker sends malicious URL to web server
  - to exploit a buffer overflow
  - to invoke a shell or some other program
  - to feed malicious input to a server-side script
  - to access sensitive files
    - E.g., by including “../” in a URL or by composing URLs different from the “allowed ones” in the HTML code

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## Web site vulnerabilities (cont.)

- HTTP protocol is stateless, so web server asks client to keep state when returning a web page and to submit this state when accessing next web page
  - Cookie or URL (<http://www.store.com?clientId=4342>)
- Attacker can submit **modified** state information
  - Web server might fall victim to incomplete mediation

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## Web site vulnerabilities (cont.)

- Cross-site scripting (XSS)/request forgery (CSRF) attacks (code injection)
- Attacker adds his/her own HTML code to somebody else's web page
  - E.g., in the comments section of a blog
- Other users download and execute this code when downloading the web page
  - XSS: Code steals sensitive information (e.g., cookie) contained in the web page and sends it to attacker
    - <http://www.attacker.com/aliceCookie=secretValue>
  - CSRF: Code performs malicious action at some web site (e.g., user's bank) if user is currently logged in there
    - <http://www.bank.com/transferMoneyToAttacker>

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## Denial of service (DoS)

- Cutting a wire or jamming a wireless signal
- Flooding a node by overloading its Internet connection or its processing capacity
- Ping flood
  - Node receiving a ping packet is expected to generate a reply
  - Attacker could overload victim
  - Different from “ping of death”, which is a malformed ping packet that crashes victim’s computer
- Smurf attack
  - Spoof (source) address of sender end node in ping packet by setting it to victim’s address
  - Broadcast ping packet to all nodes in a LAN

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## Denial of service (cont.)

- Exploit knowledge of implementation details about a node to make node perform poorly
- SYN flood
  - TCP initializes state by having the two end nodes exchange three packets (SYN, SYN-ACK, ACK)
  - Server queues SYN from client and removes it when corresponding ACK is received
  - Attacker sends many SYNs, but no ACKs
- Send packet fragments that cannot be reassembled properly
- Craft packets such that they are all hashed into the same bucket in a hash table

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## Denial of service (cont.)

- Black hole attack (AKA packet drop attack)
  - Routing of packets in the Internet is based on a distributed protocol
  - Each router informs other routers of its cost to reach a set of destinations
  - Malicious router announces low cost for victim destination and discards any traffic destined for victim
  - Has also happened because of router misconfiguration
- DNS attacks
  - DNS cache poisoning can lead to packets being routed to the wrong host

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# Reflection & Amplification DDoS Attack

- An attack where the victim is flooded with legitimate-looking traffic that originates from unsuspecting network nodes on the Internet
  - **Amplification:** A vulnerable network node (e.g., a home wifi router) runs a service (e.g., SNMP) that responds to queries with much more data than the query itself
  - **Reflection:** The attacker spoofs the source address of the queries to that of the victim so that the vulnerable network nodes send (reflect) responses to the victim
- Hard to combat:
  - The response traffic is coming from innocent nodes
  - It is hard to identify the real source (perhaps bots) of the queries due to spoofing

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## Distributed denial of service (DDoS)

- If there is only a single attacking machine, it might be possible to identify the machine and to have routers discard its traffic (see later)
- More difficult if there are lots of attacking machines
- Most attacking machines participate without knowledge of their owners
  - Attacker breaks into machines using Trojan, buffer overflow, . . . and installs malicious software
  - Machine becomes a **zombie/bot** and waits for attack command from attacker
  - A network of bots is called a **botnet**
  - How would you turn off a (classic) botnet (i.e., one with a central command node)?

4-32

## New Generation Botnets

- Today's botnets are very sophisticated
- Virus/worm/trojan for propagation, exploit multiple vulnerabilities
- Stealthiness to hide from owner of computer
- Code morphing to make detection difficult
- Bot usable for different attacks (spam, DDoS,...)

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## Botnets (cont.)

- Distributed, dynamic & redundant control infrastructure
  - P2P system for distributing updates
  - “Fast Flux”
    - A single host name maps to hundreds of addresses of infected machines
    - Machines proxy to malicious websites or to “mothership”
    - Machines are constantly swapped in/out of DNS to make tracking difficult
  - Domain Generation Algorithm
    - Infected machine generates a large set (50,000 in the case of Conficker) of domain names that changes every day
    - It contacts a random subset of these names for updates
    - To control the botnet, authorities would have to take control of 50,000 different domain names each day

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## Botnets (cont.)

- Earlier worms (Nimda, Slammer) were written by hackers for **fame** with the goal to spread worm as fast as possible
  - Caused disruption and helped detection
- Today’s botnets are controlled by crackers looking for **profit**, which rent them out
  - Criminal organizations
- Spread more slowly, infected machine might lie dormant for weeks

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## Sample botnet: Storm

- In September 2007, **Storm Worm** botnet included hundreds of thousands or even millions of machines
- Bots were used to send out junk emails advertising web links that when clicked attempted to download and install worm, or to host these websites
- Botnet was also rented out for pharmacy and investment spam
- As a self-defence mechanism, it ran DDoS attacks against Internet addresses that scanned for it
- Authors were thought to reside in St. Petersburg, Russia
- Problem: implementation of p2p protocol created >10 times normal traffic (=> detectable)

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## Sample botnet: Mirai

- In fall 2016, Mirai botnet attacked several high-profile targets, including a popular security blog and a large DNS provider
- Attack traffic of so far unseen 1 Tbps or more
- Botnet consisted of 600,000 IoT devices (routers, cameras) infected due to unchanged default passwords
- Distribution based on self-propagating worm
- Each bot flooded targets with UDP, TCP, and HTTP traffic, no amplification or reflection
- Botnet is now believed to be part of a rivalry between Minecraft server operators

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## Active code

- To reduce load on server, server might ask client to execute code on its behalf
  - Java, JavaScript, ActiveX, Flash, Silverlight
  - Invoke another application (Word, iTunes, Steam...)
  - Maybe inadvertently (see XSS attack)
- Obviously, this can be dangerous for client
- Java 1.1 ran in a sandbox with limited capabilities, code is checked for correctness
  - No writing to a file, no talking to random network nodes
  - Similar for JavaScript
  - But it could still use up CPU or memory resources, wreak havoc with display, or play annoying music

4-38

## Active code (cont.)

- Java 1.2+ can break out of sandbox if approved by user
  - What's the problem here?
- Worse: Java 7 runs signed applets out of sandbox **by default**
- Third-party applications
  - Turn out to be a huge problem, for all browsers
  - Malicious input parameters, Word macros...
  - Potentially disastrous if application has full access rights to a user's account

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## Active code (cont.)



- **Privileged:** The application will run with unrestricted access which may put your computer and personal information at risk.
- **Sandboxed:** The application will run with restricted access that is intended to protect your computer and personal information.

4-40

## Script kiddies

- For all of the discussed attacks, exploit code and complete attack scripts are available on the Internet
- **Script kiddies** can download scripts and raise an attack with minimum effort
- There are even tools that allow easy building of individual attacks based on existing exploits
  - E.g., Metasploit Framework

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## Design and implementation

- Use controls against security flaws in programs that we talked about earlier
- **Always check inputs**, don't ever trust input from a client
  - Use a white list of allowed characters, not a black list of forbidden ones

4-43

## Blacklist vs whitelist



4-44

## Segmentation and separation

- Don't put all a company's servers on a single machine
- Deploy them on multiple machines, depending on their functional and access requirements
- If a machine gets broken into, only some services will be affected
- E.g., the web server of a company needs to be accessible from the outside and is therefore more vulnerable
- Therefore, it shouldn't be trusted by other servers of the company, and it should be deployed outside the company firewall (see DMZ later)

4-45

# Redundancy

- Avoid single points of failure
  - Even if you don't have to worry about attackers
  - Disk crash, power failure, earthquake, . . .
- (Important) servers should be deployed in a redundant way on multiple machines, ideally with different software to get genetic diversity and at different locations
- Redundant servers should be kept in (close) sync so that backup servers can take over easily
  - Test this!
  - Keep backup copies at a safe place in case you get hit by Murphy's law

4-46

# Access controls

- ACLs on routers
  - All traffic to a company typically goes through a single (or a few) routers
  - In case of flooding attack, define router ACL that drops packets with particular source and destination address
  - ACLs are expensive for high-traffic routers
  - Difficult to gather logs for forensics analysis
  - Source addresses of packets in flood are typically spoofed and dynamic
- Firewalls
  - Firewalls have been designed to filter traffic, maybe based on other criteria than just packet addresses

4-47

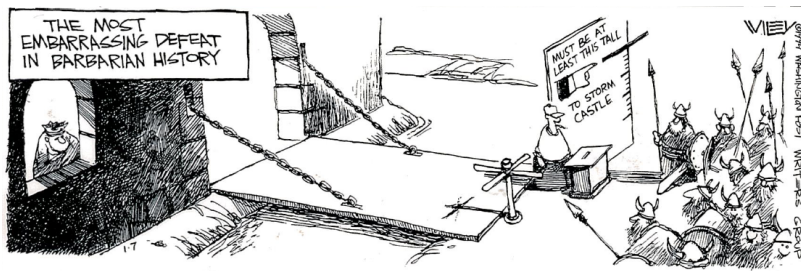
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# Firewalls



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## Firewalls

- Firewalls are the castles of the Internet age
- **All traffic** into/out of a company has to go through a small number of gates (choke points)
  - Wireless access point should be outside of firewall
- **Choke points** carefully examine traffic, especially incoming, and might refuse it access
  - Two strategies: "permit everything unless explicitly forbidden" or "forbid everything unless explicitly allowed"
- Company firewalls do not protect against attacks on company hosts that originate within the company
  - Need **multiple layers of defense / defense in depth**

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## Types of firewalls

- Packet filtering gateways / screening routers
- Stateful inspection firewalls
- Application proxies
- Personal firewalls
- Firewalls are attractive targets for attackers, they (except personal ones) are typically deployed on designated computers that have been stripped of all unnecessary functionality to limit attack surface

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## Packet filtering gateways

- Simplest type
- Make decision based on **header of a packet**
  - Header contains source and destination addresses and port numbers, port numbers can be used to infer type of packet
    - 80 -> Web, 22 -> SSH
    - E.g., allow Web, but not SSH
- Ignore payload of packet
- Can drop spoofed traffic
  - uWaterloo's firewall could drop all packets originating from uWaterloo whose source address is not of the form 129.97.x.y
  - And traffic originating from outside of uWaterloo whose source address is of the form 129.97.x.y
  - Does this eliminate spoofed traffic completely?

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## Stateful inspection firewalls

- More expensive than packet filtering
- Keep **state** to identify packets that belong together
  - When a client within the company opens a TCP connection to a server outside the company, firewall must recognize response packets from server and let (only) them through
  - Some application-layer protocols (e.g., FTP) require additional (expensive) inspection of packet content to figure out what kind of traffic should be let through
- IP layer can fragment packets, so firewall might have to re-assemble packets for stateful inspection

4-53

## Application proxy

- Client talks to proxy, proxy talks to server
  - Specific for an application (email, Web, ...)
  - Not as transparent as packet filtering or stateful inspection
  - **Intercepting proxy** requires no explicit configuration by client (or knowledge of this filtering by client)
  - All other traffic is blocked
- For users within the company wanting to access a server outside the company (forward proxy) and vice versa (reverse proxy)
- Proxy has full knowledge about communication and can do sophisticated processing
  - Limit types of allowed database queries, filter URLs, log all emails, scan for viruses
- Can also do strong user authentication

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# Personal firewalls

- Firewall that runs on a (home) user's computer
  - Especially important for computers that are always online
- Typically “forbid everything unless explicitly allowed”
  - Definitely for communication originating from other computers
  - Maybe also for communication originating on the user's computer
    - Why? What's the problem here?

4-55

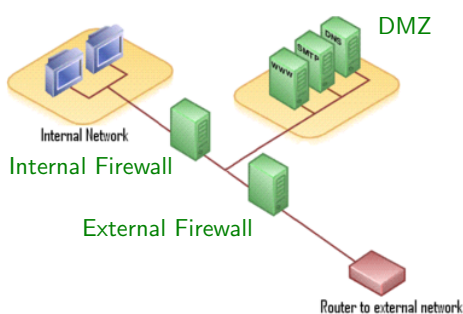
## Personal firewalls (cont.)

- Protect against attacks on servers running on computer
  - Servers that are running unnecessarily (e.g., Windows XP before SP 1 suffered from this)
  - Servers that are wrongly configured and that allow access from other computers (or that cannot be configured to disallow this)
  - Servers that have a remotely exploitable bug

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## Demilitarized Zone (DMZ)

- Subnetwork that contains an organization's external services, accessible to the Internet
- Deploy external and internal firewall
  - External firewall protects DMZ
  - Internal firewall protects internal network from attacks lodged in DMZ



Source: Wikipedia

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# Censorship

Some governments try to block access to certain information or functionalities: political/historical text, encrypted communication, etc.

For example through:

- Checking search queries or URL strings for certain keywords
- Blocking specific protocols
- Filtering certain IPs or Domain names
- Network blackouts

4-58

## Censorship circumvention

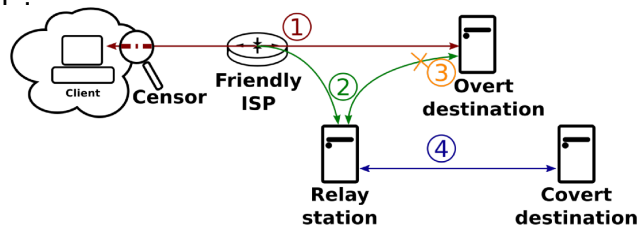
Some solutions:

- Encryption: SSL/TLS, SSH
- Virtual Private Networks (VPN)
- Tor
- Decoy Routing
- Alternative networks

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## Decoy Routing

Slitheen<sup>1</sup>:



<sup>1</sup>Cecylia Bocovich, Ian Goldberg. Slitteen: Perfectly Imitated Decoy Routing Through Traffic Replacement, CCS 2016

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## Honeypots / honeynets

- Set up an (unprotected) computer or an entire network as a trap for an attacker
- System has no production value, so **any activity is suspicious**
  - Any received email is considered spam
- Observe attacker to learn about new attacks, to identify and stop attacker, or to divert attacker from attacking real system
- Obviously, attacker should not be able to learn that attacked system is a honeypot/-net
  - Cat-and-mouse game
- Also, attacker might be able to use honeypot/-net to break into real system

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## Types of honeypots/-nets

- Low interaction
  - Daemon that emulates one or multiple hosts, running different services
  - Easy to install and maintain
  - Limited amount of information gathering possible
  - Easier for the attacker to detect than high interaction honeynets
- High interaction
  - Deploy real hardware and software, use stealth network switches or keyloggers for logging data
  - More complex to deploy
  - Can capture lots of information
  - Can capture unexpected behaviour by attacker

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## Intrusion detection systems (IDSs)

- Firewalls do not protect against inside attackers or insiders making mistakes and can be subverted
- IDSs are next line of defense
- Monitor activity to identify malicious or suspicious events
  - Receive events from sensors
  - Store and analyze them
  - Take action if necessary
- Host-based and network-based IDSs
- Signature-based and heuristic/anomaly-based IDSs

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## Host-based and network-based IDSs

- Host-based IDSs
  - Run on a host to protect this host
  - Can exploit lots of information (packets, disk, memory, . . .)
  - Miss out on information available to other (attacked) hosts
  - If host gets subverted, IDS likely gets subverted, too
- Network-based IDSs
  - Run on dedicated node to protect all hosts attached to a network
  - Have to rely on information available in monitored packets
  - Typically more difficult to subvert
- Distributed IDSs combine the two of them

4-66

## Signature-based IDSs

- Each (known) attack has its signature
  - E.g., many SYNs to ports that are not open could be part of a port scan
- Signature-based IDSs try to detect attack signatures
- Fail for new attacks or if attacker manages to modify attack such that its signature changes
  - Polymorphic worms
- Might exploit statistical analysis

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## Heuristic/anomaly-based IDSs

- Look for behaviour that is out of the ordinary
- By modelling good behaviour and raising alert when system activity no longer resembles this model
- Or by modelling bad behaviour and raising alert when system activity resembles this model
- All activity is classified as good/benign, suspicious, or unknown
- Over time, IDS learns to classify unknown events as good or suspicious
  - Maybe with machine learning

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## Example: Tripwire

- Anomaly-based, host-based IDS, detects file modifications
- Initially, compute digital fingerprint of each system file and store fingerprints at a safe place
- Periodically, re-compute fingerprints and compare them to stored ones
- (Malicious) file modifications will result in mismatches
- Why is it not a good idea to perform the second step directly on the production system?

4-69

# IDS discussion

- Stealth mode
  - Two network interfaces, one for monitoring traffic, another one for administration and for raising alarms
  - First one has no published address, so it does not exist for routing purposes (passive wiretap)
- Responding to alarms
  - Type of response depends on impact of attack
  - From writing a log entry to calling a human
- False positives/negatives
  - Former might lead to real alarms being ignored
  - IDS might be tunable to strike balance between the two
  - In general, an IDS needs to be monitored to be useful

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## Recap

- Network concepts
- Threats in networks
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- Firewalls
- Honeypots / honeynets
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