# Internet Attacks and Defenses

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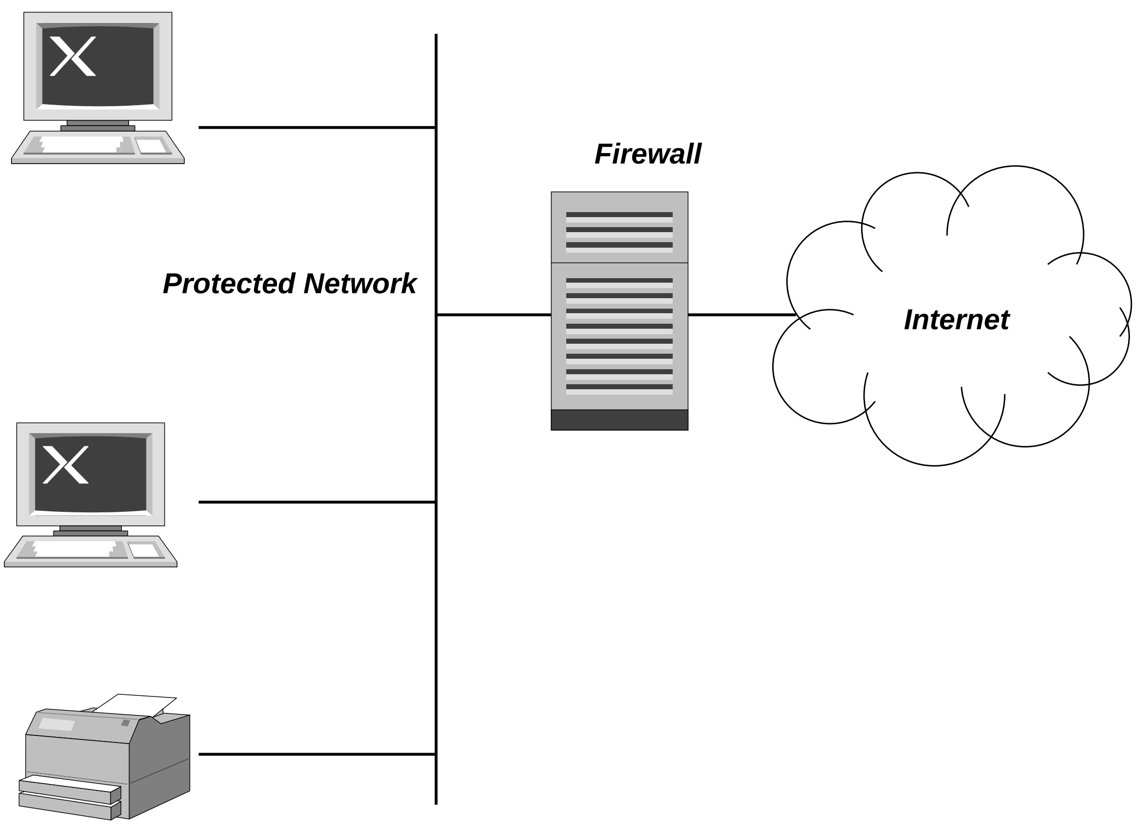
# Internet

- Decentralized approach -> no control/responsibility
- Open architecture -> anonymous endpoints/spoofing
- End-to-end principle -> security built at the edges
- Automation, scripting, action-at-a-distance

# Partial Answer: Firewalls

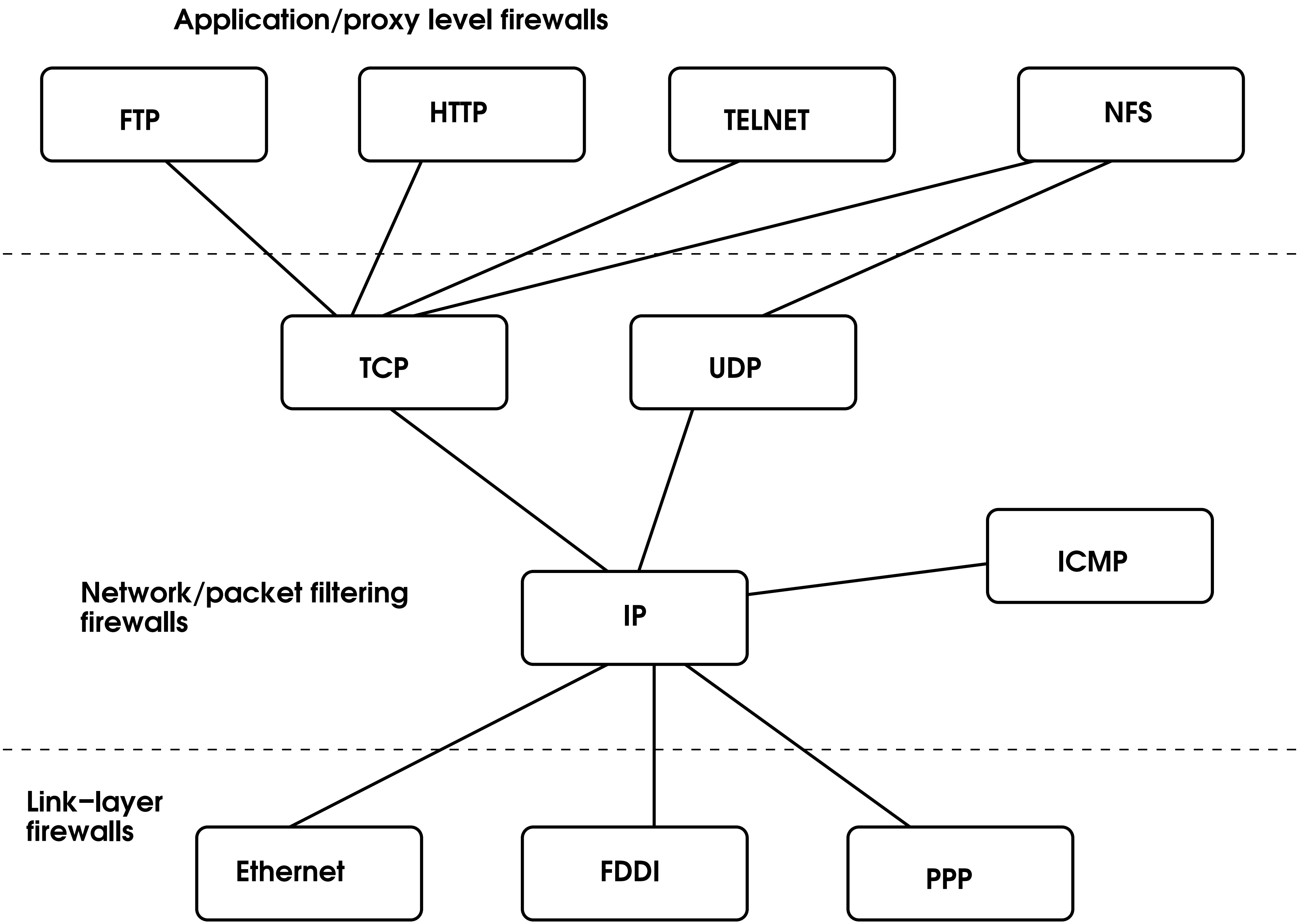
- Devices examining traffic -> access control decisions
  - Divide the world between trusted and not
  - Only authorized traffic is allowed to pass



# Firewalls

- "Crunchy shell, soft chewy center"
- Originally devised to contain bad network software problems
- Can operate at various levels in the stack
    - Link, network, application
    - Packet filtering vs. circuit switching
    - Transparent vs. proxies
    - Stateful vs. stateless

# Operation At Different Layers



# Problems With Firewalls

- All attachments to the public network must be protected
  - High degree of connectivity
  - Consistency, administration becomes a problem
  - Unidentified network attachments can bypass security
  - Topologies not as clear-cut as in the past
    - Telecommuting, extranets
- Complicated protocols
- End-to-end encryption
- Performance bottleneck
- Very coarse-grain protection
  - Majority of attacks are from insiders

# Distributed Firewalls

- Firewalls are convenient for specification and enforcement of policy
- Keep specification centralized, distribute enforcement
  - Each node on the network becomes its own firewall
  - Encryption becomes an asset
  - Protocol/application information available
  - Distributed performance
  - Anyone can be treated as an outsider
- Firewall policy can be pushed or pulled
- Commercial products available
  - Even at the network card level

# Current Problems

- Network denial of service (DoS)
- Remote software exploits
- Worms

# Denial of Service

- Limited resources
  - Bandwidth, memory, CPU cycles
  - More abstract: service (e.g., web server)
- Saturate with requests for resource
  - Deny service to other users
  - Degrade performance, exhaust resources
- Real-life examples
  - Yell near someone, pull the plug on a machine, etc.

- Resource accounting problem

# Denial of Service (cont.)

- Easier to launch than other (e.g., crypto) attacks
  - Often, this is sufficient
- DoS in operating systems
  - CPU: "while (1) ;"
  - Memory: "while (1) malloc(65537);"
  - OS tables: "while (1) fork();"
- Resource allocation per-user/process
  - getrusage()
  - Sometimes it works

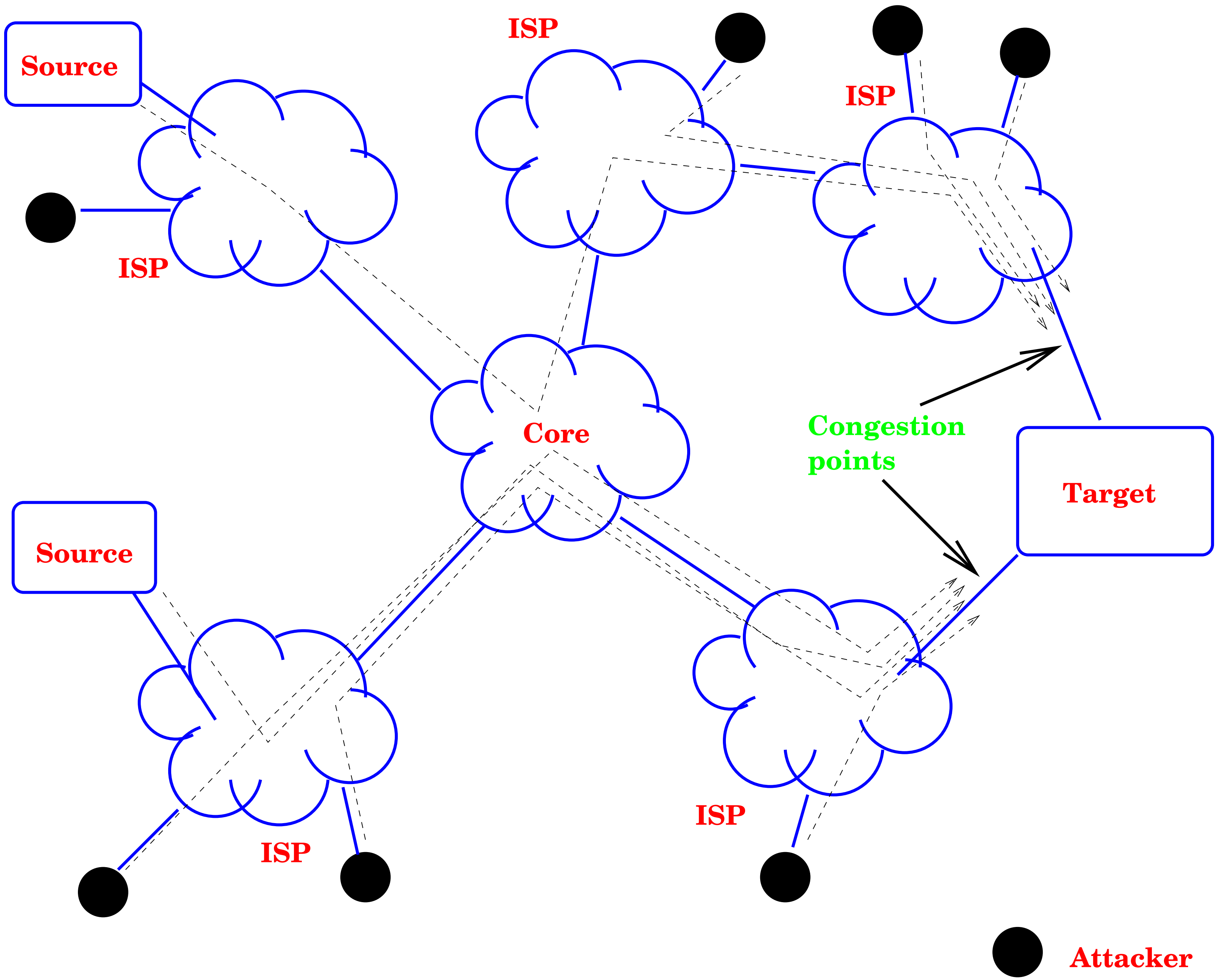
# Network DoS

- Over a network
  - No need to be a legitimate user
- Action at a distance
  - Minimize risk
- Larger volume
  - Distributed DoS (DDoS)
- Authentication/encryption do not help by itself
  - Firewall becomes easy DoS target

# Types of DoS

- Link congestion (forward or reverse)
  - Send many large packets or ask for many larger web pages
  - Saturate target’s access link
- Router processing capacity
  - Send many small packets
  - High processing overhead on router
  - Also acts as link congestion
- End-host (server) processing capacity
  - Ask for "expensive" operations (show complete database)

# Currently...



Source
ISP
ISP
ISP
Core
Congestion
points
Target
Source
ISP
ISP
Attacker

# Simple Protection

- Reserving bandwidth (RSVP/Diffserv)
- Authentication + process/task scheduling by the OS
- Load balancing (multiple links/servers)

- Do not help with congestion attacks
- High-speed Internet core
  - Routers cannot spend cycles verifying packets
  - Routers close to target can, but links are smaller

# Distributed DoS (DDoS)

- Coordinate attack on target from various sources
- Higher aggregate attack bandwidth
- Subvert hosts, use them as "zombies"
  - Hard-coded attack, time-based, or control channel
- Worms, email viruses make it easy to launch DDoS
  - Fundamentally, it’s bad security
- IP address spoofing may be used
  - Ingress filtering would help
  - Cannot be and is not universally deployed

# Defenses Against DDoS

- Data replication (Akamai, CDNs)
  - Only works with static content
- Black-holing by ISPs
- Attack prevention
- Trace the source of attacks
- Secure Overlay Services

# Attack Prevention

- Better security
- Ingress filtering
  - Only helps against spoofing
  - A worm that takes over 1M hosts need not spoof
- Apply IDS techniques
  - At the edge routers or the core
- Build models of good traffic
  - Treat preferentially
- Build models of bad traffic
  - Filter or limit such traffic
- Susceptible to probing attacks (guess characteristics of good traffic and spoof)

# Pushback

- Detect attack
- Determine characteristics
  - Predicates on packet fields that can be used to filter
- Contact upstream routers and pass them the predicates
  - Continue as far as possible
  - Potentially all the way to the sources' edge routers
- Automated mechanism

# Pushback (cont.)

- Potentially subject to "gaming"
- Can be used to deny service to innocent hosts, if filters are not pushed all the way to edge routers
    - Spoof from real DoS target
    - Network will filter/rate-limit traffic from that host
- Who is allowed to push filters to an ISP’s routers ?
    - Business weapon...

# Attack detection

- Determine who the real sources of an attack are
- Contact administrator or use pushback
    - Generally, of limited use
    - Attack clouds of 10,000 hosts or more

# Algebraic approaches to detection

- In-band notification of target
- First approach: probabilistically add router identity in packe
    - Use "opaque" fields, e.g., IP ID field
- Second approach: encode a digital watermark in packet
    - Again, use "opaque" fields on packet
- When target receives enough attack packets, router path can be determined

# ICMP Traceback

- Out-of-band notification of target
- Routers probabilistically send ICMP message to destination of sampled packet
- Include the packet header of sampled packet
- In a DDoS, target will eventually receive ICMPs from all routers in the path of the DDoS

# Polling-based Traceback

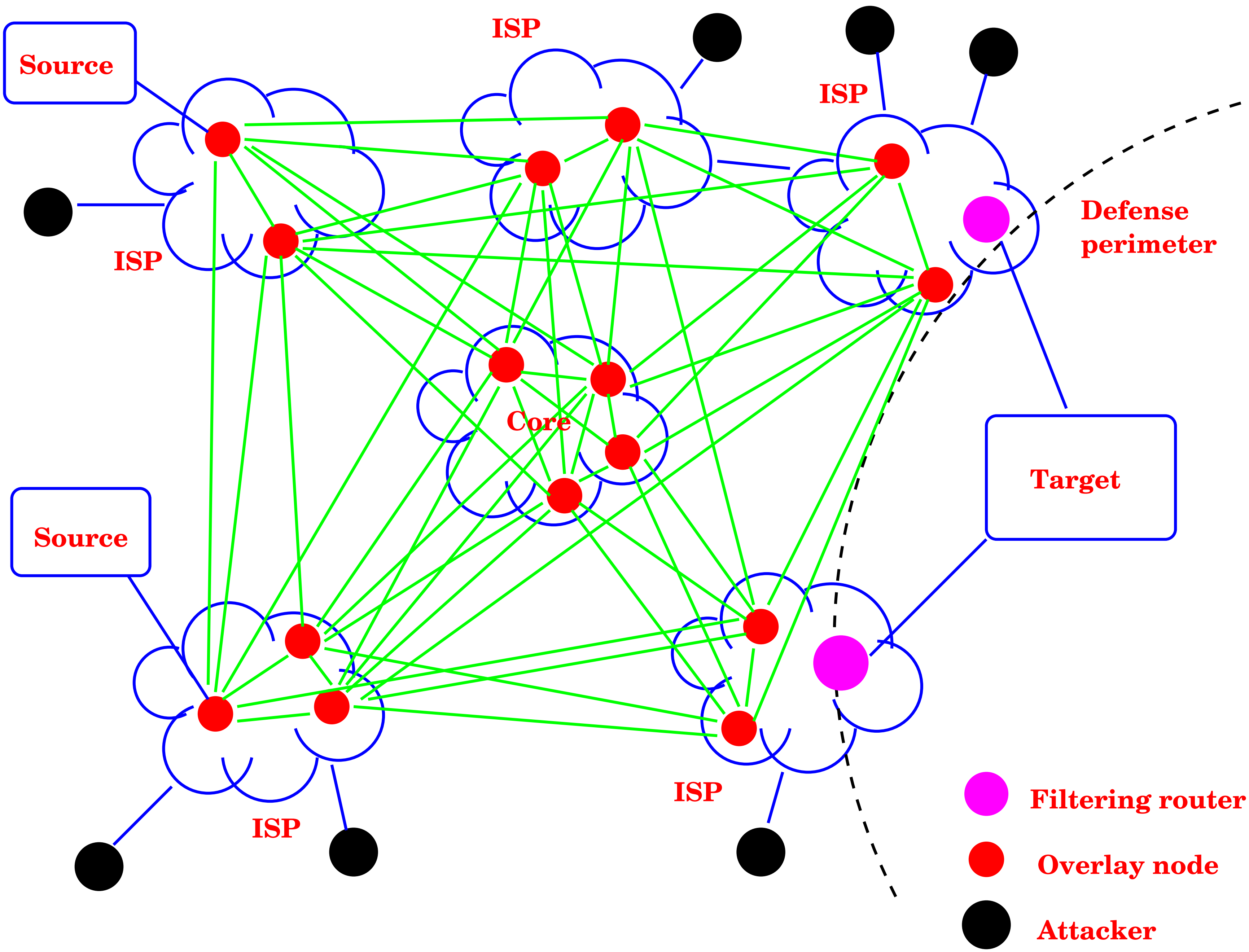
- Source Path Isolation Engine (SPIE)
  - Routers "remember" whether packet was recently seen
  - Targets query upstream routers to determine who has seen attack packet
  - Apply recursively
- Use Bloom filters to probabilistically remember if packet was seen
- Considerable hardware support required

# Secure Overlay Services (SOS)

- Proactive mechanism using overlay services and distributed firewalls
  - Build filtering perimeter around target
  - Permit traffic only from authorized nodes (Secret Servlets)
    - Packet filtering faster than crypto
    - Identity of SS variable over time
  - Authorized users authenticate to any node
  - Traffic then relayed to Secret Servlet node

- Assumptions
  - Attackers cannot saturate Internet core
  - Attackers cannot eavesdrop in arbitrary links

# SOS


Source
ISP
ISP
ISP
Defense perimeter
Core
Source
Target
ISP
ISP
Filtering router
Overlay node
Attacker

# Current Problems

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# Remote Software Exploits

- Protocols and algorithms may be perfect
  - Implementations is another story!
- Majority of vulnerabilities are result of bad code
  - Buffer overflows
  - Race conditions
  - Insufficient/wrong argument validation
- Backdoors, malicious code, viruses

# Applicability

- Applications
  - Usually privileged ones
- Extensible (operating) systems
- Mobile agents

# Buffer Overflows

- Overwrite return pointer in caller’s stack frame
  - Arguments on the stack
  - Missing bounds checking
- BSS and heap overflows
  - Virtual functions, object methods

# Race Conditions

- Time Of Check To Time Of Use (TOCTTOU) bugs
- Example of updating /etc/passwd
    - Pick "random" filename
    - Check that it does not exist in /tmp
        - If it does, loop
    - If not, open file
    - Copy contents of /etc/passwd
    - Add new entry
    - Copy temp file to /etc/passwd
- Other example: changing symbolic link pointer between check and use

# Bad Argument Validation

- Example: sendmail debug flag
  - Given as number in command line
  - Used as index in table to set appropriate debug flag
  - But: no bounds checking
  - And: sendmail running "setuid"
- Result: able to add code (and execute it)
- Example: sprintf format string
- Solutions ?

# Better APIs

- Engineering solution
  - strcpy/strcat -> strncpy/strncat
  - sprintf -> snprintf
  - tmpnam -> mkstemp
  - ...
- Not always possible (thanks to standards)
  - Sometimes, new API confusing
    - strlcpy/strlcat

# Safe Languages

- Use a language where "bad thoughts" are impossible
- Examples: Java, ML/Caml, Erlang, etc.
  - Type safety
  - Memory management
- VM may still be unsafe (Java bytecode, JIT, ...)

# Proof-Carrying Code

- Input: piece of code, safety policy
- Output: safety proof
- Proof generation is computationally expensive
  - Verification simpler and less expensive
- Compiler need not be trusted
  - Only the verifier

# Proof-Carrying Code (2)

- Burden is on the code producer
  - Prove once, use everywhere (with same policy)
- Reliance only on the verifier (which is small)
- Tamperproof programs: modifying a program will
  - Invalidate the proof
  - Make the proof non-applicable to the program
  - Proof and program still valid -> good
- Simple programs (packet filters) / policies
  - Promising

# Software Fault Isolation (SFI)

- Software encapsulation of code
- Partition code into data and code segments
    - Prevent self-modifying code
- Code is inserted before each load, store, and jump instruction
    - Verify that the target address is safe
- Done at compiler, link, or run time
    - Increases program size, slow down
- "Tricky" for CISC architectures

# Code Signing

- Code producer (or trusted compiler) digitally signs code
- User checks signature, verifies code comes from "trusted" identity
- Generally insufficient
  - Implies "binary" trust model
  - Malevolent/subverted "trusted" party can cause damage
  - Lack of a PKI -> non-scalable approach
- Reasonable as first line of defense

# Unix chroot()

- In Unix, (almost) everything is part of the filesystem
- Limit what code/process can do by restricting their view of the filesystem
- Typically, daemon processes run in their own mini-filesystem
- Possible to escape, or cause damage even from inside a chroot'ed environment
- FreeBSD jail()
    - Different virtual machine based on IP address

# Capabilities

- Use fine-grained access control for all resources
- Allow users to specify exactly what resources processes have access to
    - Increased administrative complexity
    - Must modify existing applications

# System Call Monitoring

- Sandbox untrusted applications by monitoring system calls
  - Enforce particular policy
- Policy may be uploaded to kernel
- Similar to virus checker
- Have to hand-tune policy for individual applications
  - Fine for widely-used daemons, tricky for downloaded code (e.g., plug-ins)
- Java security manager approach fundamentally similar

# OpenBSD systrace

- System call interposition
- User-level daemon listening to socket to the kernel
  - Receives information about monitored process
  - Evaluates request based on policy
  - Responds to kernel
- Allows manual intervention through GUI
- Policy discovery
- Performance, complexity

# Emulators

- Create virtual machine, run individual programs (or instances of the operating system) in it
  - Increased reliability
- Can take advantage of hardware capabilities for improved performance
- No explicit policy to be determined
  - Similar to chroot/jail
- Good for daemons/services, less so for really practical use
  - Applications tend to become "little OSes" themselves
  - Integrated application suites

# Compiler Tricks

- StackGuard: inject runtime checks for buffer overflows
- A lot of other related work
  - StackGhost, ProPolice, FormatGuard, etc.
- Not fool-proof
  - Heap-based overflows, SQL-injection
- Performance penalty (sometimes significant)

# Code Randomization Techniques

- Apply Kerckhoff's principle on programs
  - Key-driven randomization of certain aspects of binary
  - Reveal key to OS
  - Attacker must mount exhaustive-search attack

- Randomize location/size of stack/activation records
- Randomize location of linked libraries
- Randomize instruction set!

# Current Problems

- Network denial of service (DoS)
- Remote software exploits
- Worms

# Worms

- Self-propagating malicious code
- Infection vector and payload
  - So far limited use of malicious payload
- Common vectors
  - Remotely-exploitable software faults
    - Buffer overflows
  - Too-smart e-mail agents/web browsers
  - Unsuspecting/naive humans
    - "Click to see photo of Pamela Anderson..."
- Propagation speeds exceed human reaction
  - "Slammer" (SQL) worm infected all targets in 8 minutes
  - Faster worms possible
    - "Warhol" worms, hit-list scanning, ...

# Protection Mechanisms

- Sandboxing
  - Only limits damage to remainder of system
- Connection throttling
- Content filtering
  - Slow, error-prone, breaks in presence of encryption
- Anti-worms
  - Dangerous, not dependable
- Artificial diversity
  - See code randomization
- Automated software patching
- Open problem

# Sources

- Proceedings of security conferences
  - IEEE Security & Privacy
    - http://www.ieee-security.org/TC/SP-Index.html
  - USENIX Security
    - http://www.usenix.org
  - ISOC NDSS
    - http://www.isoc.org/isoc/conferences/ndss
  - ACM CCS
    - http://www.acm.org/sigs/sigsac/ccs.html