Chapter 26: Network Security

- Introduction to the Drib
- Policy Development
- Network Organization
- Availability
- Anticipating Attacks

Introduction

- Goal: apply concepts, principles, mechanisms discussed earlier to a particular situation
  - Focus here is on securing network
  - Begin with description of company
  - Proceed to define policy
  - Show how policy drives organization

The Drib

- Builds and sells dribbles
- Developing network infrastructure allowing it to connect to Internet to provide mail, web presence for consumers, suppliers, other partners

Specific Problems

- Internet presence required
  - E-commerce, suppliers, partners
  - Drib developers need access
  - External users cannot access development sites
- Hostile takeover by competitor in progress
  - Lawyers, corporate officers need access to development data
  - Developers cannot have access to some corporate data

Goals of Security Policy

- Data related to company plans to be kept secret
  - Corporate data such as what new products are being developed is known on a need-to-know basis only
- When customer supplies data to buy a dribble, only folks who fill the order can access that information
  - Company analysts may obtain statistics for planning
- Lawyers, company officials must approve release of any sensitive data

Policy Development

- Policy: minimize threat of data being leaked to unauthorized entities
- Environment: 3 internal organizations
  - Customer Service Group (CSG)
    - Maintains customer data
    - Interface between clients, other internal organizations
  - Development Group (DG)
    - Develops, modifies, maintains products
    - Relies on CSG for customer feedback
  - Corporate Group (CG)
    - Handles patents, lawsuits, etc.

Nature of Information Flow

- Public
  - Specs of current products, marketing literature
- CG, DG share info for planning purposes
  - Problems, patent applications, budgets, etc.
- Private
  - CSG: customer info like credit card numbers
  - CG: corporate info protected by attorney privilege
  - DG: plans, prototypes for new products to determine if production is feasible before proposing them to CG

Data Classes

- Public data (PD): available to all
- Development data for existing products (DDEP): available to CG, DG only
- Development data for future products (DDFP): available to DG only
- Corporate data (CpD): available to CG only
- Customer data (CuD): available to CSG only

Data Class Changes

- DDFP → DDEP: as products implemented
- DDEP → PD: when deemed advantageous to publicize some development details
  - For marketing purposes, for example
- CpD → PD: as privileged info becomes public through mergers, lawsiut filings, etc.
- Note: no provision for revealing CuD directly
  - This protects privacy of Drib's customers

User Classes

- Outsiders (O): members of public
  - Access to public data
  - Can also order, download drivers, send email to company
- Developers (D): access to DDEP, DDFP
  - Cannot alter development data for existing products
- Corporate executives (C): access to CD
  - Can read DDEP, DDFP, CuD but not alter them
  - Sometimes can make sensitive data public
- Employees (E): access to CuD only

Access Control Matrix for Policy

	O	**D**	**C**	**E**
PD	*r*	*r*	*r*	*r*
DDEP		*r*	*r*	
DDFP		*r*, *w*	*r*	
CpD			*r*, *w*	
CuD	*w*		*r*	*r*, *w*

r is read right, *w* is write right

Type of Policy

- Mandatory policy
  - Members of O, D, C, E cannot change permissions to allow members of another user class to access data
- Discretionary component
  - Within each class, individuals may have control over access to files they own
  - View this as an issue internal to each group and not of concern at corporate policy level
    - At corporate level, discretionary component is “allow always”

Reclassification of Data

- Who must agree for each?
  - C, D must agree for DDFP → DDEP
  - C, E must agree for DDEP → PD
  - C can do CpD → PD
    - But *two* members of C must agree to this
- Separation of privilege met
  - At least two different people must agree to the reclassification
  - When appropriate, the two must come from different user classes

Availability

- Drib world-wide multinational corp
  - Does business on all continents
- Imperative anyone be able to contact Drib at any time
  - Drib places very high emphasis on customer service
  - Requirement: Drib’s systems be available 99% of the time
    - 1% allowed for planned maintenance, unexpected downtime

Consistency Check: Goal 1

- Goal 1: keep sensitive info confidential
  - Developers
    - Need to read DDEP, DDFP, and to alter DDFP
    - No need to access CpD, CuD as don’t deal with customers or decide which products to market
  - Corporate executives
    - Need to read, alter CpD, and read DDEP
- This matches access permissions

Consistency Check: Goal 2

- Goal 2: only employees who handle purchases can access customer data, and only they and customer can alter it
  - – Outsiders
    - Need to alter CuD, do not need to read it
  - – Customer support
    - Need to read, alter CuD
  - – This matches access permissions

Consistency Check: Goal 3

- Goal 3: releasing sensitive info requires corporate approval
  - Corporate executives
    - Must approve any reclassification
    - No-one can write to PD, *except* through reclassification
- This matches reclassification constraints

Consistency Check: Transitive Closure

	O	**D**	**C**	**E**
PD	*r*	*r*	*r*	*r*
DDEP		*r*	*r*	
DDFP		*r*, *w*	*r*	
CpD		*w*	*r*, *w*	*w*
CuD	*w*		*r*	*r*, *w*

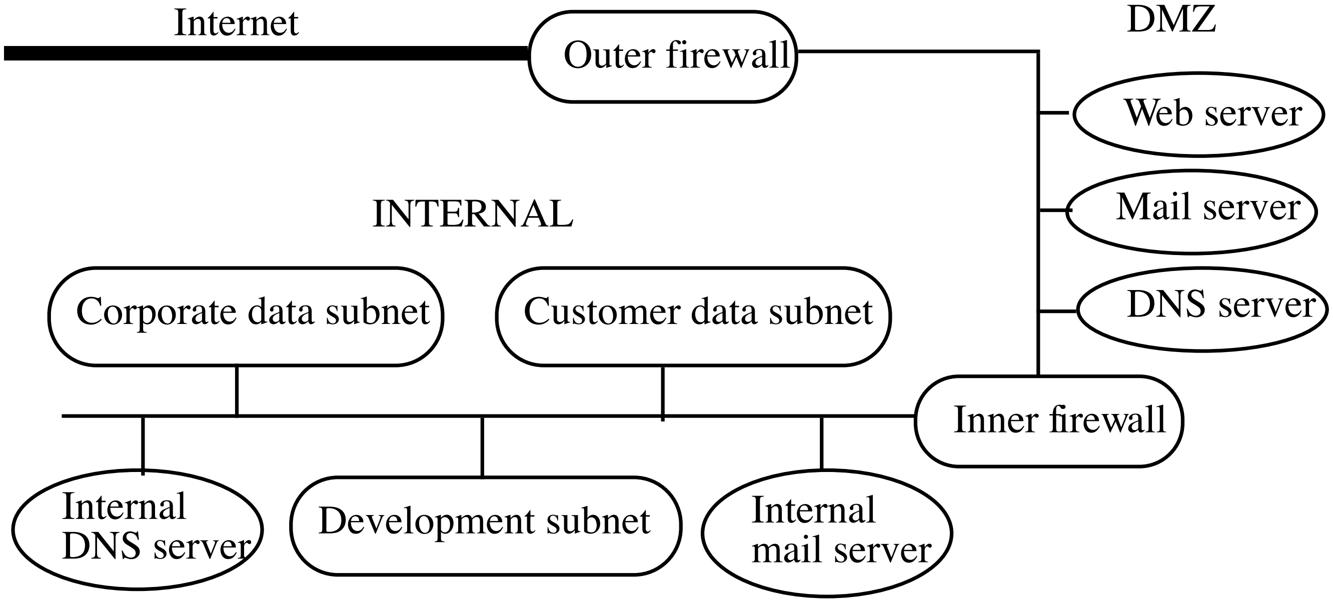
r is read right, *w* is write right

Interpretation

- From transitive closure:
  - *Only* way for data to flow into PD is by reclassification
  - Key point of trust: members of C
  - By rules for moving data out of DDEP, DDFP, someone other than member of C must also approve
    - Satisfies separation of privilege
- Conclusion: policy is consistent

Network Organization

- Partition network into several subnets
  - Guards between them prevent leaks



DMZ

- Portion of network separating purely internal network from external network
  - Allows control of accesses to some trusted systems inside the corporate perimeter
  - If DMZ systems breached, internal systems still safe
  - Can perform different types of checks at boundary of internal,DMZ networks and DMZ,Internet network

Firewalls

- Host that mediates access to a network
  - Allows, disallows accesses based on configuration and type of access
- Example: block Back Orifice
  - BO allows external users to control systems
    - Requires commands to be sent to a particular port (say, 25345)
  - Firewall can block all traffic to or from that port
    - So even if BO installed, outsiders can't use it

Filtering Firewalls

- *A*ccess control based on attributes of packets and packet headers
  - Such as destination address, port numbers, options, etc.
  - Also called a *packet filtering firewall*
  - Does not control access based on content
  - Examples: routers, other infrastructure systems

Proxy

- Intermediate agent or server acting on behalf of endpoint without allowing a direct connection between the two endpoints
  - So each endpoint talks to proxy, thinking it is talking to other endpoint
  - Proxy decides whether to forward messages, and whether to alter them

Proxy Firewall

- Access control done with proxies
  - Usually bases access control on content as well as source, destination addresses, etc.
  - Also called an *applications level* or *application level firewall*
  - Example: virus checking in electronic mail
    - Incoming mail goes to proxy firewall
    - Proxy firewall receives mail, scans it
    - If no virus, mail forwarded to destination
    - If virus, mail rejected or disinfected before forwarding

Views of a Firewall

- Access control mechanism
  - Determines which traffic goes into, out of network
- Audit mechanism
  - Analyzes packets that enter
  - Takes action based upon the analysis
    - Leads to traffic shaping, intrusion response, etc.

Analysis of Drib Network

- Security policy: “public” entities on outside but may need to access corporate resources
  - Those resources provided in DMZ
- No internal system communicates directly with systems on Internet
  - Restricts flow of data to “public”
  - For data to flow out, must pass through DMZ
    - Firewalls, DMZ are “pump”

Implementation

- Conceal all internal addresses
  - Make them all on 10., 172., or 192.168. subnets
    - Inner firewall uses NAT to map addresses to firewall's address
  - Give each host a non-private IP address
    - Inner firewall never allows those addresses to leave internal network
- Easy as all services are proxied by outer firewall
  - Email is a bit tricky …

Email

- Problem: DMZ mail server must know address in order to send mail to internal destination
  - Could simply be distinguished address that causes inner firewall to forward mail to internal mail server
- Internal mail server needs to know DMZ mail server address
  - Same comment

DMZ Web Server

- In DMZ so external customers can access it without going onto internal network
  - If data needs to be sent to internal network (such as for an order), transmission is made separately and not as part of transaction

Application of Principles

- Least privilege
  - Containment of internal addresses
- Complete mediation
  - Inner firewall mediates every access to DMZ
- Separation of privilege
  - Going to Internet must pass through inner, outer firewalls and DMZ servers

Application of Principles

- Least common mechanism
  - Inner, outer firewalls distinct; DMZ servers separate from inner servers
  - DMZ DNS *violates* this principle
    - If it fails, multiple systems affected
    - Inner, outer firewall addresses fixed, so they do not depend on DMZ DNS

Outer Firewall Configuration

- Goals: restrict public access to corporate network; restrict corporate access to Internet
- Required: public needs to send, receive email; access web services
  - So outer firewall allows SMTP, HTTP, HTTPS
  - Outer firewall uses its address for those of mail, web servers

Details

- Proxy firewall
- SMTP: mail assembled on firewall
  - Scanned for malicious logic; dropped if found
  - Otherwise forwarded to DMZ mail server
- HTTP, HTTPS: messages checked
  - Checked for suspicious components like very long lines; dropped if found
  - Otherwise, forwarded to DMZ web server
- Note: web, mail servers *different systems*
  - Neither same as firewall

Attack Analysis

- Three points of entry for attackers:
  - Web server ports: proxy checks for invalid, illegal HTTP, HTTPS requests, rejects them
  - Mail server port: proxy checks email for invalid, illegal SMTP requests, rejects them
  - Bypass low-level firewall checks by exploiting vulnerabilities in software, hardware
    - Firewall designed to be as simple as possible
    - Defense in depth

Defense in Depth

- Form of separation of privilege
- To attack system in DMZ by bypassing firewall checks, attacker must know internal addresses
  - Then can try to piggyback unauthorized messages onto authorized packets
- But the rewriting of DMZ addresses prevents this

Inner Firewall Configuration

- Goals: restrict access to corporate internal network
- Rule: block *all* traffic except for that *specifically* authorized to enter
  - Principle of fail-safe defaults
- Example: Drib uses NFS on some internal systems
  - Outer firewall disallows NFS packets crossing
  - Inner firewall disallows NFS packets crossing, too
    - DMZ does not need access to this information (least privilege)
    - If inner firewall fails, outer one will stop leaks, and vice versa (separation of privilege)

More Configuration

- Internal folks require email
  - SMTP proxy required
- Administrators for DMZ need login access
  - So, allow SSH through *provided:*
    - Destination is a DMZ server
    - Originates at specific internal host (administrative host)
  - Violates least privilege, but ameliorated by above
- DMZ DNS needs to know address of administrative host
  - More on this later

DMZ

- Look at servers separately:
  - Web server: handles web requests with Internet
    - May have to send information to internal network
  - Email server: handles email with Internet
    - Must forward email to internal mail server
  - DNS
    - Used to provide addresses for systems DMZ servers talk to
  - Log server
    - DMZ systems log info here

DMZ Mail Server

- Performs address, content checking on *all* email
- Goal is to hide internal information from outside, but be transparent to inside
- Receives email from Internet, forwards it to internal network
- Receives email from internal network, forwards it to Internet

Mail from Internet

- Reassemble messages into header, letter, attachments as files
- Scan header, letter, attachments looking for "bad" content
  - "Bad" = known malicious logic
  - If none, scan original letter (including attachments and header) for violation of SMTP spec
- Scan recipient address lines
  - Address rewritten to direct mail to internal mail server
  - Forward letter there

Mail to Internet

- Like mail from Internet with 2 changes:
  - Step 2: also scan for sensitive data (like proprietary markings or content, etc.)
  - Step 3: changed to rewrite all header lines containing host names, email addresses, and IP addresses of internal network
    - All are replaced by “drib.org” or IP address of external firewall

Administrative Support

- Runs SSH server
  - Configured to accept connections *only* from trusted administrative host in internal network
  - All public keys for that host fixed; no negotiation to obtain those keys allowed
  - Allows administrators to configure, maintain DMZ mail host remotely while minimizing exposure of host to compromise

DMZ Web Server

- Accepts, services requests from Internet
- Never contacts servers, information sources in internal network
- CGI scripts checked for potential attacks
  - Hardened to prevent attacks from succeeding
  - Server itself contains no confidential data
- Server is www.drib.org and uses IP address of outer firewall when it must supply one

Updating DMZ Web Server

- Clone of web server kept on internal network
  - Called “WWW-clone”
- All updates done to WWW-clone
  - Periodically admins copy contents of WWW-clone to DMZ web server
- DMZ web server runs SSH server
  - Used to do updates as well as maintenance, configuration
  - Secured like that of DMZ mail server

Internet Ordering

- Orders for Drib merchandise from Internet
  - Customer enters data, which is saved to file
  - After user confirms order, web server checks format, content of file and then uses public key of system on internal customer subnet to encipher it
    - This file is placed in a spool area not accessible to web server program
  - Original file deleted
  - Periodically, internal trusted administrative host uploads these files, and forwards them to internal customer subnet system

Analysis

- If attacker breaks into web server, cannot get order information
  - There is a slight window where the information of customers still on system can be obtained
- Attacker can get enciphered files, public key used to encipher them
  - Use of public key cryptography means it is computationally infeasible for attacker to determine private key from public key

DMZ DNS Server

- Supplies DNS information for some hosts to DMZ:
  - DMZ mail, web, log hosts
  - Internal trusted administrative host
    - Not fixed for various reasons; could be …
  - Inner firewall
  - Outer firewall
- Note: Internal server addresses not present
  - Inner firewall can get them, so DMZ hosts do not need them

DMZ Log Server

- DMZ systems all log information
  - Useful in case of problems, attempted compromise
- Problem: attacker will delete or alter them if successful
  - So log them off-line to this server
- Log server saves logs to file, also to write-once media
  - Latter just in case log server compromised
- Runs SSH server
  - Constrained in same way server on DMZ mail server is

Summary

- Each server knows only what is needed to do its task
  - Compromise will restrict flow of information but not reveal info on internal network
- Operating systems and software:
  - All unnecessary features, servers disabled
  - Better: create custom systems
- Proxies prevent direct connection to systems
  - For all services except SSH from internal network to DMZ, which is itself constrained by source, destination

Internal Network

- Goal: guard against unauthorized access to information
  - “read” means fetching file, “write” means depositing file
- For now, ignore email, updating of DMZ web server, internal trusted administrative host
- Internal network organized into 3 subnets, each corresponding to Drib group
  - Firewalls control access to subnets

Internal Mail Server

- Can communicate with hosts on subnets
- Subnet may have mail server
  - Internal DNS need only know subnet mail server's address
- Subnet may allow mail to go directly to destination host
  - Internal DNS needs to know addresses of all destination hosts
- Either satisfies policy

WWW-close

- Provides staging area for web updates
- All internal firewalls allow access to this
  - WWW-clone controls who can put and get what files and where they can be put
- Synchronized with web pages on server
  - Done via internal trusted administrative host
- Used as testbed for changes in pages
  - Allows corporate review before anything goes public
  - If DMZ web server trashed or compromised, all web pages can be restored quickly

Trusted Administrative Host

- Access tightly controlled
  - Only system administrators authorized to administer DMZ systems have access
- All connections to DMZ through inner firewall must use this host
  - Exceptions: internal mail server, possibly DNS
- All connections use SSH
  - DMZ SSH servers accept connections from this host only

Analysis

- DMZ servers never communicate with internal servers
  - All communications done via inner firewall
- Only client to DMZ that can come from internal network is SSH client from trusted administrative host
  - Authenticity established by public key authentication
- Only data non-administrative folks can alter are web pages
  - Even there, they do not access DMZ

Analysis

- Only data from DMZ is customer orders and email
  - Customer orders already checked for potential errors, enciphered, and transferred in such a way that it cannot be executed
  - Email thoroughly checked before it is sent to internal mail server

Assumptions

- Software, hardware does what it is supposed to
  - If software compromised, or hardware does not work right, defensive mechanisms fail
  - Reason separation of privilege is *critical*
    - If component A fails, other components provide additional defenses
- Assurance is vital!

Availability

- Access over Internet must be unimpeded
  - Context: flooding attacks, in which attackers try to overwhelm system resources
- Example: SYN flood
  - Problem: server cannot distinguish legitimate handshake from one that is part of this attack
    - Only difference is whether third part of TCP handshake is sent
  - Flood can overwhelm communication medium
    - Can’t do anything about this (except buy a bigger pipe)
  - Flood can overwhelm resources on our system
    - We start here

Intermediate Hosts

- Use routers to divert, eliminate illegitimate traffic
  - Goal: only legitimate traffic reaches firewall
  - Example: Cisco routers try to establish connection with source (TCP intercept mode)
    - On success, router does same with intended destination, merges the two
    - On failure, short time-out protects router resources and target never sees flood

Intermediate Hosts

- Use network monitor to track status of handshake
  - Example: synkill monitors traffic on network
    - Classifies IP addresses as not flooding (good), flooding (bad), unknown (new)
    - Checks IP address of SYN
      - If good, packet ignored
      - If bad, send RST to destination; ends handshake, releasing resources
      - If new, look for ACK or RST from same source; if seen, change to good; if not seen, change to bad
    - Periodically discard stale good addresses

Intermediate Hosts

- Problem: don’t solve problem!
  - They move the locus of the problem to the intermediate system
  - In Drib’s case, Drib does not control these systems
- So, consider endpoints

Endpoint Hosts

- Control how TCP state is stored
  - When SYN received, entry in queue of pending connections created
    - Remains until an ACK received or time-out
    - In first case, entry moved to different queue
    - In second case, entry made available for next SYN
  - In SYN flood, queue is always full
    - So, assure legitimate connections space in queue to some level of probability
    - Two approaches: SYN cookies or adaptive time-outs

SYN Cookies

- Source keeps state
- Example: Linux 2.4.9 kernel
  - Embed state in sequence number
  - When SYN received, compute sequence number to be function of source, destination, counter, and random data
    - Use as reply SYN sequence number
    - When reply ACK arrives, validate it
  - Must be hard to guess

Adaptive Time-Out

- Change time-out time as space available for pending connections decreases
- Example: modified SunOS kernel
  - Time-out period shortened from 75 to 15 sec
  - Formula for queueing pending connections changed:
    - Process allows up to *b* pending connections on port
    - *a* number of completed connections but awaiting process
    - *p* total number of pending connections
    - *c* tunable parameter
    - Whenever $a + p > cb$, drop current SYN message

Anticipating Attacks

- Drib realizes compromise may come through unanticipated means
  - Plans in place to handle this
- Extensive logging
  - DMZ log server does intrusion detection on logs

Against Outer Firewall

- Unsuccessful attacks
  - Logged, then ignored
  - Security folks use these to justify budget, train new personnel
- Successful attack against SMTP proxy
  - Proxy will start non-standard programs
  - Anomaly detection component of IDS on log server will report unusual behavior
    - Security officers monitor this around the clock

In the DMZ

- Very interested in attacks, successful or not
- Means someone who has obtained access to DMZ launched attack
  - Some trusted administrator shouldn’t be trusted
  - Some server on outer firewall is compromised
  - Software on DMZ system not restrictive enough
- IDS system on DMZ log server looks for misuse (known attacks) to detect this

Ignoring Failed Attacks

- Sounds dangerous
  - Successful attacker probably tried and failed earlier
- Drib: “So what?”
  - Not sufficient personnel to handle all alerts
  - Focus is on what Drib cares most about
    - Successful attacks, or failed attacks where there should be none

Checking the IDS

- IDS allows Drib to add attack signatures and tune parameters to control reporting of events
  - Experimented to find good settings
  - Verify this every month by doing manual checks for two 1-hour periods (chosen at random) and comparing with reported events

Key Points

- Begin with policy
- Craft network architecture and security measures from it
- Assume failure will occur
  - Try to minimize it
  - Defend in depth
  - Have plan to handle failures