CS 419: Computer Security

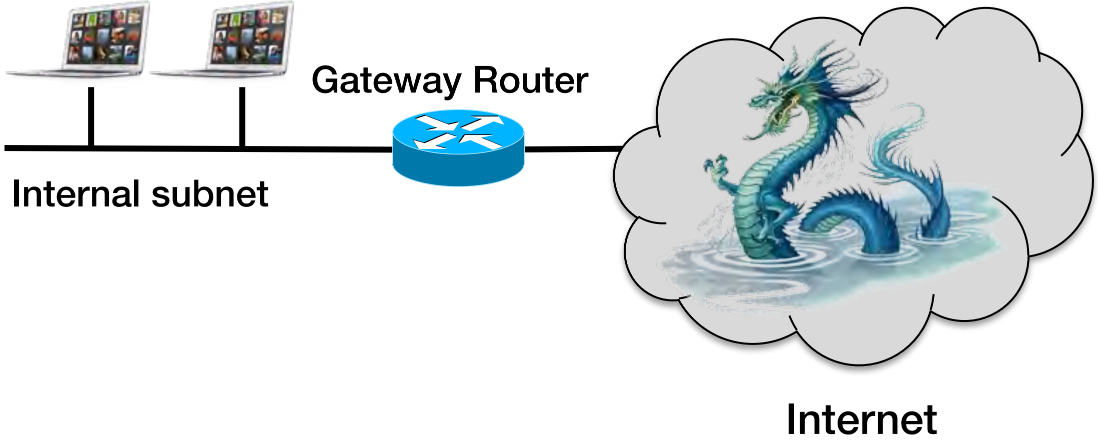
Week 12: Network Security

Firewalls

Paul Krzyzanowski

Network Security Goals

- **Confidentiality**: sensitive data & systems not accessible
- **Integrity**: data not modified during transmission
- **Availability**: systems should remain accessible



Firewall

- **Separate your local network from the Internet**
  - Protect the border between trusted internal networks and the untrusted Internet

- **Approaches**
  - Network Address Translation (NAT)
  - Packet filters
  - Application proxies
  - Intrusion detection / intrusion protection systems
  - Zero Trust Architecture

Network Address Translation (NAT)

NAT: Network Address Translation

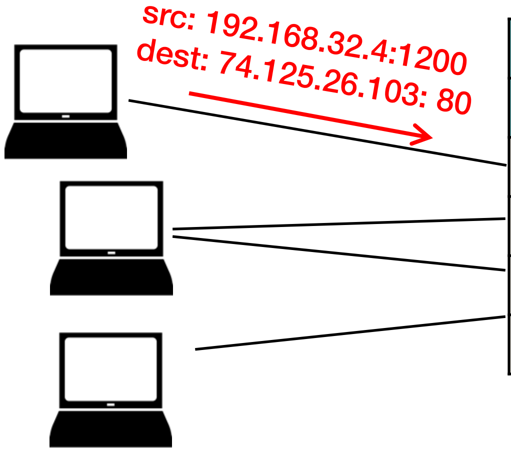
**NAT converts between
private (internal) IP addresses and
one or more public-facing (external) addresses**

Running out of IP addresses

- **Every device on the Internet needs an IP address**
  - Every address must be unique
    … otherwise, how do you address a host?
- **IP addresses are not plentiful (with IPv4)**
  - Does an organization with 10,000 IP hosts really need 10,000 globally-unique addresses?
  - Prior to 1993, the answer was "YES!"

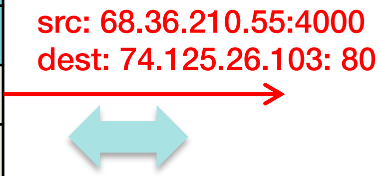
IP Address Translation

- **Private IP address space in the organization**
  - One external IP address, multiple internal addresses
- **NAT – Translation Table**
  - Map source address:port in outgoing IP requests to a unique external address:port
  - Inverse mapping for incoming requests
- **A NAT-enabled router looks like a single device with one IP address**



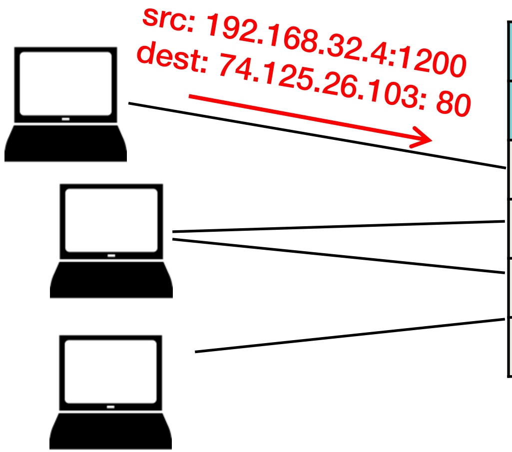
Internal		External	
Host	**Port**	**Host**	**Port**
192.168.32.4	1200	68.36.210.55	4000
192.168.32.6	1200	68.36.210.55	4001
192.168.32.6	1102	68.36.210.55	4002
192.168.32.11	9000	68.36.210.55	4003

Translation Table in a NAT-Enabled Router



IP Address Translation

- **NAT requires a router to look at the transport layer**
  - Source port (outgoing) & destination port (incoming) may change
  - TCP/UDP checksum must be recomputed



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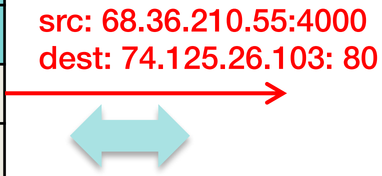


Translation Table in a NAT-Enabled Router

Private Addresses

- **We cannot use IP addresses of valid external hosts locally**

  … how will we distinguish local vs. external hosts?

- **RFC 1918: Address Allocation for Private Internets**
  - Defines unregistered, non-routable addresses for internal networks

Address Range	# addresses	IP address block
10.0.0.0 – 10.255.255.255	16,777,216	10.0.0.0/8
172.16.0.0 – 172.31.255.255	1,048,576	172.16.0.0/12
192.168.0.0 – 192.168.255.255	65,536	192.168.0.0/16

Advantages of NAT

- **Internal address space can be much larger than the addresses allocated by the ISP**

- **No need to change internal addresses if ISP changes your address**

- **Enhanced security**
  - A computer on an external network cannot contact an internal computer

    … unless the internal computer initiated the communication

    Even then – it can only contact the computer on that specific port

First-Generation Firewalls:
Packet Filters

Screening router

Border router (gateway router)

- Router between the internal network(s) and external network(s)
- Any traffic between internal & external networks passes through the border router

Instead of just routing the packet, decide whether to route it

Screening router = Packet filter

Allow or deny packets based on

- Incoming & outgoing interfaces
- Source & destination IP addresses
- Protocol (e.g., TCP, UDP, ICMP, IGMP, RSVP, etc.)
- Source & destination TCP/UDP ports, ICMP command

Filter chaining

An IP packet entering a router is matched against a set of rules: access control list (ACL) or chain

Each rule contains criteria and an action

- **Criteria**: packet screening rule
- **Actions**
  - ***Accept*** – and stop processing additional rules
  - ***Drop*** – discard the packet and stop processing additional rules
  - ***Reject*** – and send an error to the sender (ICMP Destination Unreachable)

  Also
  - ***Route*** – reroute packets
  - ***Nat*** – perform network address translation
  - ***Log*** – record the activity

Screening Router (Packet Filter) – Filter Chain

protocol	src addr	src port	dest addr	dest port	Incoming Interface	Outgoing Interface

IP packet

? src addr = 128.6.*
Incoming interface = external
→ **Reject**:
Packet masquerading as from our network

? protocol = tcp
dest addr = 128.6.46.88
dest port = 80, 443
→ **Accept**:
TCP packet to our web service

? protocol = tcp
dest addr = 128.6.13.*
dest port = 22
→ **Accept**:
ssh connections to 128.6.13.* subnet

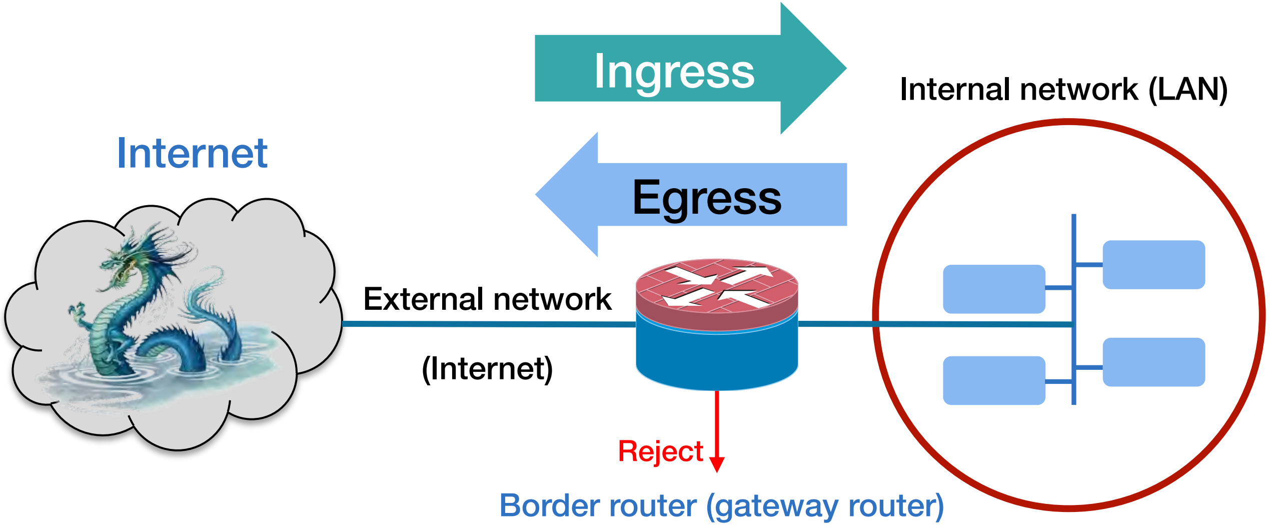
? Anything (*)
→ **Reject**:
We don't support any other service

Filter structure is vendor specific

- **Windows: *Allow*, *Block***
  - Options such as
    - *Discard* all traffic except packets allowed by filters (*default deny*)
    - *Pass* through all traffic except packets prohibited by filters (*default allow*)
- **OpenBSD**: ***Pass* (allow), *Block***
- **Linux nftables (netfilter)**
  - Chain types: ***filter***, ***route***, ***nat***
  - Chain control
    - ***Return*** – stop traversing a chain
    - ***Jump*** – jump to another chain (***goto*** = same but no return)

Vocabulary: Ingress & Egress

- **Ingress = Entry**
  - The flow of packets from an external network to an internal network
- **Egress = Exit**
  - The flow of packets from an internal network to an external network



Network Ingress Filtering: incoming packets

Basic firewalling principle

No direct inbound connections external systems (Internet) to any internal host – all traffic must flow through a firewall and be inspected

1. **Determine which services you want to expose to the Internet**

2. **Allow only those inbound ports and protocols to the machines hosting the services**
   – E.g., Web server: 10.0.0.10 TCP port 80, TCP port 443
   Mail server: 10.0.0.12 TCP port 587

Default Deny model – by default, *deny all*

– Anything not specifically permitted is dropped

– May want to log denies to identify who is attempting access

Network Ingress Filtering (inbound)

- **Disallow IP source address spoofing**
  - Restrict forged traffic (RFC 2827)
- **Disallow incoming/outgoing traffic from private, non-routable IP addresses**
  - Helps with DDoS attacks such as SYN flooding from lots of invalid addresses
- **At the ISP**
  - Filter upstream traffic - prohibit an attacker from sending traffic from forged IP addresses
  - Attacker must use a valid, reachable source address

```
                            address          mask            port
access-list 199 deny ip  192.168.0.0 0.0.255.255  any log
access-list 199 deny ip  224.0.0.0 0.0.0.255  any log
                    ....
access-list 199 permit ip any any
```

Network Egress Filtering (outbound)

- **We don't usually worry about outbound traffic**
  - *Communication from a higher security network (internal) to a lower security network (Internet) is usually fine*

- **Why might we want to restrict it?**
  - Consider: if a computer is compromised & all outbound traffic is allowed, it can connect to an external server and download more malicious code
    ... or launch a DoS attack on the internal network
  - Also, log which servers are trying to access external addresses

Second-Generation Firewalls: Stateful Packet Inspection (SPI)

Stateful Inspection – 2nd generation firewalls

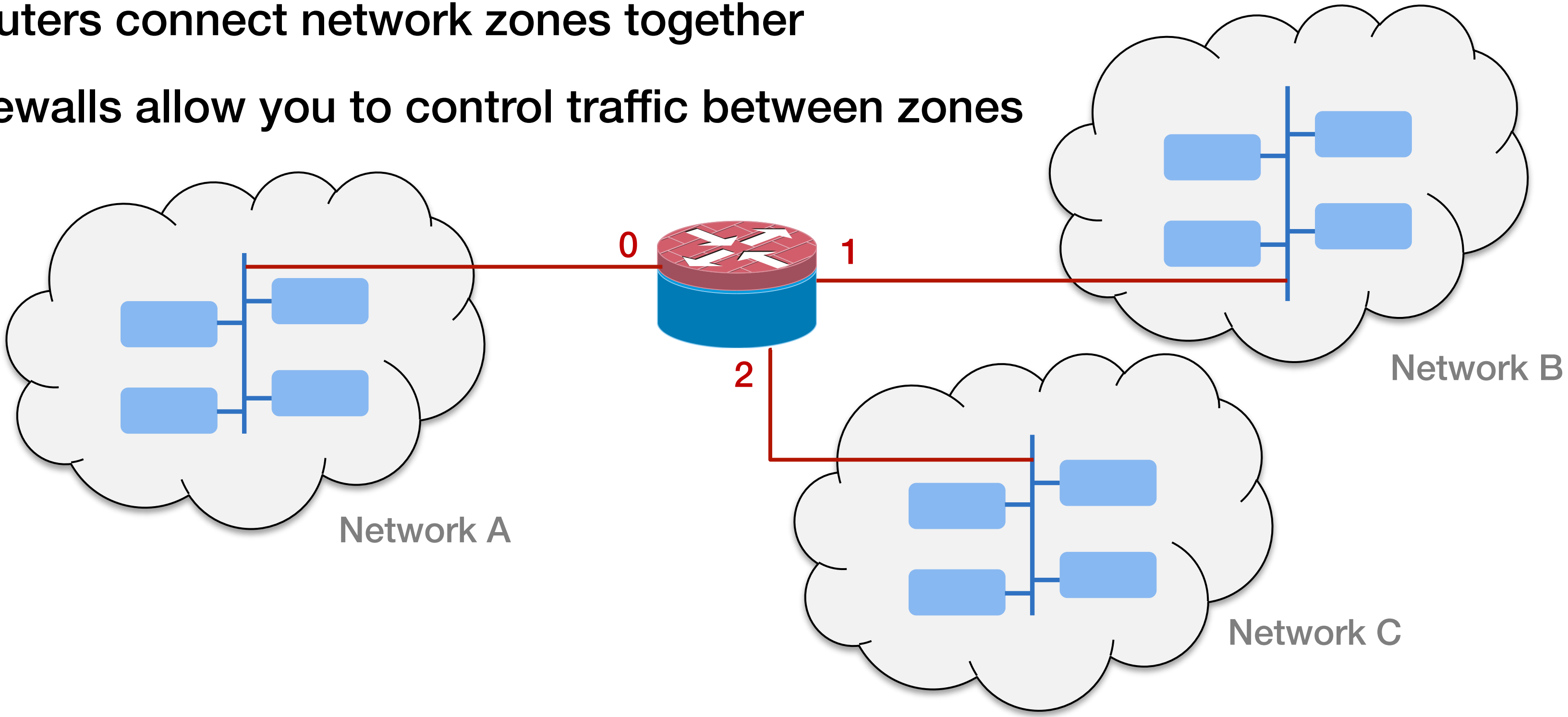
Retain state information about a stream of related packets

Examples

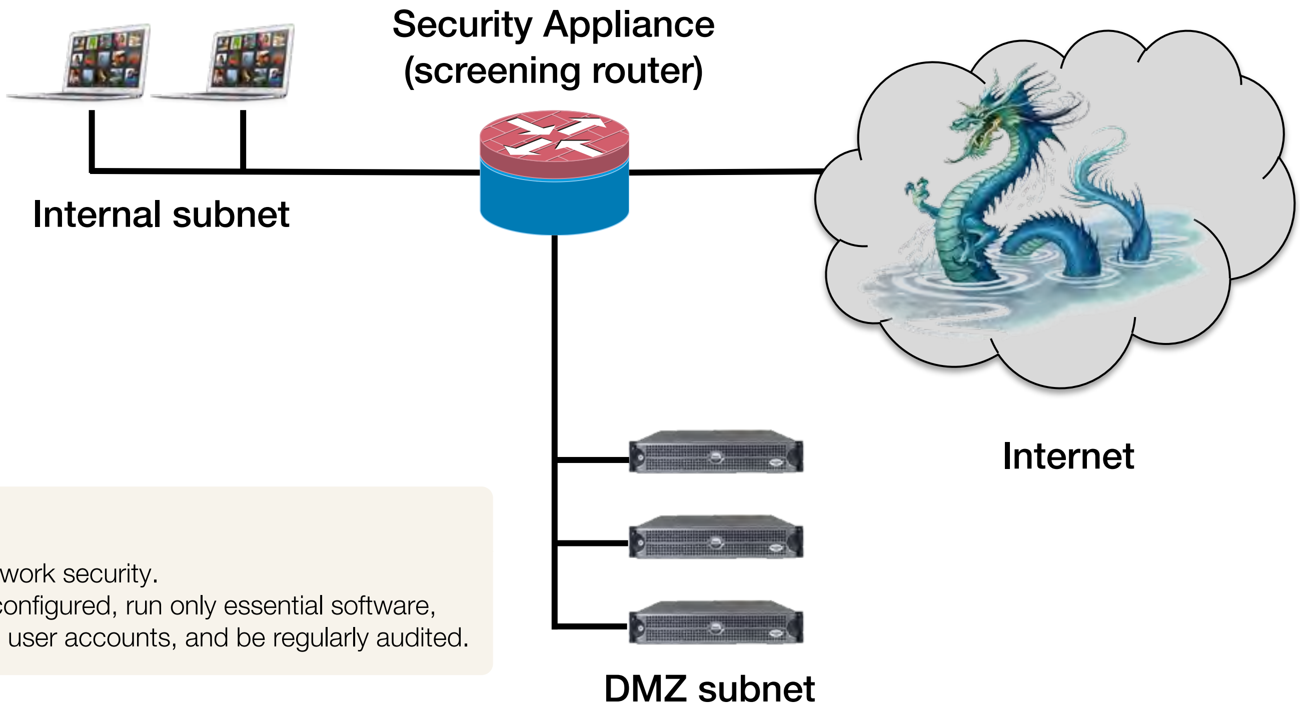
- **TCP connection tracking**
  - Disallow TCP data packets unless a connection is set up
  - Allow return traffic
- **ICMP echo-reply**
  - Allow ICMP echo-reply only if a corresponding echo request was sent.
- **Related traffic**
  - Identify & allow traffic that is related to a request or connection
  - Example: related ports in FTP
    - Client connects to server on port 21 to send commands
    - Server connects back to client on port 20 to send data

Security Zones

- Packet-filtering firewalls (almost always) live in routers
- Routers connect network zones together
- Firewalls allow you to control traffic between zones



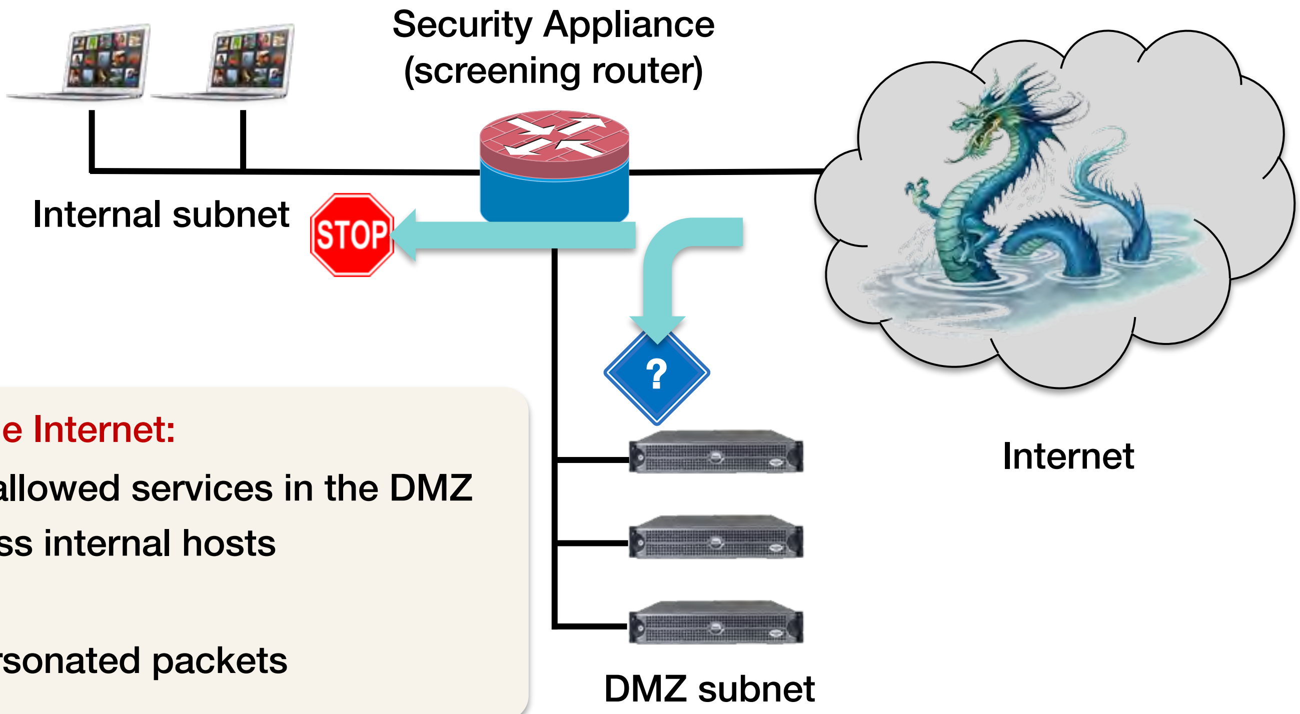
Security Zones: DMZ



Bastion hosts

Systems critical to network security.
They will be carefully configured, run only essential software, have only the required user accounts, and be regularly audited.

Security Zones: DMZ



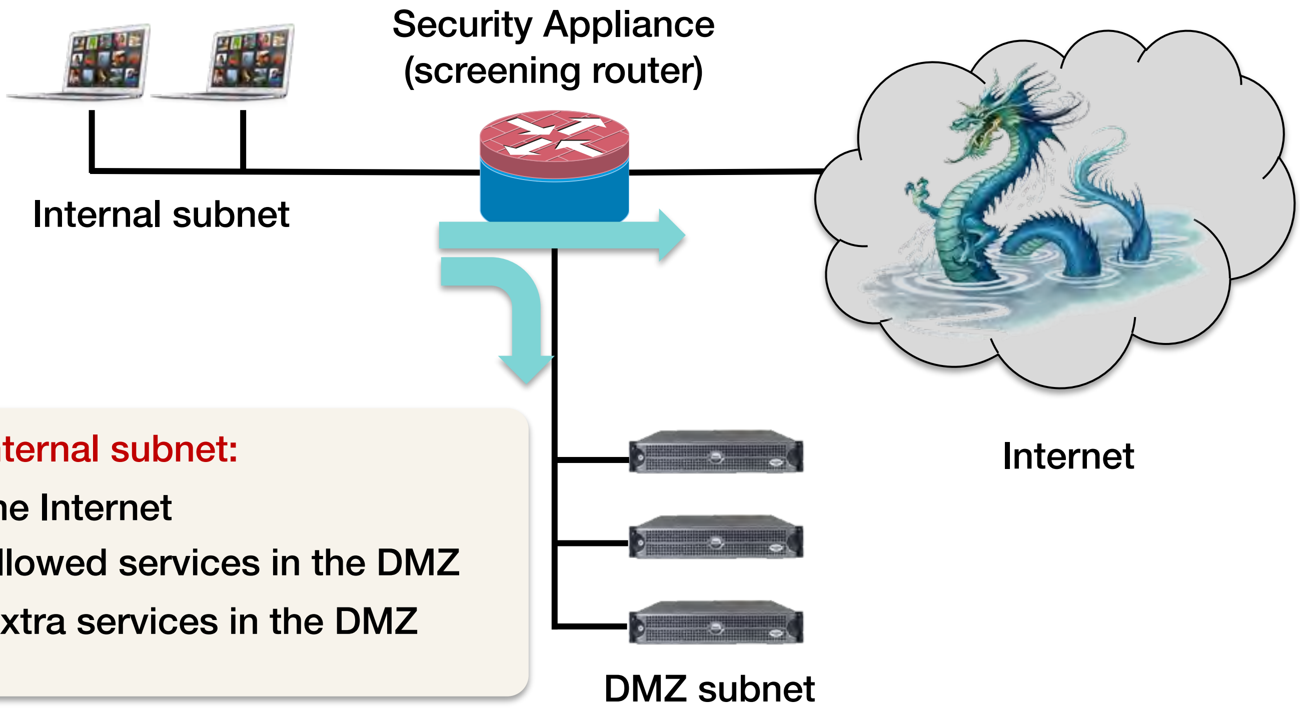
Clients from the Internet:

- Can access allowed services in the DMZ
- Cannot access internal hosts

The firewall:

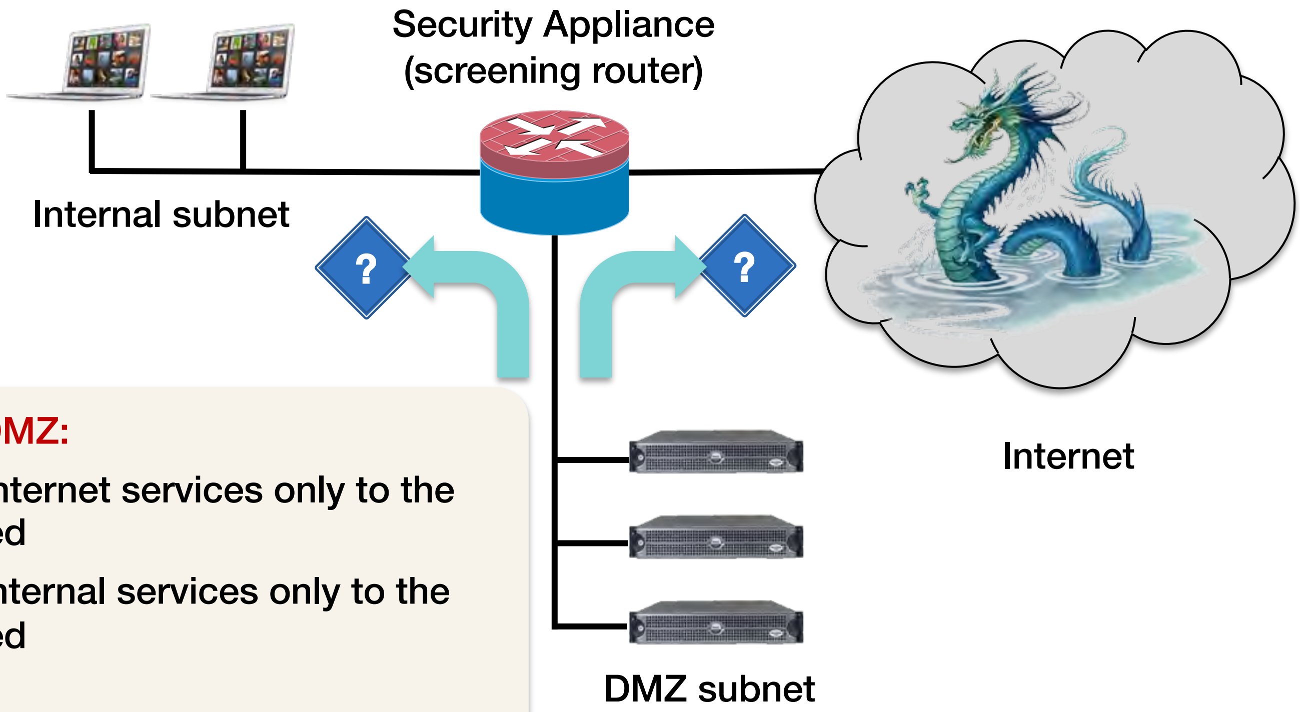
- Blocks impersonated packets

Security Zones: DMZ



Clients in the internal subnet:
- Can access the Internet
- Can access allowed services in the DMZ
- May access extra services in the DMZ

Security Zones: DMZ

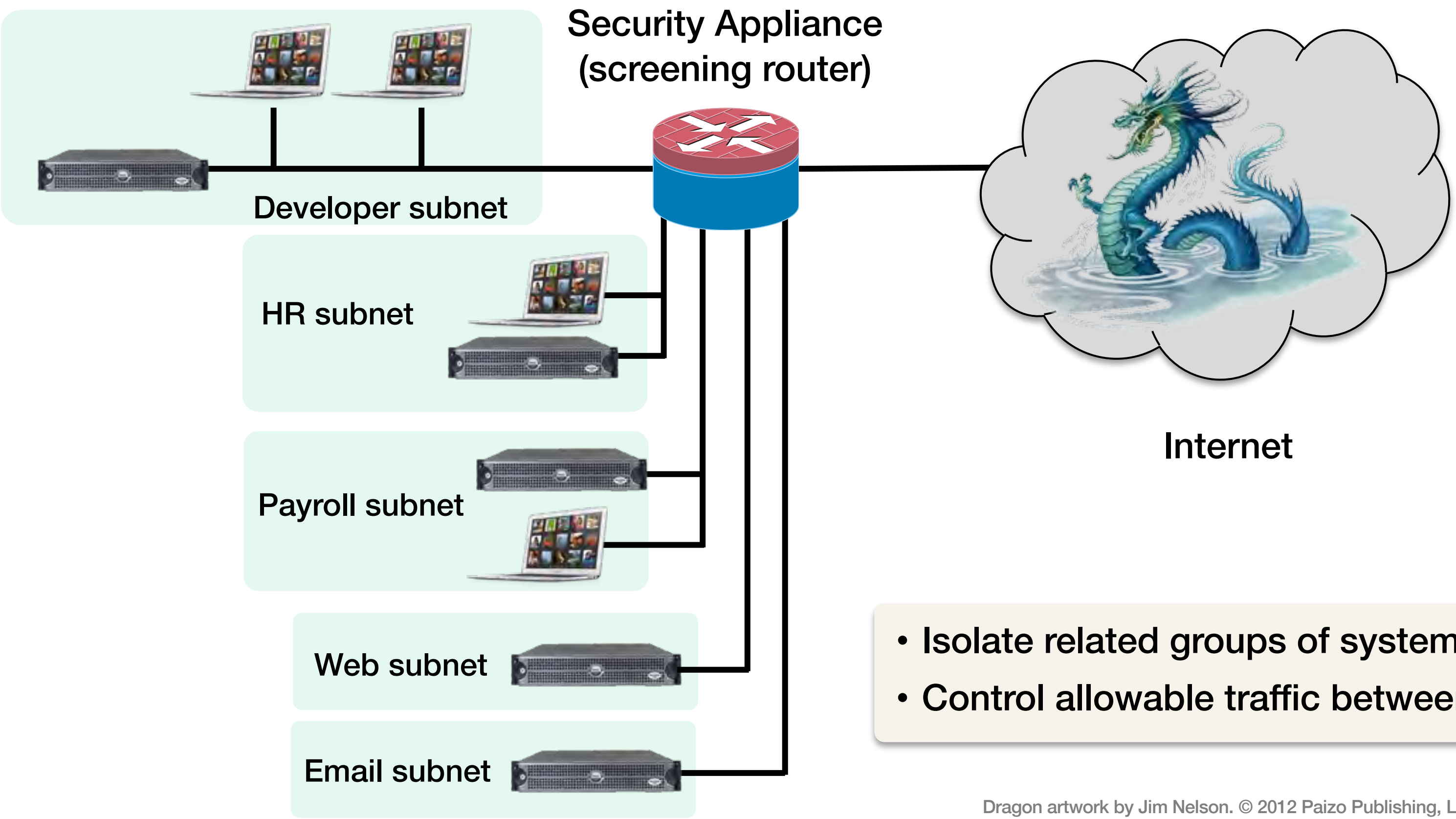


Clients in the DMZ:

- Can access Internet services only to the extent required
- Can access internal services only to the extent required

Goal:
Limit possible damage if DMZ machines are compromised

Security Zones: Segmentation



- Isolate related groups of systems
- Control allowable traffic between the zones

Third-Generation Firewalls: Deep-Packet Inspection (DPI)

Application-Layer Filtering

Firewalls don't work well when everything is a web service

Deep packet inspection (DPI)

- Look beyond layer 3 & 4 headers
- Need to know something about application protocols & formats

Examples

- **URL filtering**
  - Normal source/destination host/port filtering +
    URL pattern/keywords, rewrite/truncate rules, protocol content filters
  - Detect ActiveX and Java applets, media types; configure specific content as trusted
    - Remove others from the HTML code
- **Keyword detection**
  - Prevent classified material from leaving the organization
  - Prevent banned content from leaving or entering an organization

Design Challenges With DPI

- **DPI matches IP packet data against specified patterns**
- **This must be done at network speeds**
  - DPI hardware can only hold a limited number of packets for matching
  - DPI hardware can only store a limited amount of malware patterns

Deep Content Inspection (DCI)

Deep Packet Inspection evolves to Deep Content Inspection

- **Deep Packet Inspection systems**
  - **Examines packets, including the data in the packet**
  - Rely on pattern matching and reputation lookup

- **Deep Content Inspection systems**
  - **Examines content, even if it spans multiple packets**
  - Unpacks encoded data
    - Example: base64-encoded MIME data in web and email content
  - Signature matching, compliance analysis (including data loss prevention)
  - Behavior analysis via correlation with previous sessions

Intrusion Detection/Prevention Systems: IDS/IPS

Intrusion Detection/Prevention Systems

IDS/IPS systems are part of Application-layer firewalls

Identify threats and attacks

IDS: *Intrusion Detection System*

- Monitor traffic at various points of the network and report problems

IPS: *Intrusion Prevention System*

- Sit in between two networks & control traffic between them (like a firewall)
- Enforce admin-specified policy on detection of problems

Types of Systems

– Protocol-based

– Signature-based *We know what is bad; anything else is good*

– Anomaly-based *We know what is good; anything else is bad*

Protocol-Based IDS

Reject packets that do not follow a prescribed protocol

- **Permit return traffic as a function of incoming traffic**
- **Define traffic of interest (filter), filter on traffic-specific protocol/patterns**

Examples

– **HTTP inspection**: prevent malicious HTTP attacks:
validate headers, cookies, URL string, content types

– **DNS inspection**: prevent spoofing DNS replies:
make sure they match IDs of sent DNS requests

– **SMTP inspection**: restrict SMTP command set
… and command count, arguments, addresses

– **FTP inspection**: restrict FTP command set
… and file sizes and file names

Signature-based IDS

Don't search for protocol violations but for possible data attacks

Match patterns of known "bad" behavior

- Viruses
- Malformed URLs
- Buffer overflows

Need a database of known protocol attacks & malware

- Signature = data segments & order of packets that make up the attack
- Only detects known attacks

Anomaly-based IDS

Search for statistical deviations from normal behavior

Establish baseline behavior first

Examples:

- Port scanning
- Imbalance in protocol distribution
- Imbalance in service access

Challenge

- Distinguish anomalies from legitimate traffic

Next-Generation Firewalls (NGFW)

Term for a firewall that combines

Stateful packet inspection +
Deep packet inspection +
Intrusion prevention

- **Decrypt & re-encrypt TLS & ssh traffic**
  - Breaks end-to-end encryption; firewall is a man-in-the-middle
  - Clients will need to get & validate the firewall's certificate
- **Application awareness**
  - Classify types of apps; assign risk levels & define app-specific policies

Host-based (personal) firewalls

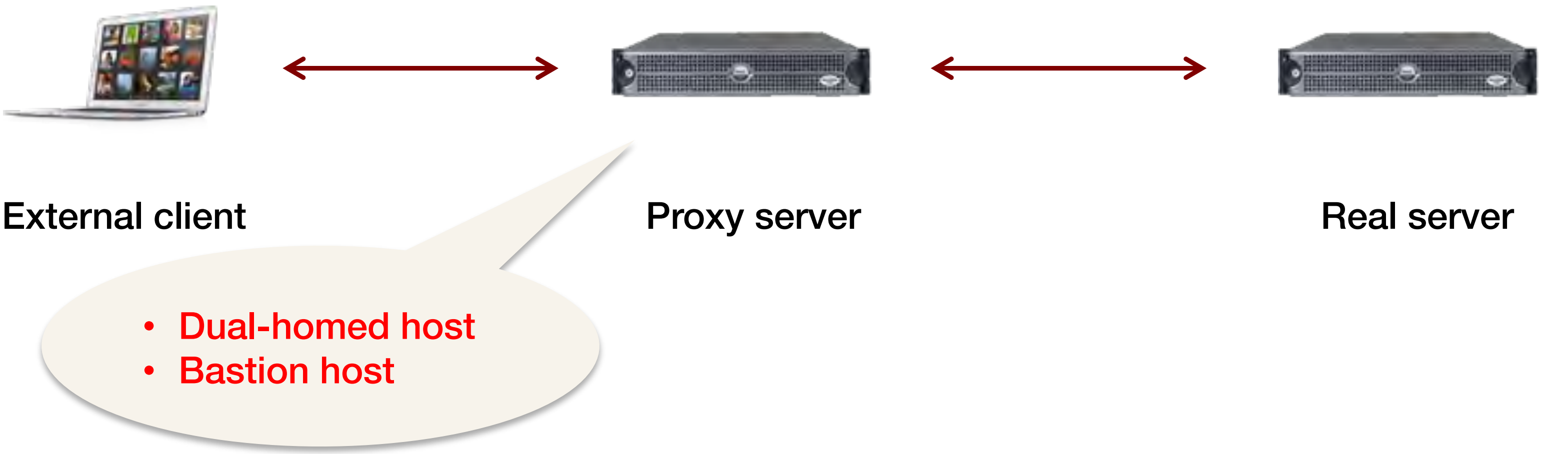
- **Run on the user's systems, not as dedicated firewalls**
- **Application awareness**
  - Manage network-facing effects of malware
    - Allow only approved applications to send or receive data over the network
- ***Important for defense in depth***
- **Problem**
  - If malware gets elevated privileges, it can reconfigure or disable the firewall
- **Personal IDS**
  - E.g., fail2ban on Linux
    - Scan log files to detect & ban suspicious IP addresses
    - High number of failed logins, probes, URLs that try to target exploits

Application proxies

Application proxies

Proxy servers

- Intermediaries between clients and servers
- Stateful inspection and protocol validation



Summary

Firewall (screening router)	1st generation packet filter that filters packets between networks. Blocks/accepts traffic based on IP addresses, ports, protocols
Stateful inspection firewall	2nd generation packet filter – like a screening router but also considers TCP connection state and information from previous connections (e.g., related ports for services)
Deep Packet Inspection firewall	3rd generation packet filter – examines application-layer protocols
Application proxy	Gateway between two networks for a specific application. Prevents direct connections to the application from outside the network. Responsible for validating the protocol.
IDS/IPS	Can usually do what a stateful inspection firewall does + examine application-layer data for protocol attacks or malicious content. Usually a part of Deep Packet Inspection firewalls
Host-based firewall	Typically screening router with per-application awareness. Sometimes includes anti-virus software for application-layer signature checking
Host-based IPS	Typically allows real-time blocking of remote hosts performing suspicious operations (port scanning, ssh logins)

Firewall Challenges

Intrusion detection & prevention problems

- **There's a lot of stuff going on**
  - People visit random websites with varying frequencies
  - Software accesses varying services
  - Buggy software may create bad packets
  - How do you detect what is hostile?
- **Traffic volume from attacks may be miniscule compared to legitimate traffic**
  - Even a small % of false positives can be annoying and hide true threats
  - Exceptions would be compromised systems launching a DDoS attack or exfiltrating data
- **Environments are dynamic**
  - Content from CDNs or other large server farms has a broad range of IP addresses
  - Malicious actors can coexist with legitimate ones

Intrusion detection & prevention problems

- **Encrypted traffic cannot be easily inspected**
  - Just because you visit a web site using HTTPS doesn't mean the site is secure … or hasn't been compromised
  - Encrypted ≠ trustworthy
- **Packet inspection provides a limited view into activity**
  - You may need to extract data from multiple packets
  - You may need to reconstruct sessions
  - Both of these are time consuming and can affect performance
- **Threats & services change over time**
  - Rules must be updated

Deperimeterization

Boundaries between internal & external systems are harder to identify and may be fluid

Systems in a trusted network cannot implicitly be assumed to be trustworthy

- Mobile devices
- Cloud-based computing
- USB flash drives
- Web applications, web services
- Internal systems may get compromised
  - Accidental downloads of malware
  - Attacks to exposed services or via outbound connections
  - Malicious insiders

Zero-Trust Architecture (ZTA)

Don't assume something is secure because it's within your network!

Don't allow access to a service until the user & service are mutually authenticated and the user is authorized to access the service

- Enforce the ***Principle of Least Privilege***
  - Enable access only when policies allow it
- No device is implicitly trusted

- **Rely on multifactor authentication, access control, and encryption**
  - Authentication to one resource doesn't mean you have access to others
  - Host-based agents or application libraries to control end-to-end security

Core principle: "Never Trust, Always Verify"

7 Tenets of Zero Trust (NIST SP 800-207)

1. All data sources and computing services are considered resources.
2. All communication is secured regardless of network location.
3. Access to individual enterprise resources is granted on a per-session basis.
4. Access to resources is determined by dynamic policy.
5. The enterprise monitors and measures the integrity and security posture of all owned and associated assets.
6. All resource authentication and authorization are dynamic and strictly enforced before access is allowed.
7. The enterprise collects as much information as possible about the current state of assets, network infrastructure, and communications and uses it to improve its security posture.

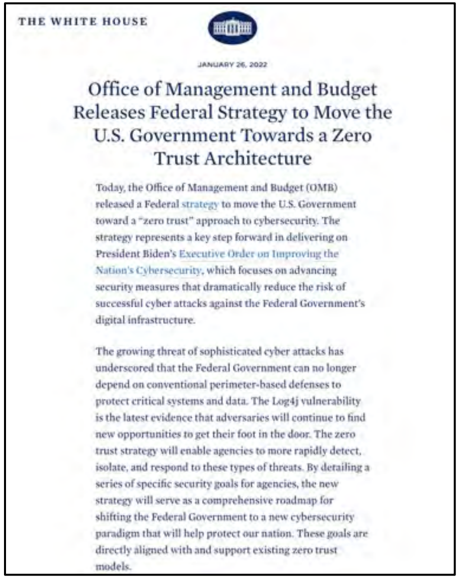
https://www.cisa.gov/sites/default/files/2023-04/zero_trust_maturity_model_v2_508.pdf

Challenges with Zero-Trust Access

- **Ideally, every connection will be authenticated, authorized, and encrypted**
  - True end-to-end connectivity requires application awareness (e.g., link with a library providing the services or have operating systems enforce end-to-end security)
  - Many services do not support centrally-managed access control – and there isn't a standard
    - Manage user authentication credentials, entitlements (permissions)
- **Fallback: Zero Trust Network Access (ZTNA)**
  - Security managed at the transport layer rather than all the way to the application
  - Fallback where zero trust is provided between hosts rather than within apps
  - E.g., create host-host VPNs with user authentication and packet filtering
- **Networks may need micro-segmentation as a safeguard**
  - Move users or groups of resources into separate network segments
  - Defense in depth strategy: limit damage even if a system gets compromised
- **Insider threat is still a problem**
  - So are stolen credentials and compromised devices

Government of Zero Trust Initiatives

US federal agencies
Deadline of Sept 30, 2024 to move from perimeter-based defenses to zero trust



THE WHITE HOUSE

JANUARY 26, 2022

Office of Management and Budget Releases Federal Strategy to Move the U.S. Government Towards a Zero Trust Architecture

Today, the Office of Management and Budget (OMB) released a Federal strategy to move the U.S. Government toward a "zero trust" approach to cybersecurity. The strategy represents a key step forward in delivering on President Biden's Executive Order on Improving the Nation's Cybersecurity, which focuses on advancing security measures that dramatically reduce the risk of successful cyber attacks against the Federal Government's digital infrastructure.

The growing threat of sophisticated cyber attacks has underscored that the Federal Government can no longer depend on conventional perimeter-based defenses to protect critical systems and data. The Log4j vulnerability is the latest evidence that adversaries will continue to find new opportunities to get their foot in the door. The zero trust strategy will enable agencies to more rapidly detect, isolate, and respond to these types of threats. By detailing a series of specific security goals for agencies, the new strategy will serve as a comprehensive roadmap for shifting the Federal Government to a new cybersecurity paradigm that will help protect our nation. These goals are directly aligned with and support existing zero trust models.

European Union
Network and Information Security Directive (NIS2)
Implementation deadline of October 2024

CIO

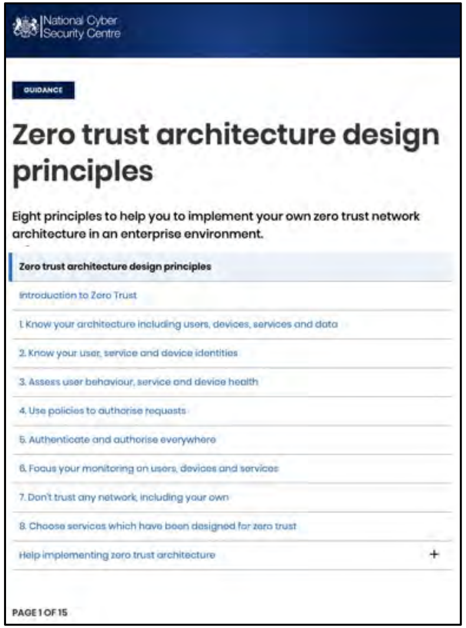
Zero Trust Security for NIS2 compliance: What you need to know

BrandPost • By Eve-Marie Lanza, Senior Security Solutions Marketing Manager, Aruba
Sep 12, 2023 • 6 mins

The NIS2 requirement to adopt a Zero Trust architecture reflects the limitations of models based on implicit trust— this security approach has exposed organizations to great risk.

CREDIT: ISTOCK

UK: No mandate but strongly promotes zero trust and provides guidelines



National Cyber Security Centre

GUIDANCE

Zero trust architecture design principles

Eight principles to help you to implement your own zero trust network architecture in an enterprise environment.

Zero trust architecture design principles
Introduction to Zero Trust
1. Know your architecture including users, devices, services and data
2. Know your user, service and device identities
3. Assess user behaviour, service and device health
4. Use policies to authorise requests
5. Authenticate and authorise everywhere
6. Focus your monitoring on users, devices and services
7. Don't trust any network, including your own
8. Choose services which have been designed for zero trust
Help implementing zero trust architecture +

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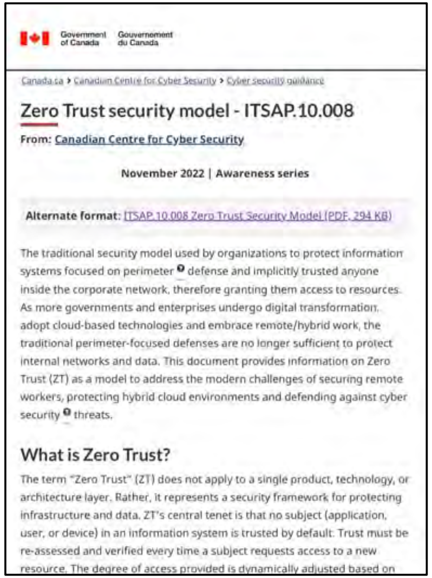
Canada: Core part of the Government's Cyber Security Strategy



Government of Canada / Gouvernement du Canada

Canada.ca > Canadian Centre for Cyber Security > Cyber security guidance

Zero Trust security model - ITSAP.10.008

From: Canadian Centre for Cyber Security

November 2022 | Awareness series

Alternate format: ITSAP.10.008 Zero Trust Security Model (PDF, 294 KB)

The traditional security model used by organizations to protect information systems focused on perimeter defense and implicitly trusted anyone inside the corporate network, therefore granting them access to resources. As more governments and enterprises undergo digital transformation, adopt cloud-based technologies and embrace remote/hybrid work, the traditional perimeter-focused defenses are no longer sufficient to protect internal networks and data. This document provides information on Zero Trust (ZT) as a model to address the modern challenges of securing remote workers, protecting hybrid cloud environments and defending against cyber security threats.

What is Zero Trust?

The term "Zero Trust" (ZT) does not apply to a single product, technology, or architecture layer. Rather, it represents a security framework for protecting infrastructure and data. ZT's central tenet is that no subject (application, user, or device) in an information system is trusted by default. Trust must be re-assessed and verified every time a subject requests access to a new resource. The degree of access provided is dynamically adjusted based on

The End