Network Security Protocols and Defensive Mechanisms

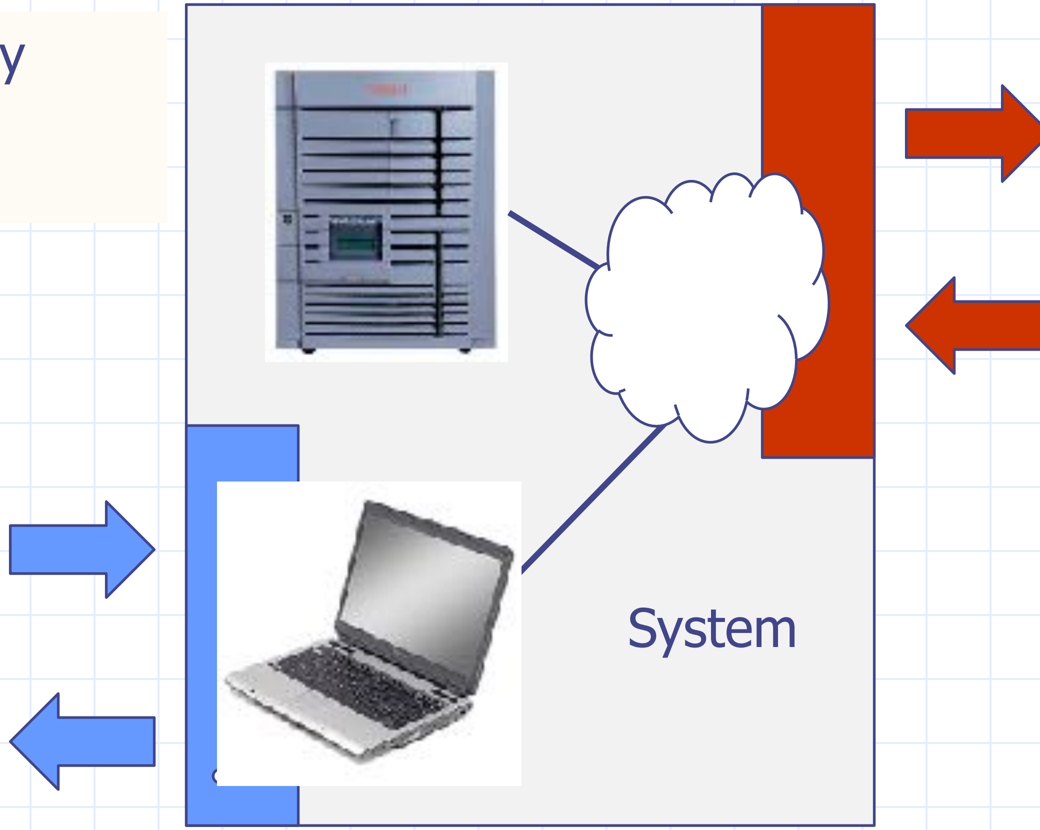
John Mitchell

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

Network security

- What is the network for?
- What properties might attackers destroy?
  - Confidentiality : no information revealed to others
  - Integrity : communication remains intact
  - Availability : messages received in reasonable time

- Confidentiality
- Integrity
- Availability



Network Attacker

Intercepts and controls network communication

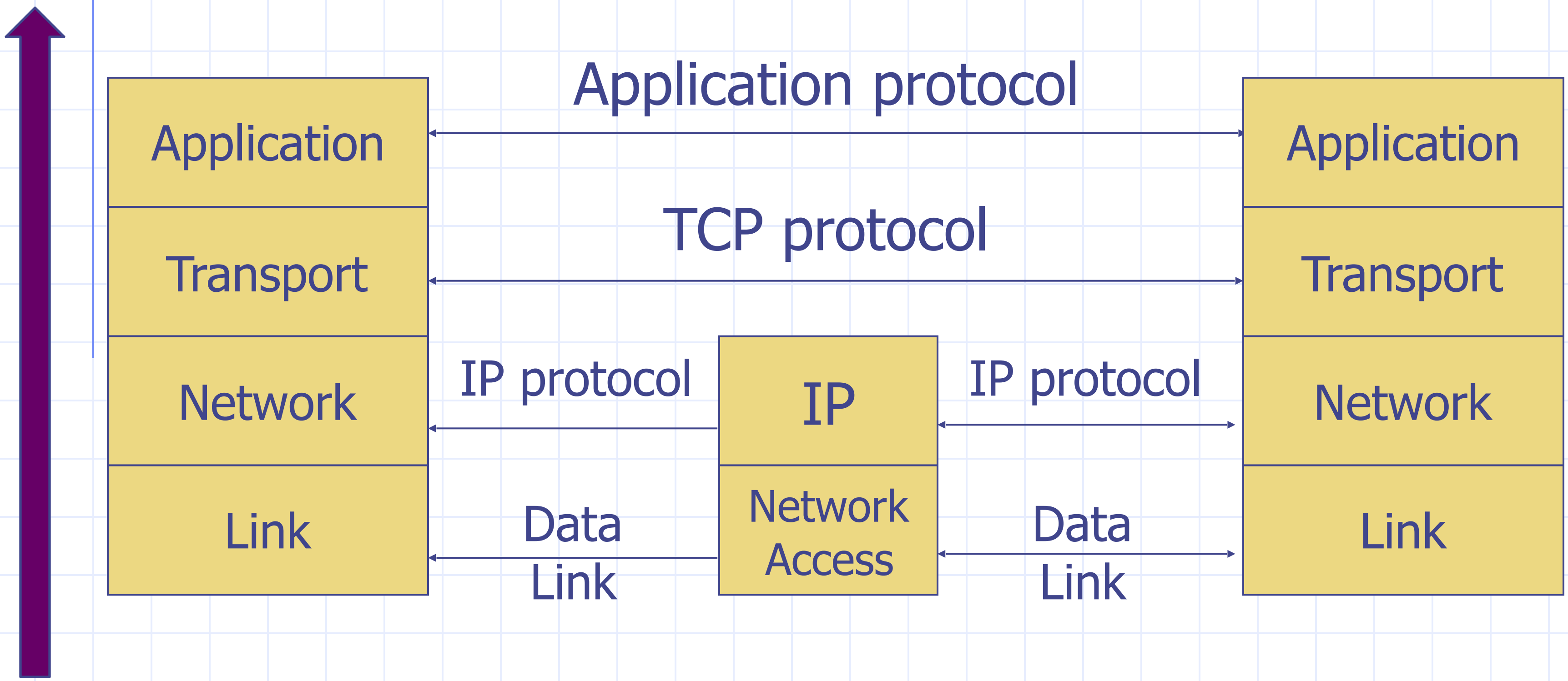
Plan for today

- Protecting network connections
  - Wireless access– 802.11i/WPA2
  - IPSEC
- Perimeter network defenses
  - Firewall
    - Packet filter (stateless, stateful), Application layer proxies
  - Intrusion detection
    - Anomaly and misuse detection
- Network infrastructure security
  - BGP instability and S-BGP
  - DNS rebinding and DNSSEC

Last lecture

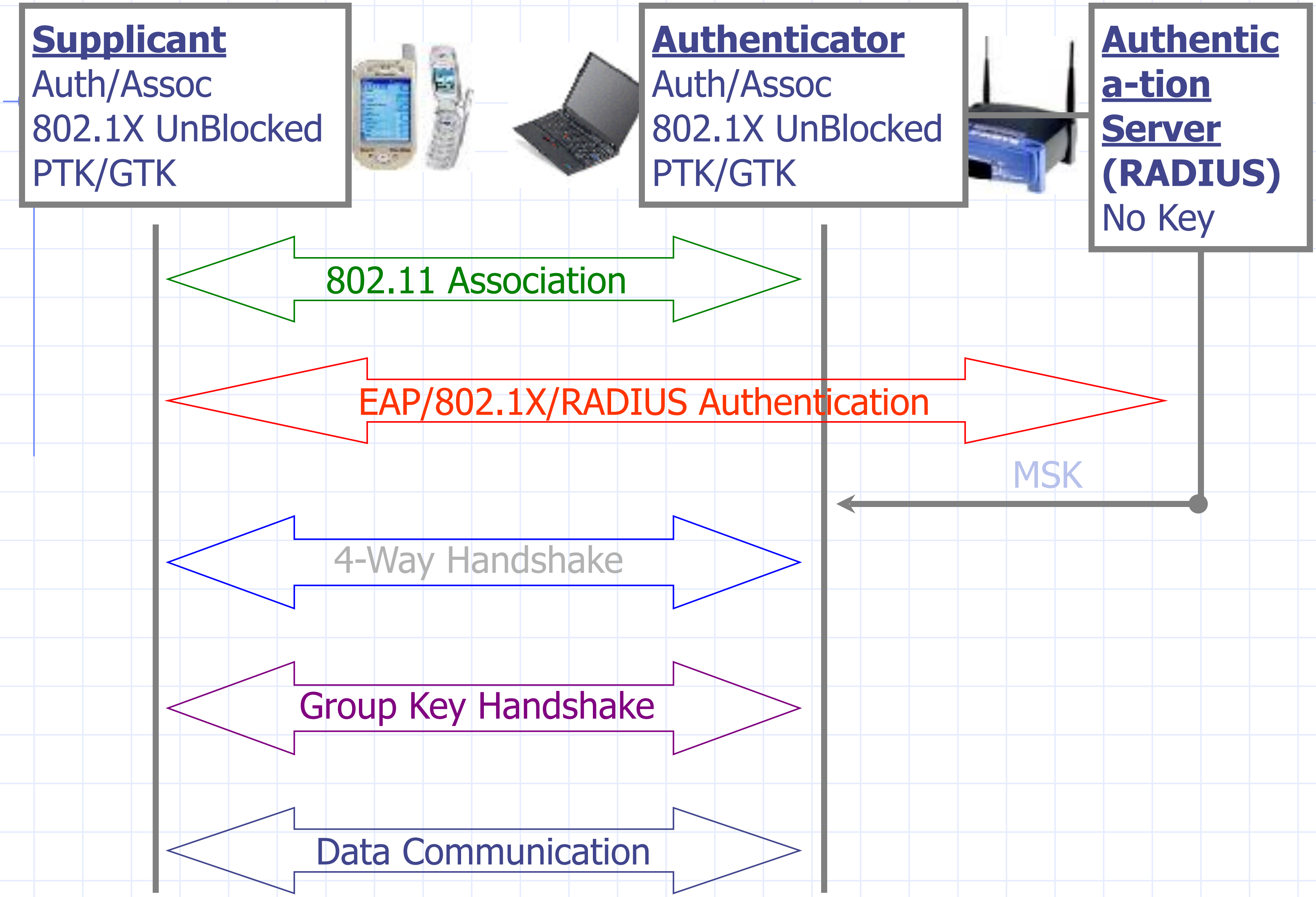
- Basic network protocols
  - IP, TCP, UDP, BGP, DNS
- Problems with them
  - TCP/IP
    - No SRC authentication: can't tell where packet is from
    - Packet sniffing
    - Connection spoofing, sequence numbers
  - BGP: advertise bad routes or close good ones
  - DNS: cache poisoning, rebinding
   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

Network Protocol Stack



Link-layer connectivity

802.11i Protocol



TCP/IP CONNECTIVITY

How can we isolate our conversation from attackers on the Internet?

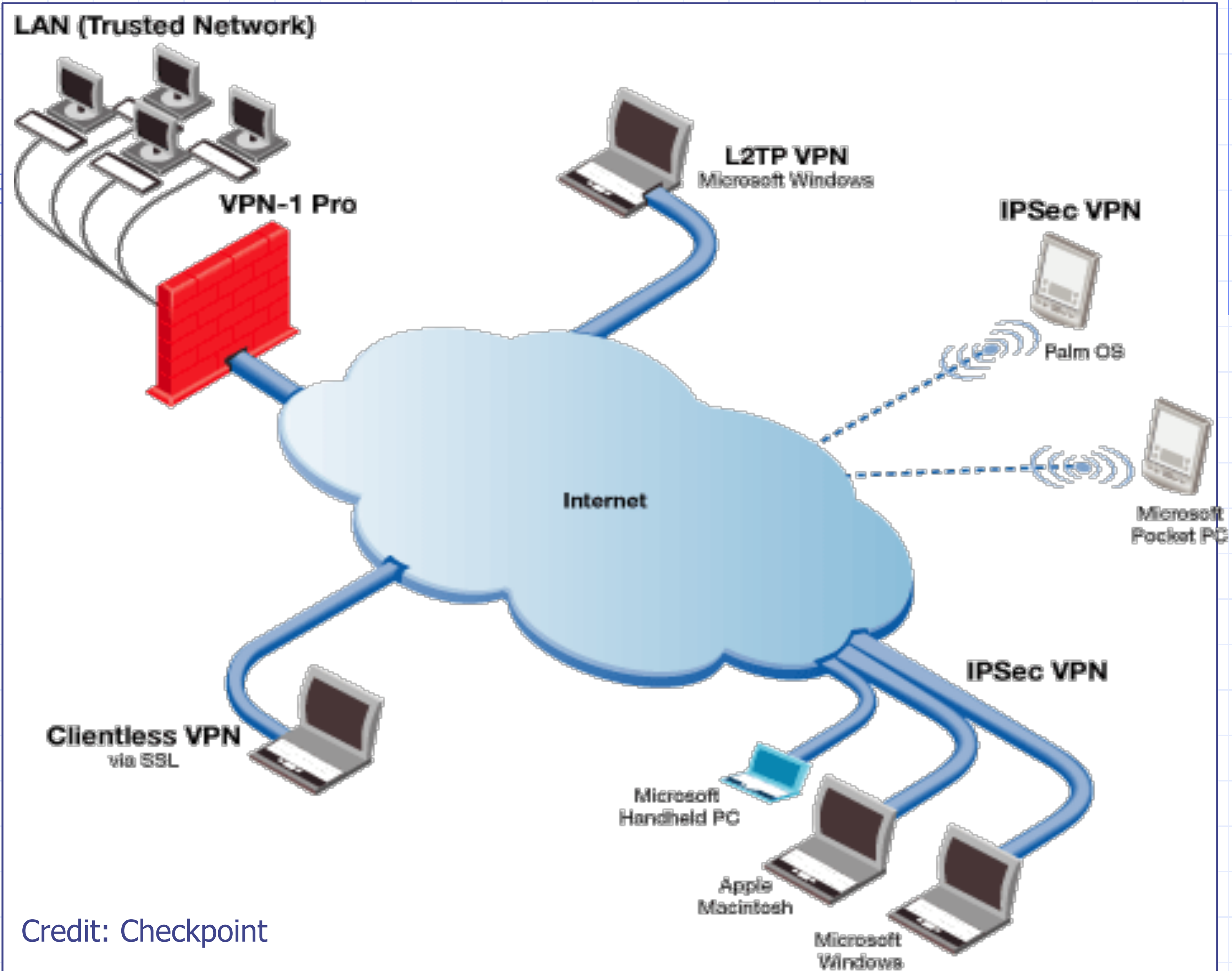
Basic Layer 2-3 Security Problems

- Network packets pass by untrusted hosts
  - Eavesdropping, packet sniffing
  - Especially easy when attacker controls a machine close to victim
- TCP state can be easy to guess
  - Enables spoofing and session hijacking

Virtual Private Network (VPN)

- Three different modes of use:
  - Remote access client connections
  - LAN-to-LAN internetworking
  - Controlled access within an intranet
- Several different protocols
  - PPTP – Point-to-point tunneling protocol
  - L2TP – Layer-2 tunneling protocol
  - IPsec (Layer-3: network layer)

(PPTP and L2TP: Data layer)

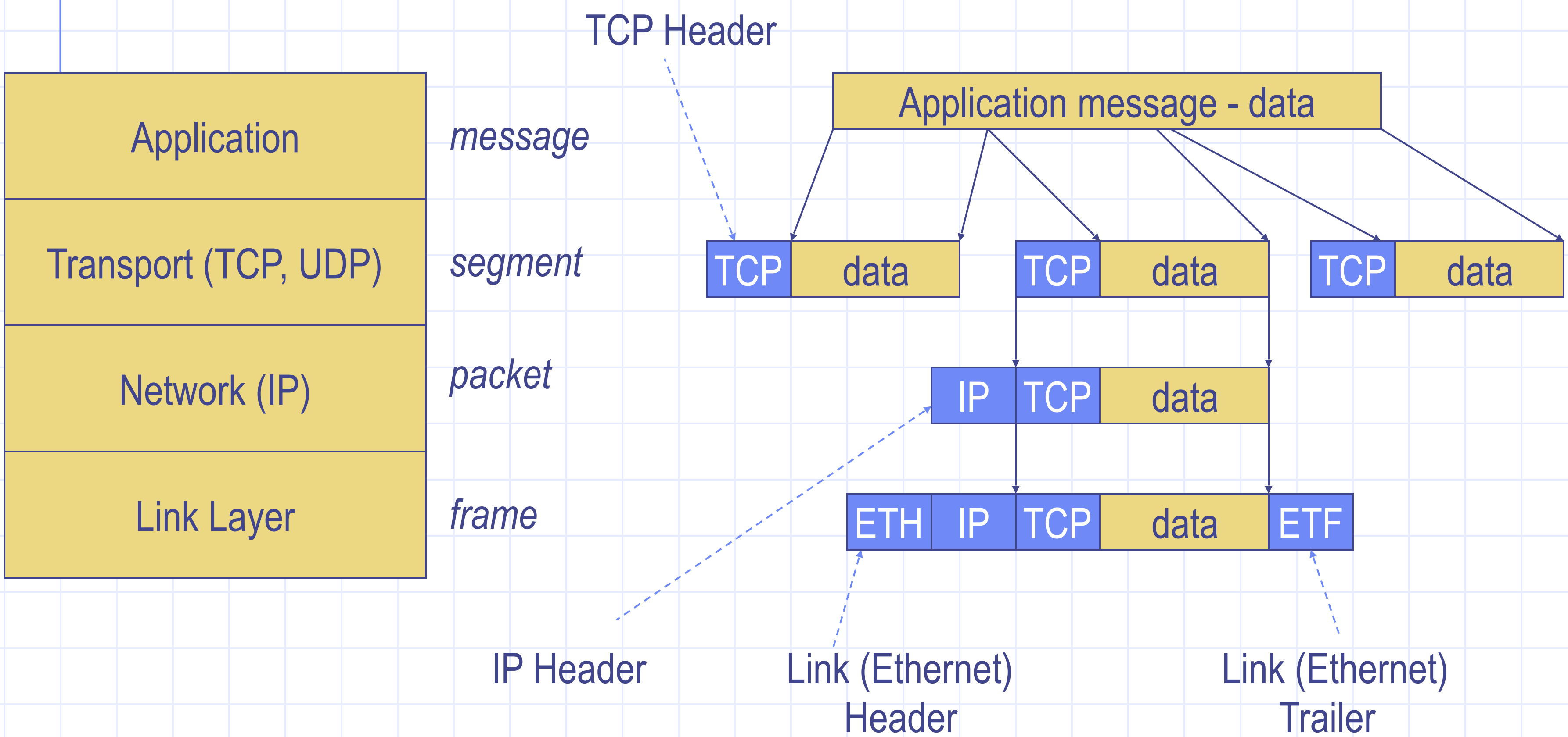


Credit: Checkpoint

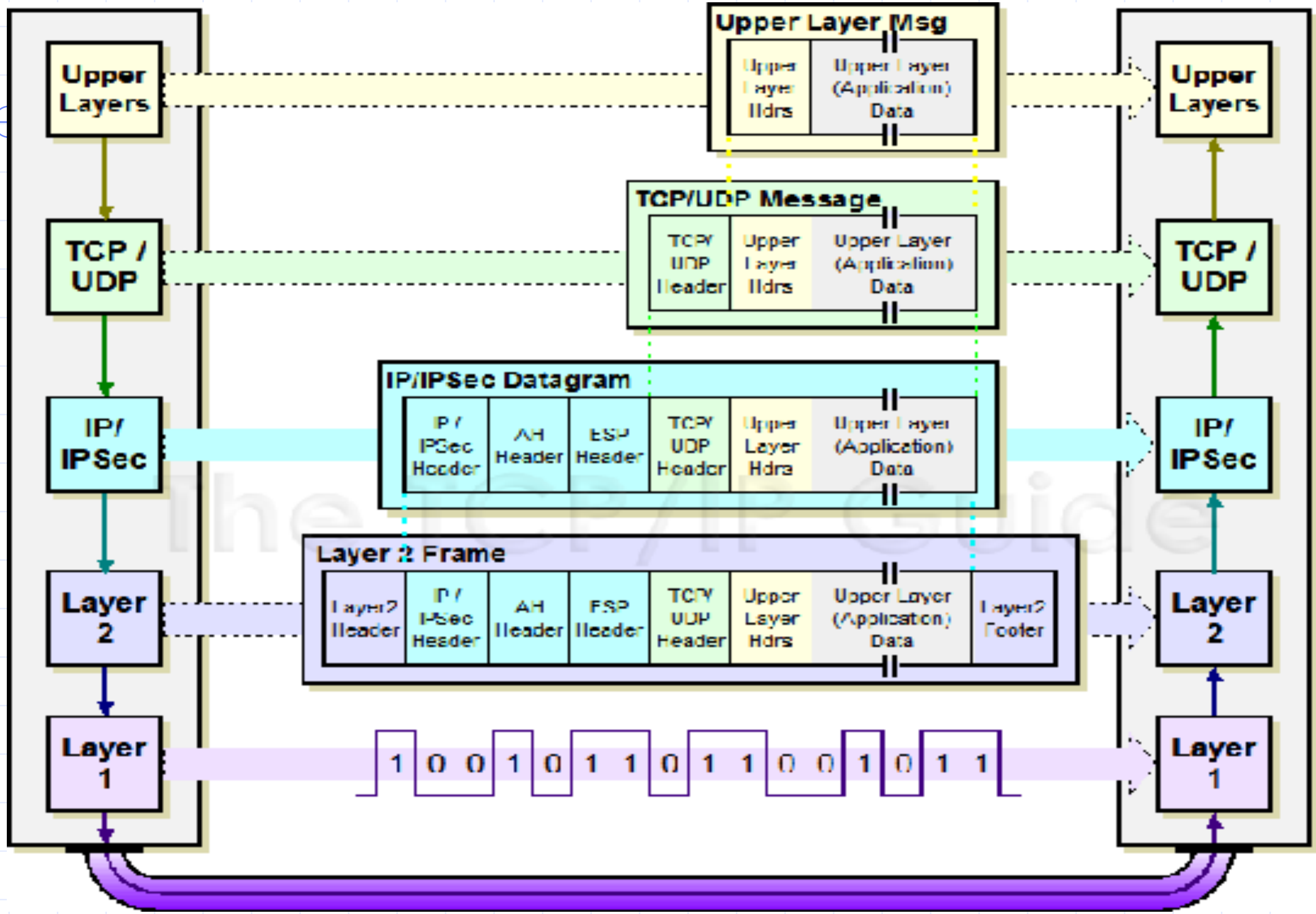
IPSEC

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

Recall packet formats and layers

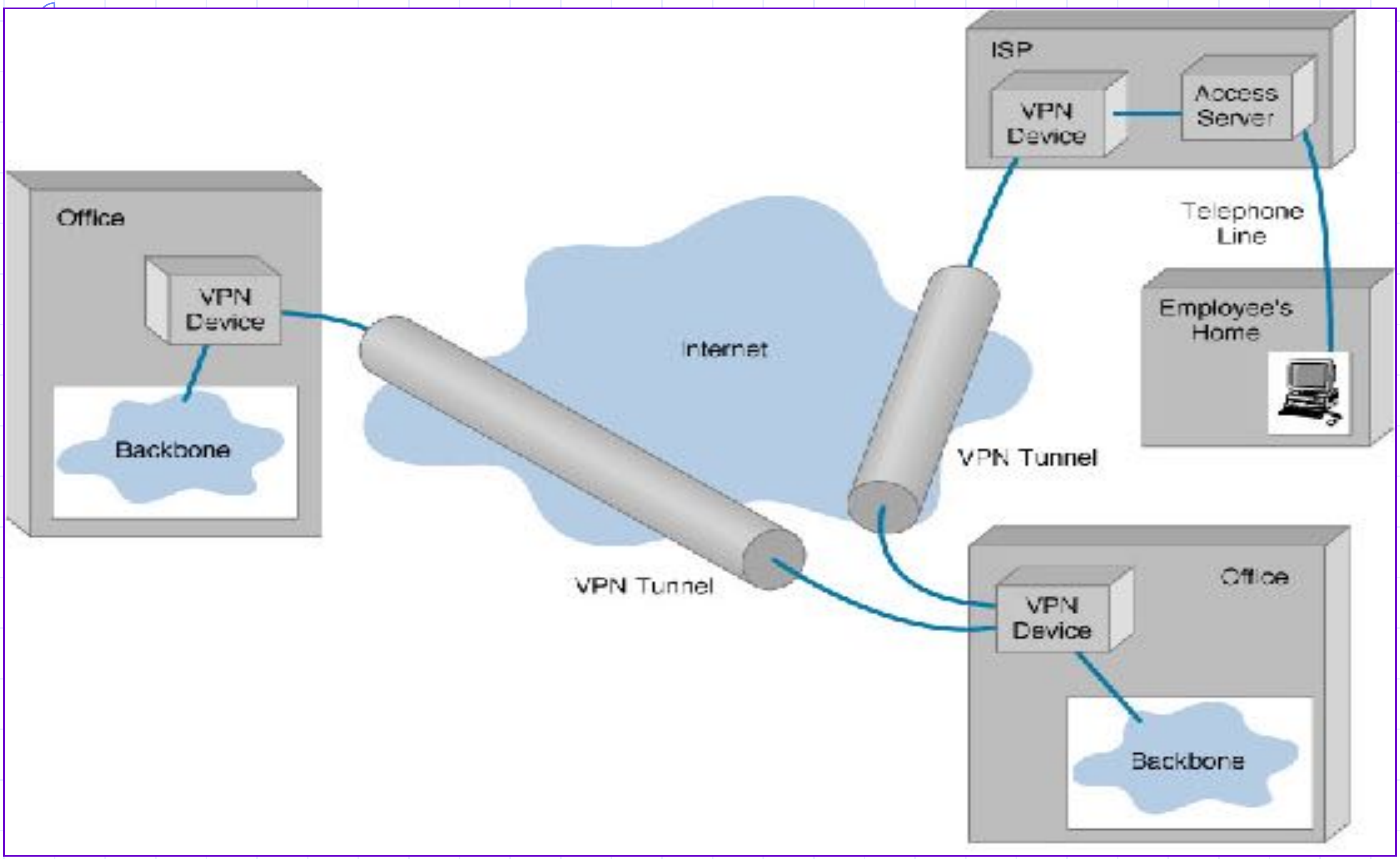


IPSec Transport Mode: IPSEC instead of IP header

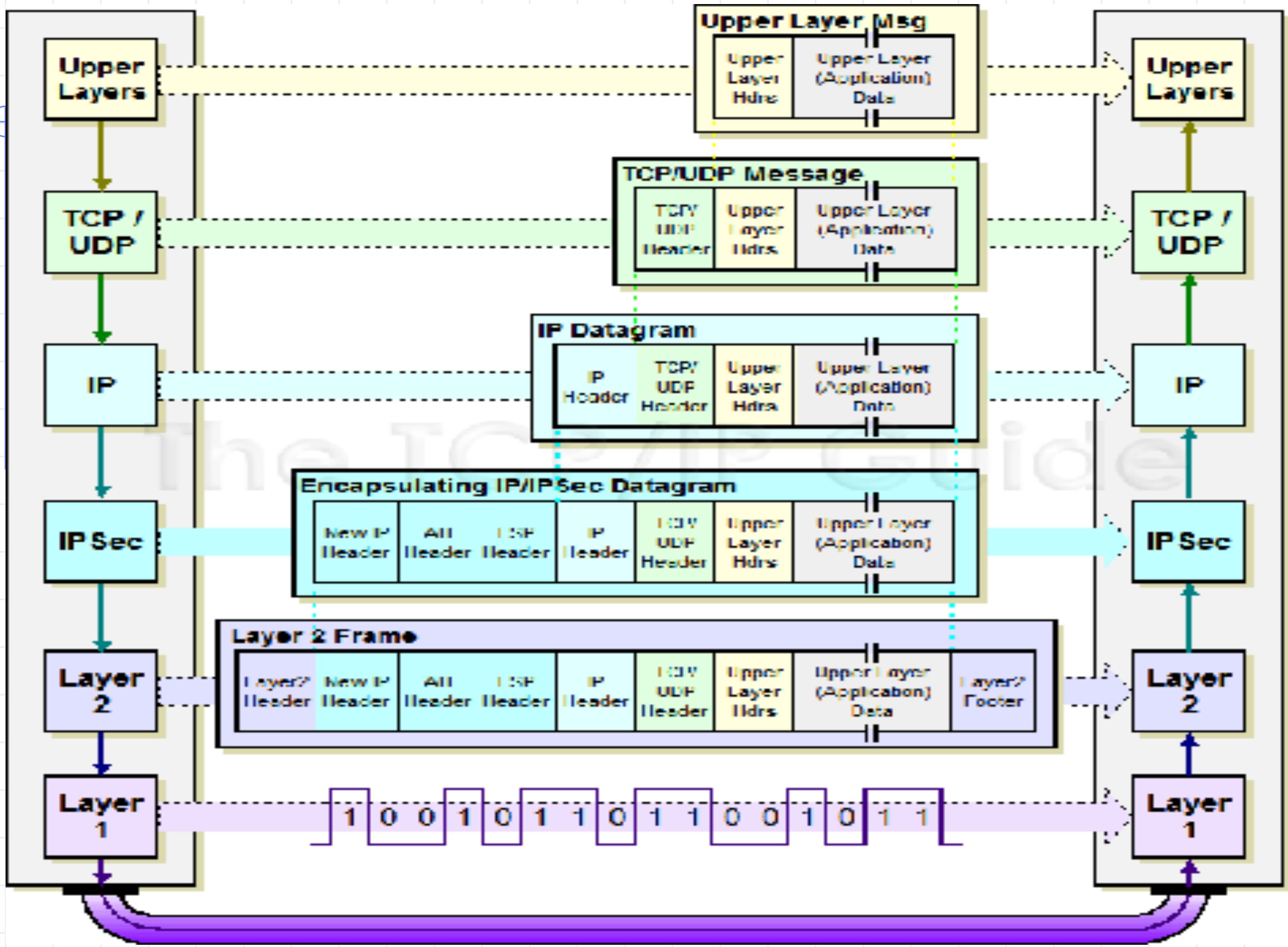


http://www.tcpipguide.com/free/t_IPSecModesTransportandTunnel.htm

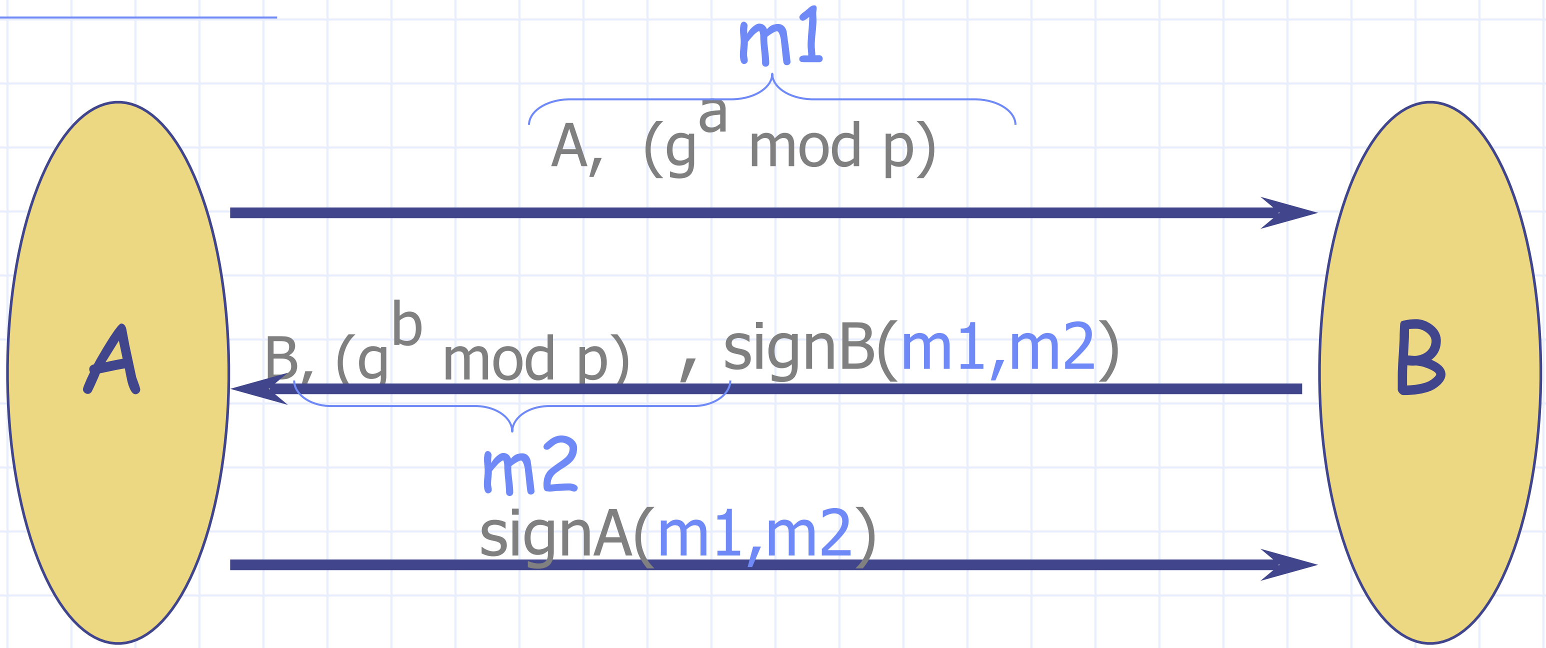
IPSEC Tunnel Mode



IPSec Tunnel Mode: IPSEC header + IP header

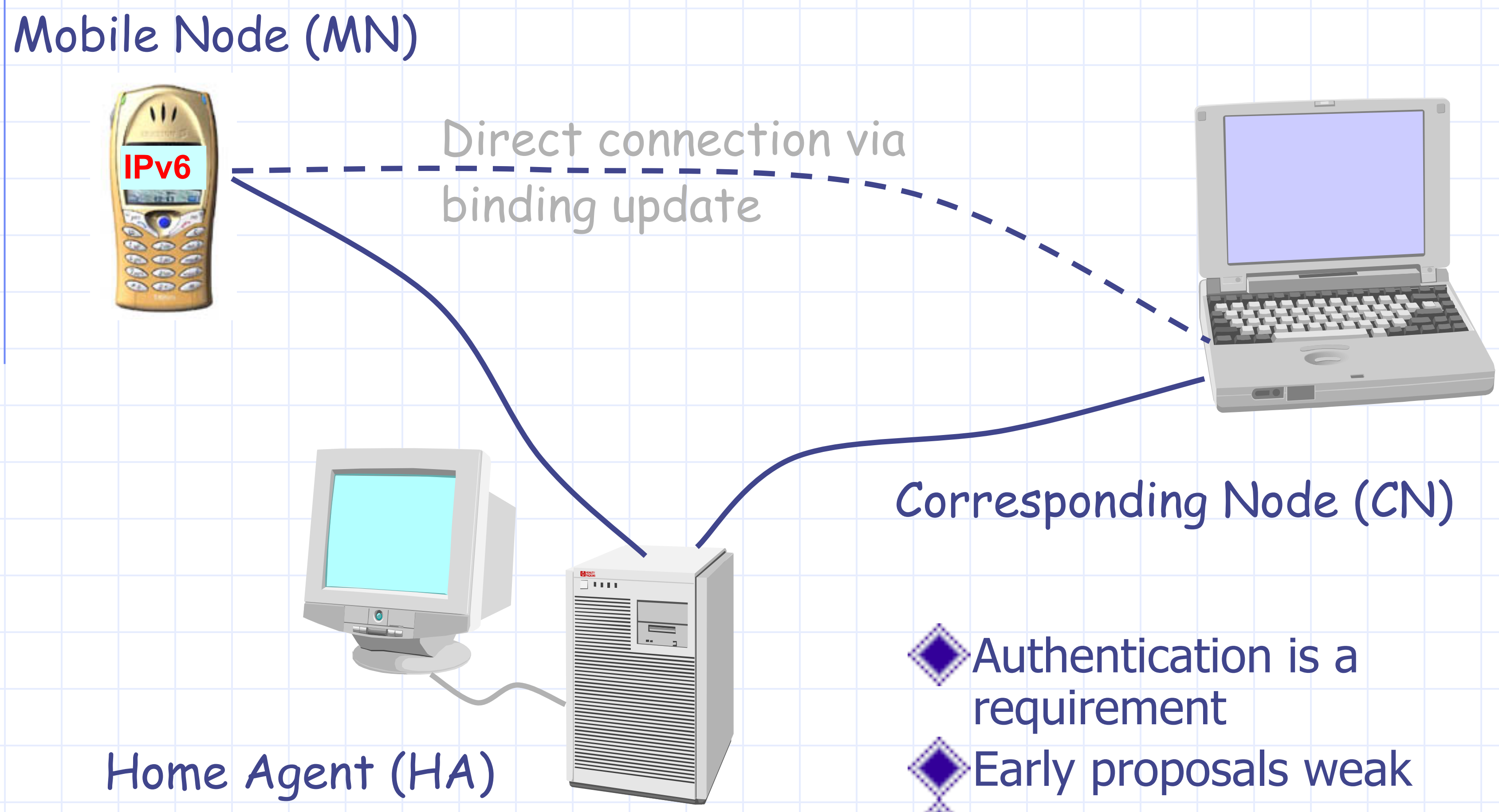


IKE subprotocol from IPSEC



Result: A and B share secret $g^{ab} \bmod p$

Mobile IPv6 Architecture



- Authentication is a requirement
- Early proposals weak
- RFC 6618 – use IPSec

Summary of first section

- Protecting network connections
  - Wireless access– 802.11i/WPA2
    - Several subprotocols provide encrypted link between user device and wireless access point
  - IPSEC
    - Give external Internet connections equivalent security to local area network connections
  - Mobility
    - Preserve network connections when a device moves to different physical portions of the network

Second topic of today’s lecture

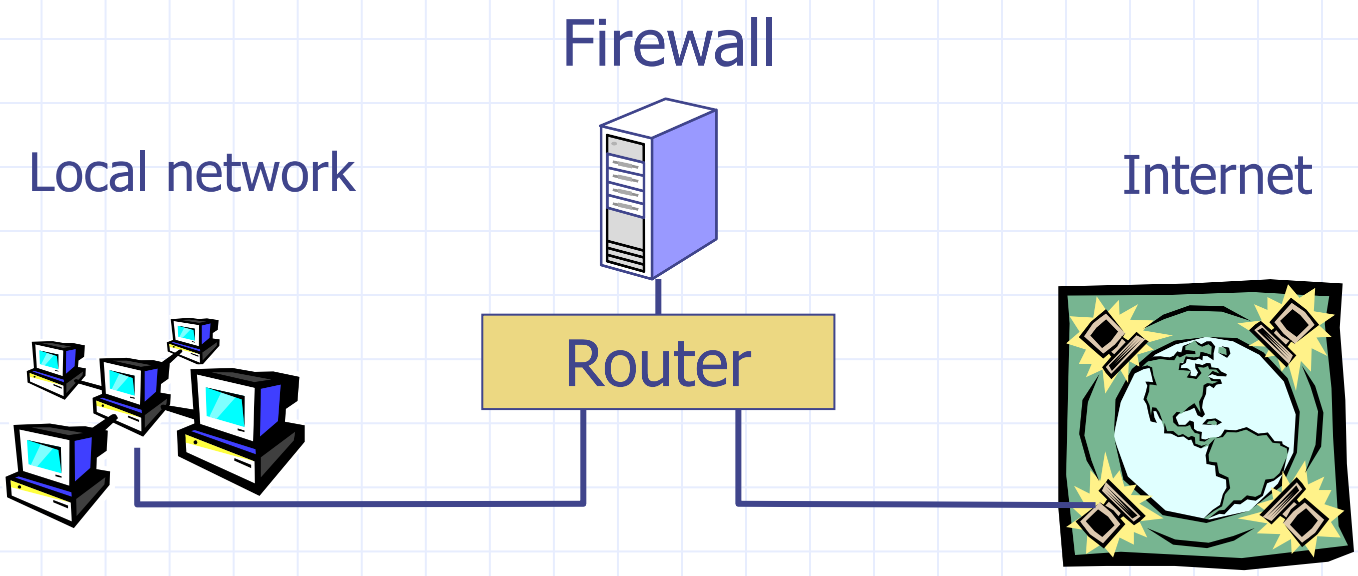
- Perimeter defenses for local networks
  - Firewall
    - Packet filter (stateless, stateful)
    - Application layer proxies
  - Intrusion detection
    - Anomaly and misuse detection

LOCAL AREA NETWORK

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

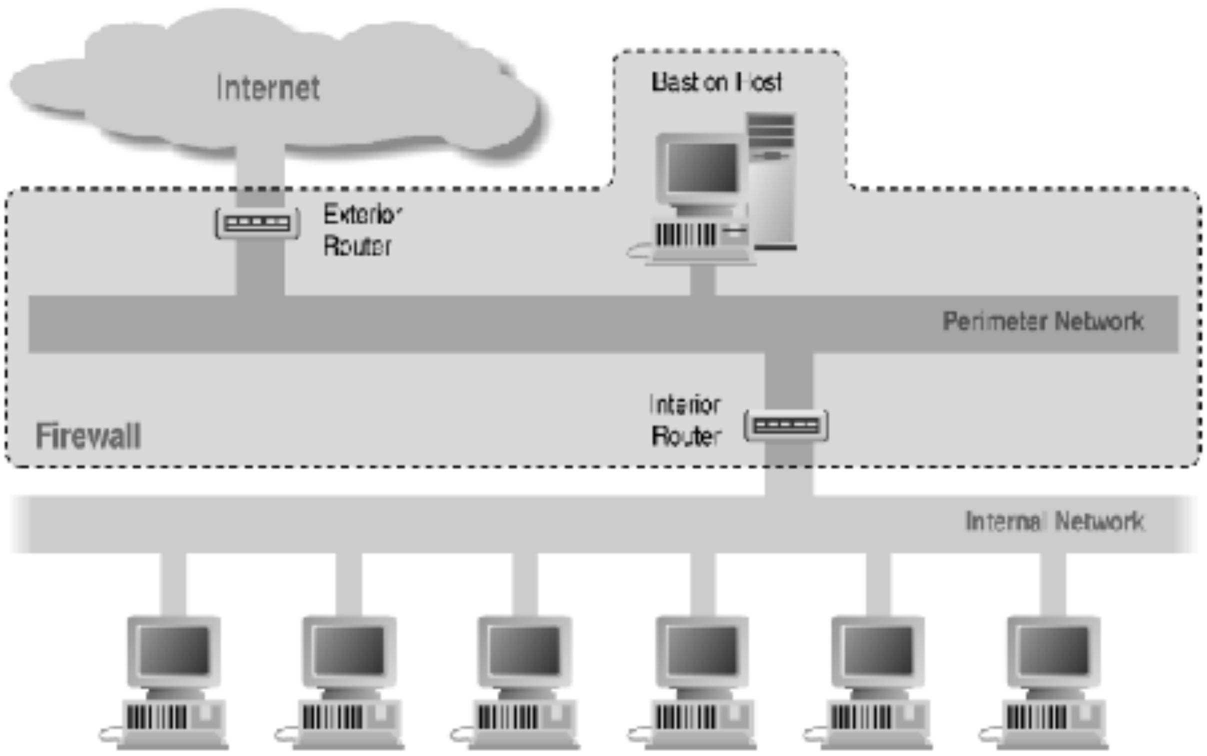
Basic Firewall Concept

- Separate local area net from internet

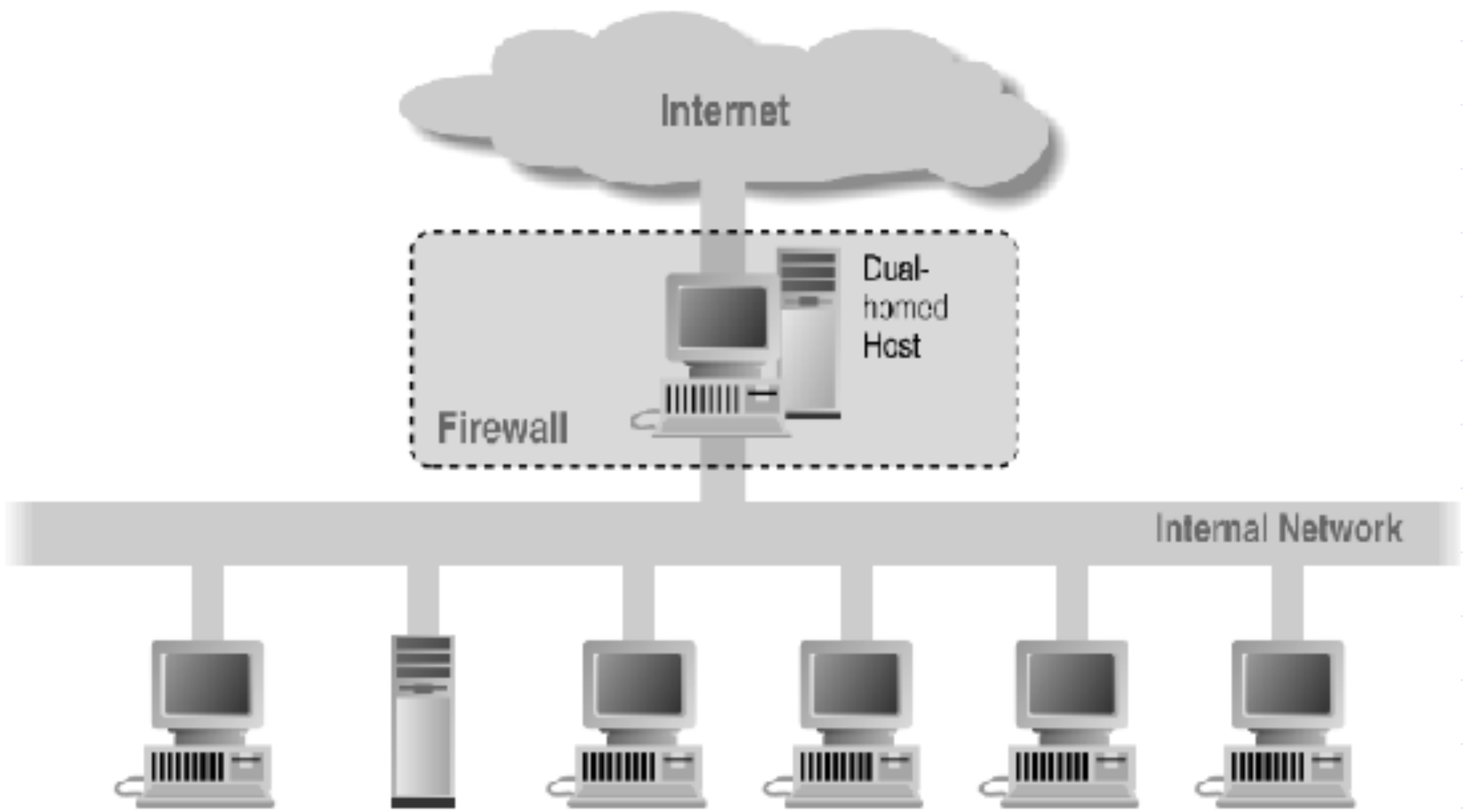


All packets between LAN and internet routed through firewall

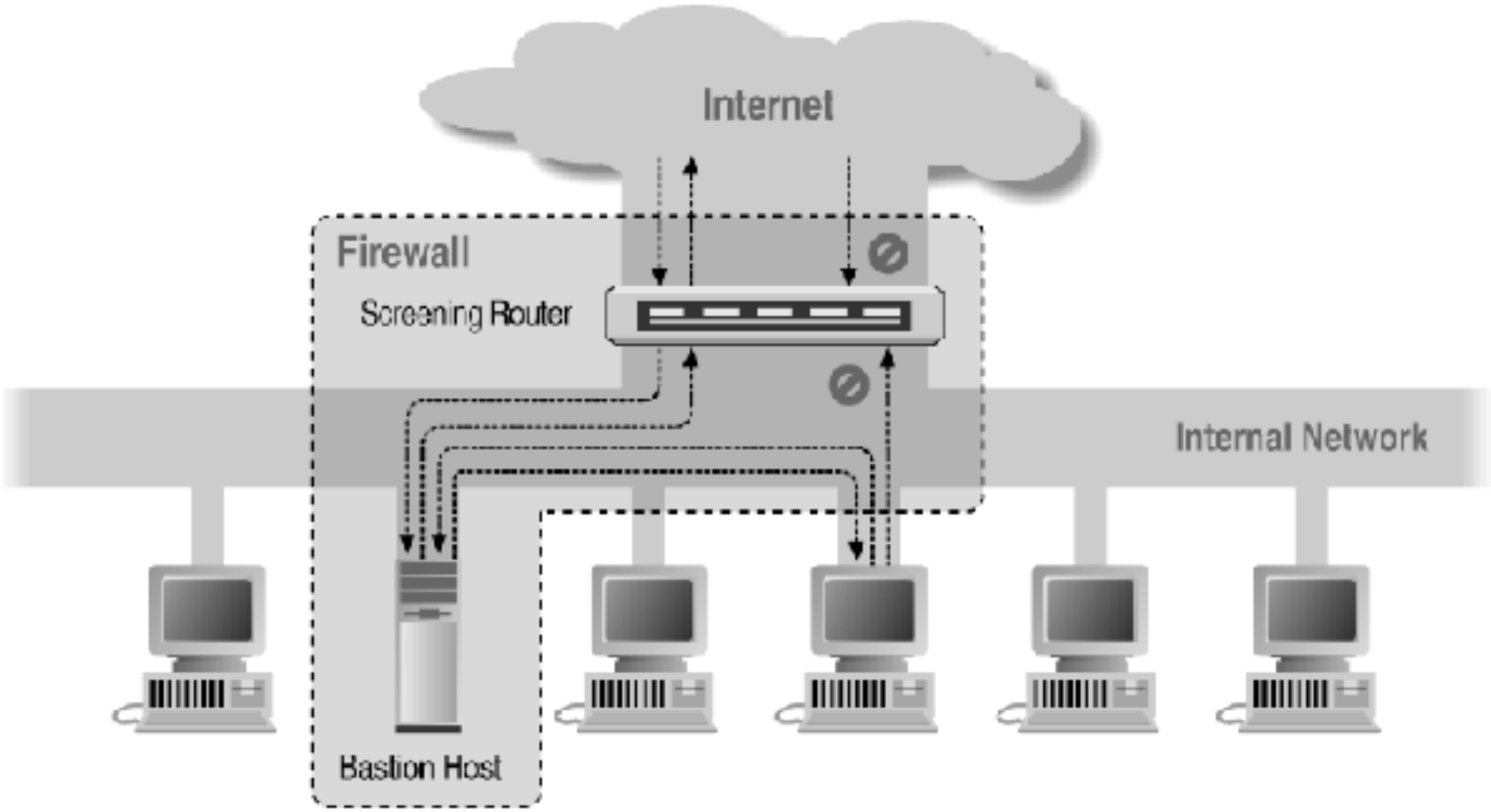
Screened Subnet Using Two Routers



Alternate 1: Dual-Homed Host



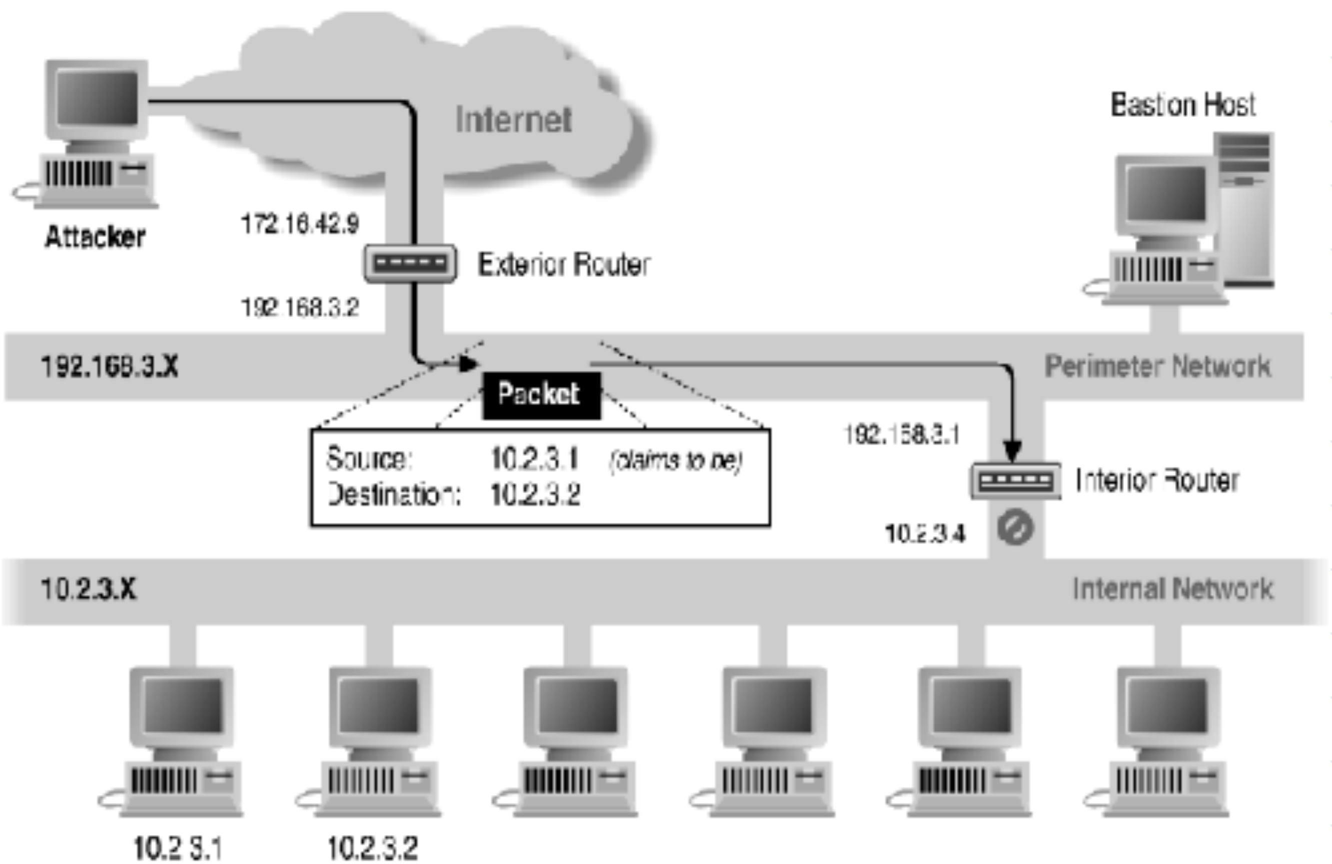
Alternate 2: Screened Host



Basic Packet Filtering

- Uses transport-layer information only
  - IP Source Address, Destination Address
  - Protocol (TCP, UDP, ICMP, etc)
  - TCP or UDP source & destination ports
  - TCP Flags (SYN, ACK, FIN, RST, PSH, etc)
  - ICMP message type
- Examples
  - DNS uses port 53
    - Block incoming port 53 packets except known trusted servers
- Issues
  - Stateful filtering
  - Encapsulation: address translation, other complications
  - Fragmentation

Source-Address Forgery

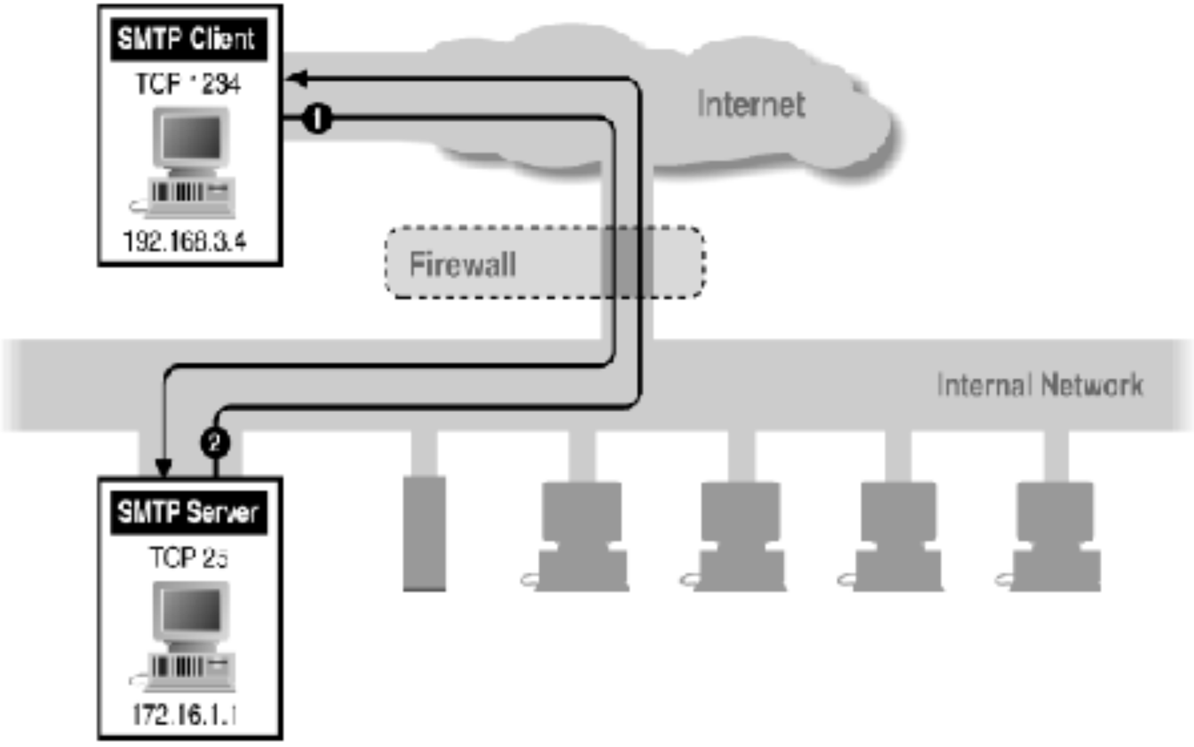


More about networking: port numbering

- TCP connection
  - Server port uses number less than 1024
  - Client port uses number between 1024 and 16383
- Permanent assignment
  - Ports <1024 assigned permanently
    - 20,21 for FTP 23 for Telnet
    - 25 for server SMTP 80 for HTTP
- Variable use
  - Ports >1024 must be available for client to make connection
  - Limitation for stateless packet filtering
    - If client wants port 2048, firewall must allow incoming traffic
  - Better: stateful filtering knows outgoing requests
    - Only allow incoming traffic on high port to a machine that has initiated an outgoing request on low port

Filtering Example: Inbound SMTP

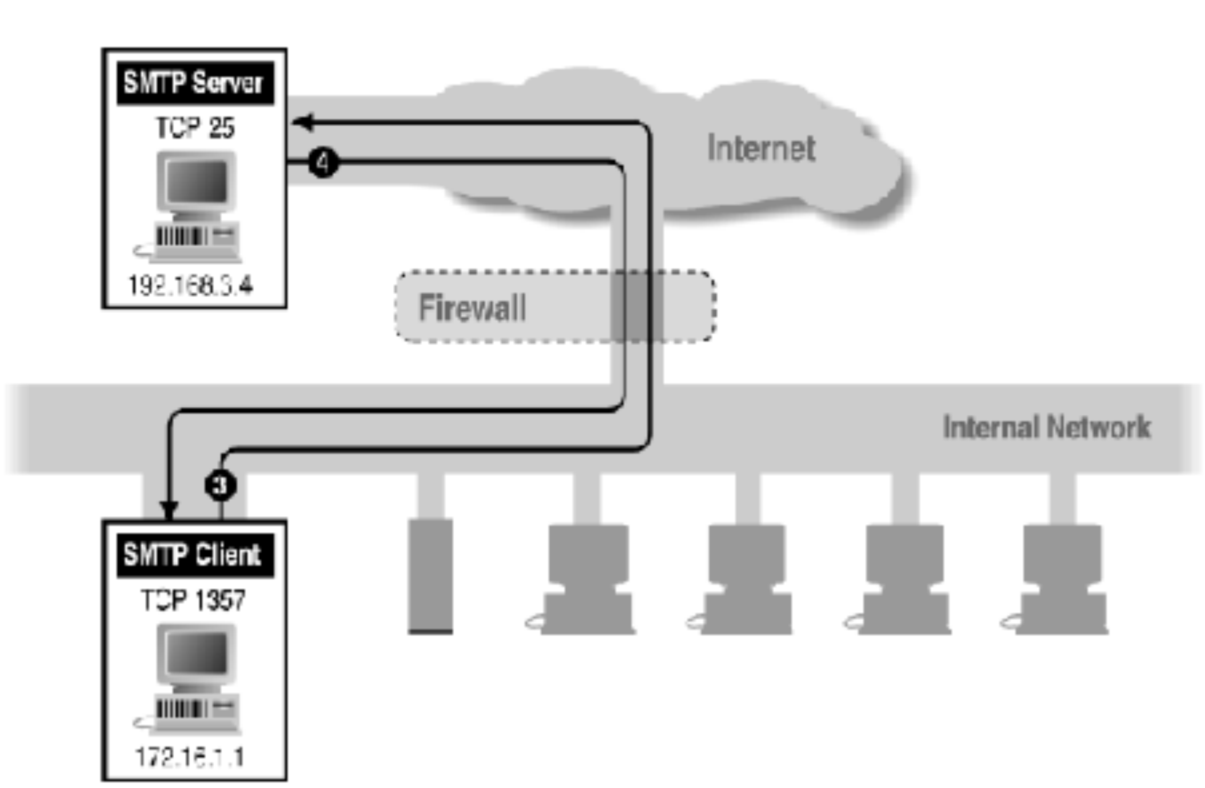
Assume we want to block internal server from external attack



Can block external request to internal server based on port number

Filtering Example: Outbound SMTP

Assume we want to allow internal access to external server

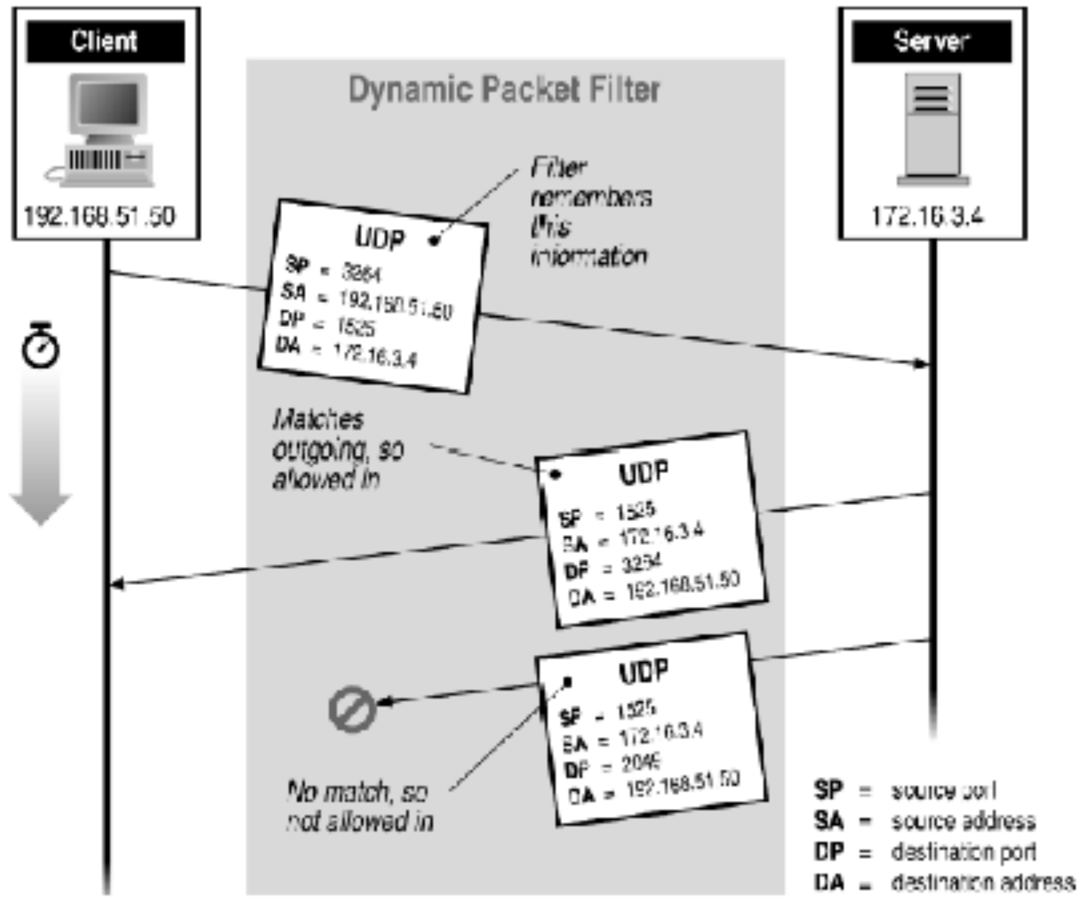


Known low port out, arbitrary high port in

If firewall blocks incoming port 1357 traffic then connection fails

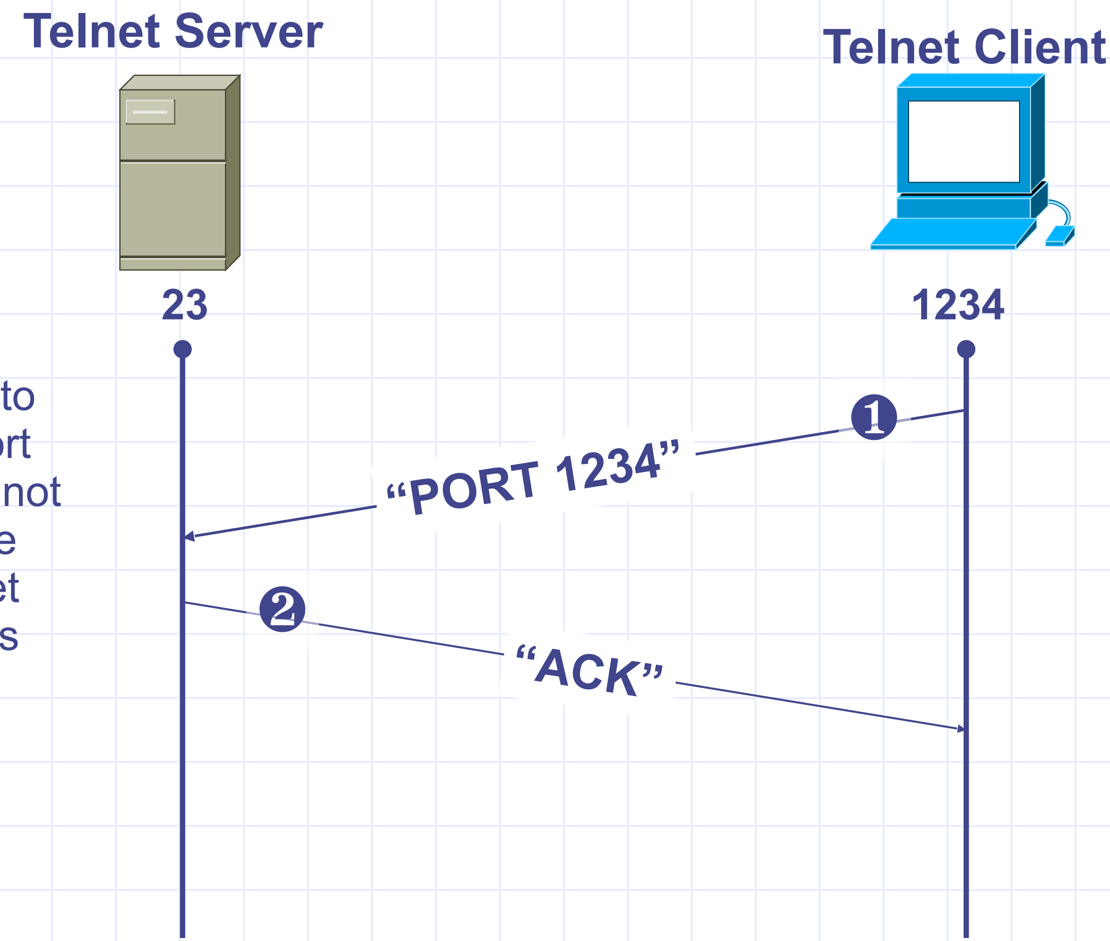
Stateful or Dynamic Packet Filtering

Assume we want to allow external UDP only if requested



Telnet

How can stateful filtering identify legitimate session?



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

❷ Server acknowledges

Stateful filtering can use this pattern to identify legitimate sessions

FTP

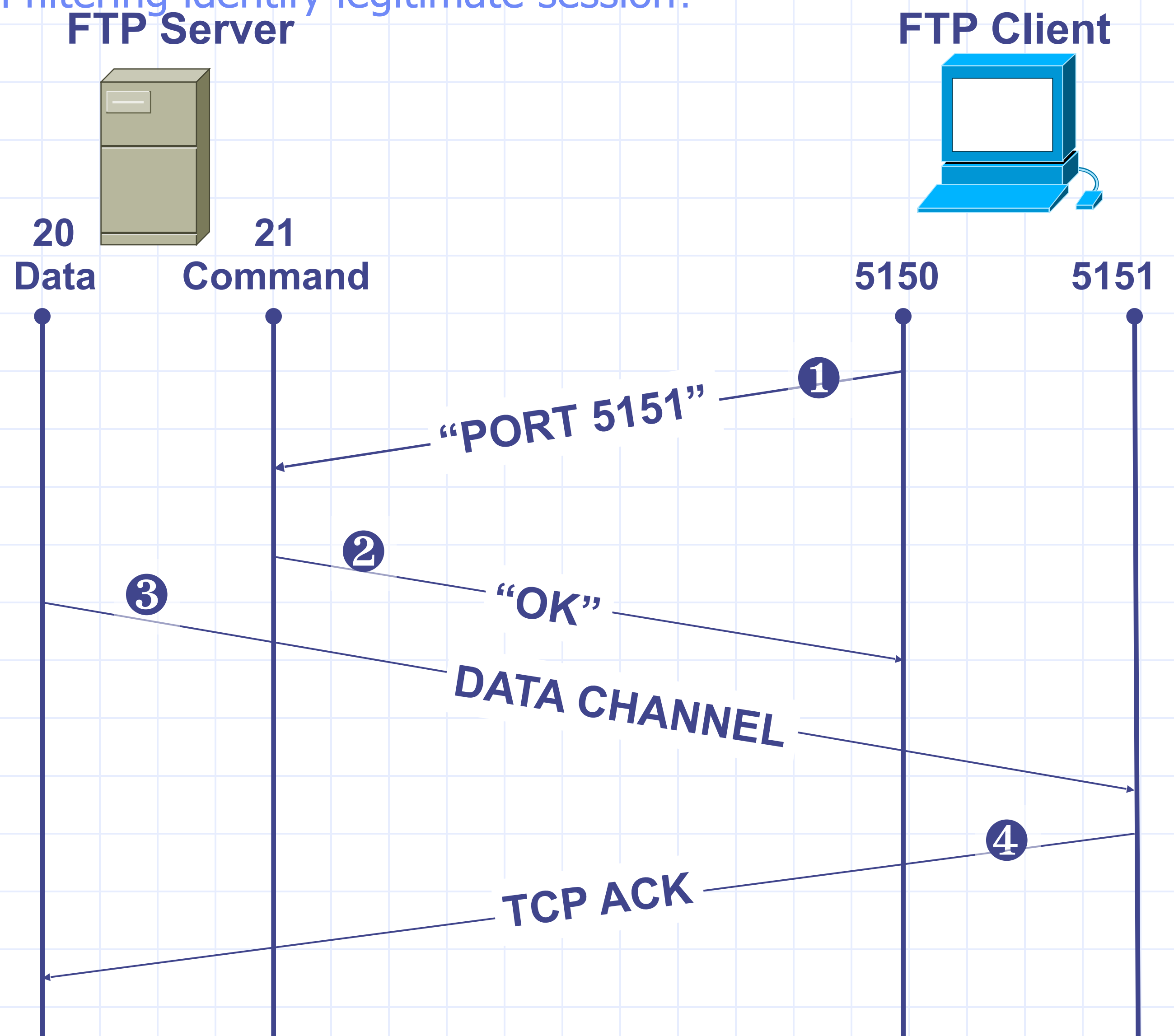
How can stateful filtering identify legitimate session?

❶ Client opens command channel to server; tells server second port number

❷ Server acknowledges

❸ Server opens data channel to client's second port

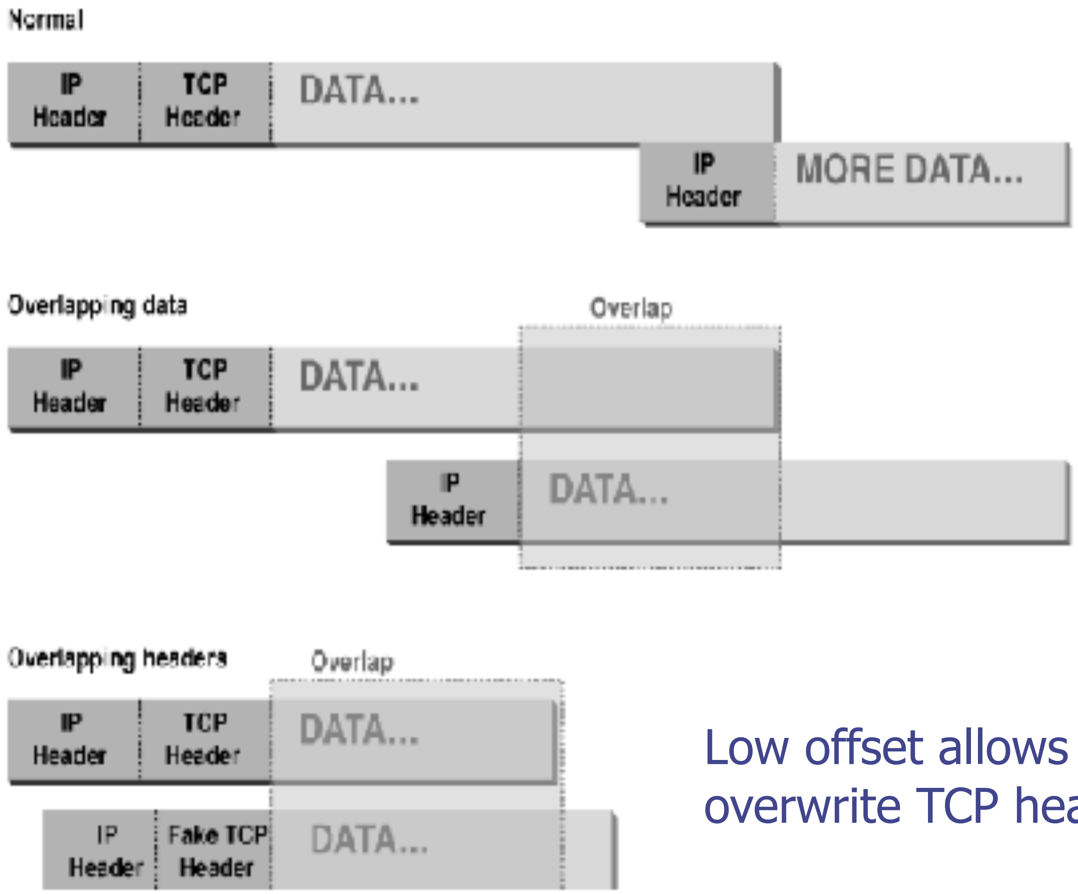
❹ Client acknowledges



Normal IP Fragmentation

Flags and offset inside IP header indicate packet fragmentation

Abnormal Fragmentation

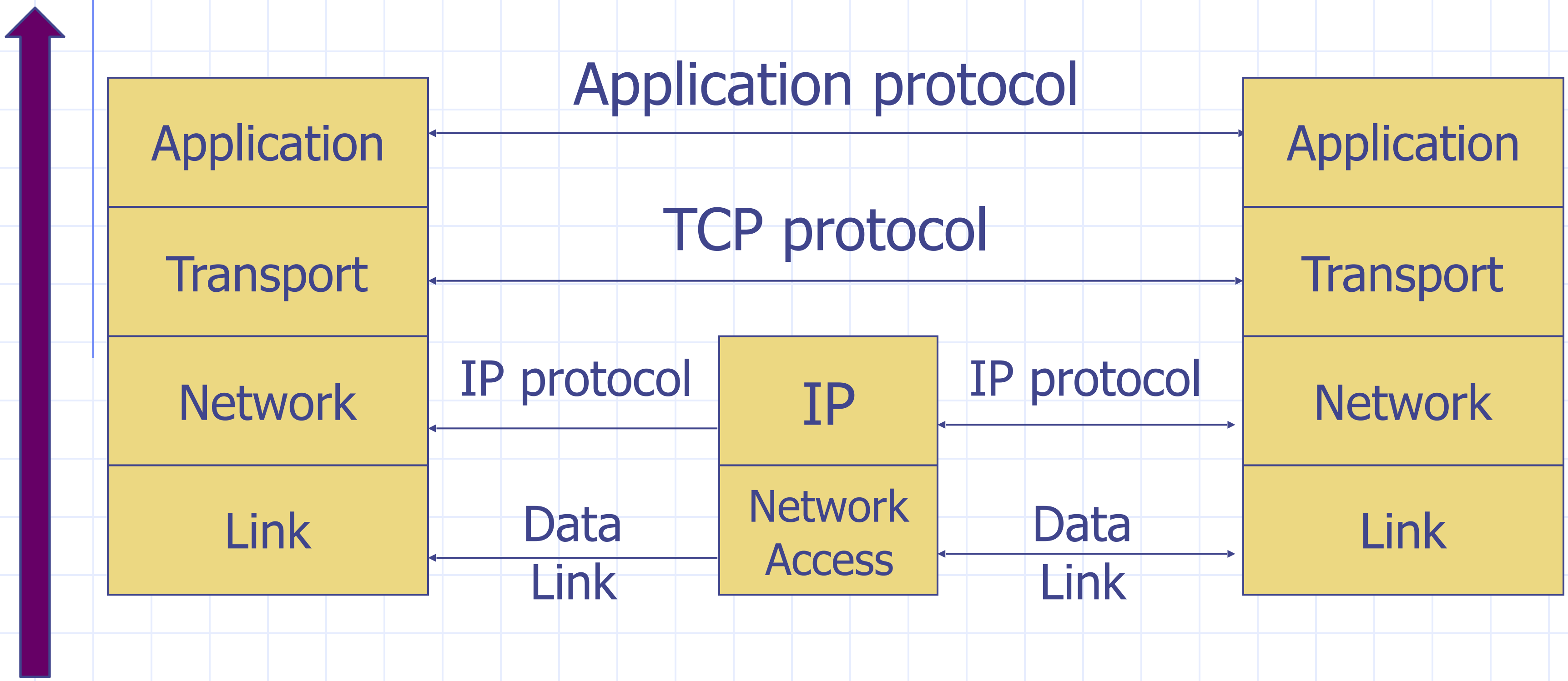


Low offset allows second packet to overwrite TCP header at receiving host

Packet Fragmentation Attack

- Firewall configuration
  - TCP port 23 is blocked but SMTP port 25 is allowed
- First packet
  - Fragmentation Offset = 0.
  - DF bit = 0 : "May Fragment"
  - MF bit = 1 : "More Fragments"
  - Destination Port = 25. TCP port 25 is allowed, so firewall allows packet
- Second packet
  - Fragmentation Offset = 1: second packet overwrites all but first 8 bits of the first packet
  - DF bit = 0 : "May Fragment"
  - MF bit = 0 : "Last Fragment."
  - Destination Port = 23. Normally be blocked, but sneaks by!
- What happens
  - Firewall ignores second packet "TCP header" because it is fragment of first
  - At host, packet reassembled and received at port 23

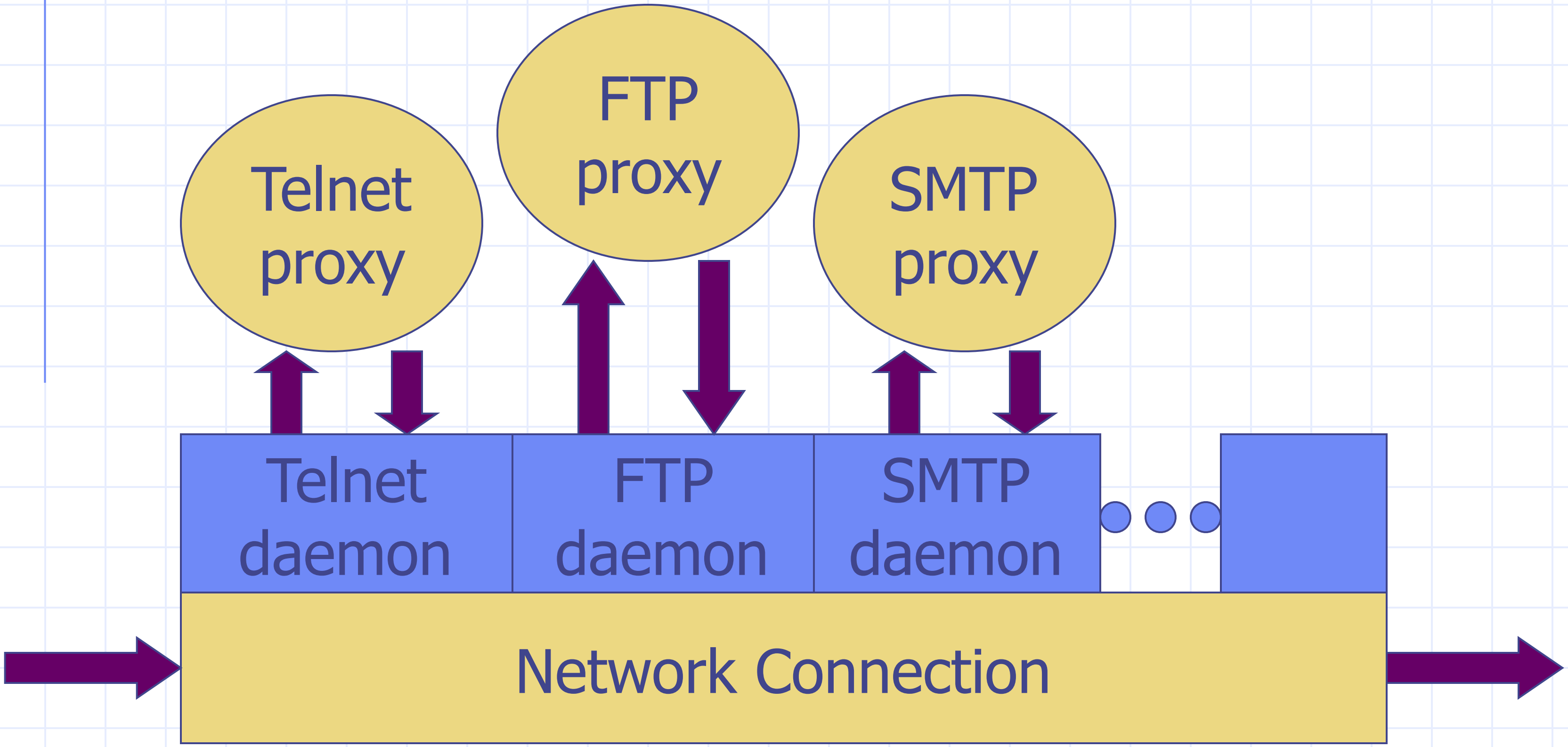
TCP Protocol Stack



Proxying Firewall

- Application-level proxies
  - Tailored to http, ftp, smtp, etc.
  - Some protocols easier to proxy than others
- Policy embedded in proxy programs
  - Proxies filter incoming, outgoing packets
  - Reconstruct application-layer messages
  - Can filter specific application-layer commands, etc.
    - Example: only allow specific ftp commands
    - Other examples: ?
- Several network locations – see next slides

Firewall with application proxies



Daemon spawns proxy when communication detected …

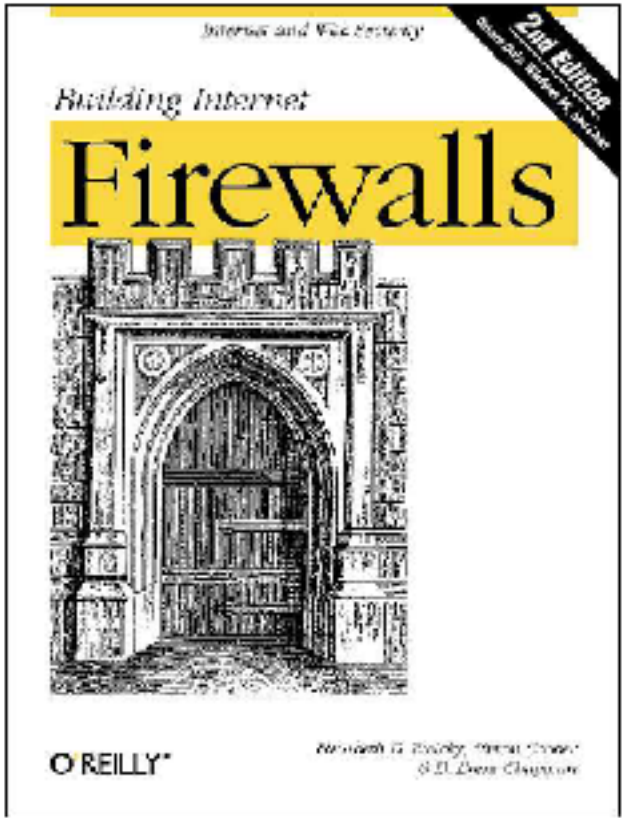
Application-level proxies

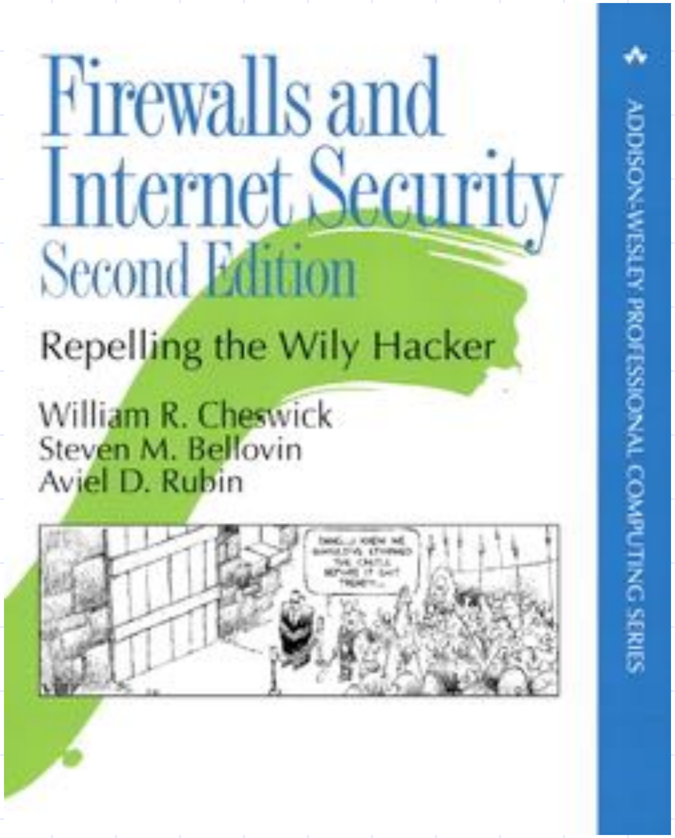
- Enforce policy for specific protocols
  - E.g., Virus scanning for SMTP
    - Need to understand MIME, encoding, Zip archives
  - Flexible approach, but may introduce network delays
- "Batch" protocols are natural to proxy
  - SMTP (E-Mail) NNTP (Net news)
  - DNS (Domain Name System) NTP (Network Time Protocol)
- Must protect host running protocol stack
  - Disable all non-required services; keep it simple
  - Install/modify services you want
  - Run security audit to establish baseline
  - Be prepared for the system to be compromised

Web traffic scanning

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

Firewall references





Elizabeth D. Zwicky
Simon Cooper
D. Brent Chapman

William R Cheswick
Steven M Bellovin
Aviel D Rubin

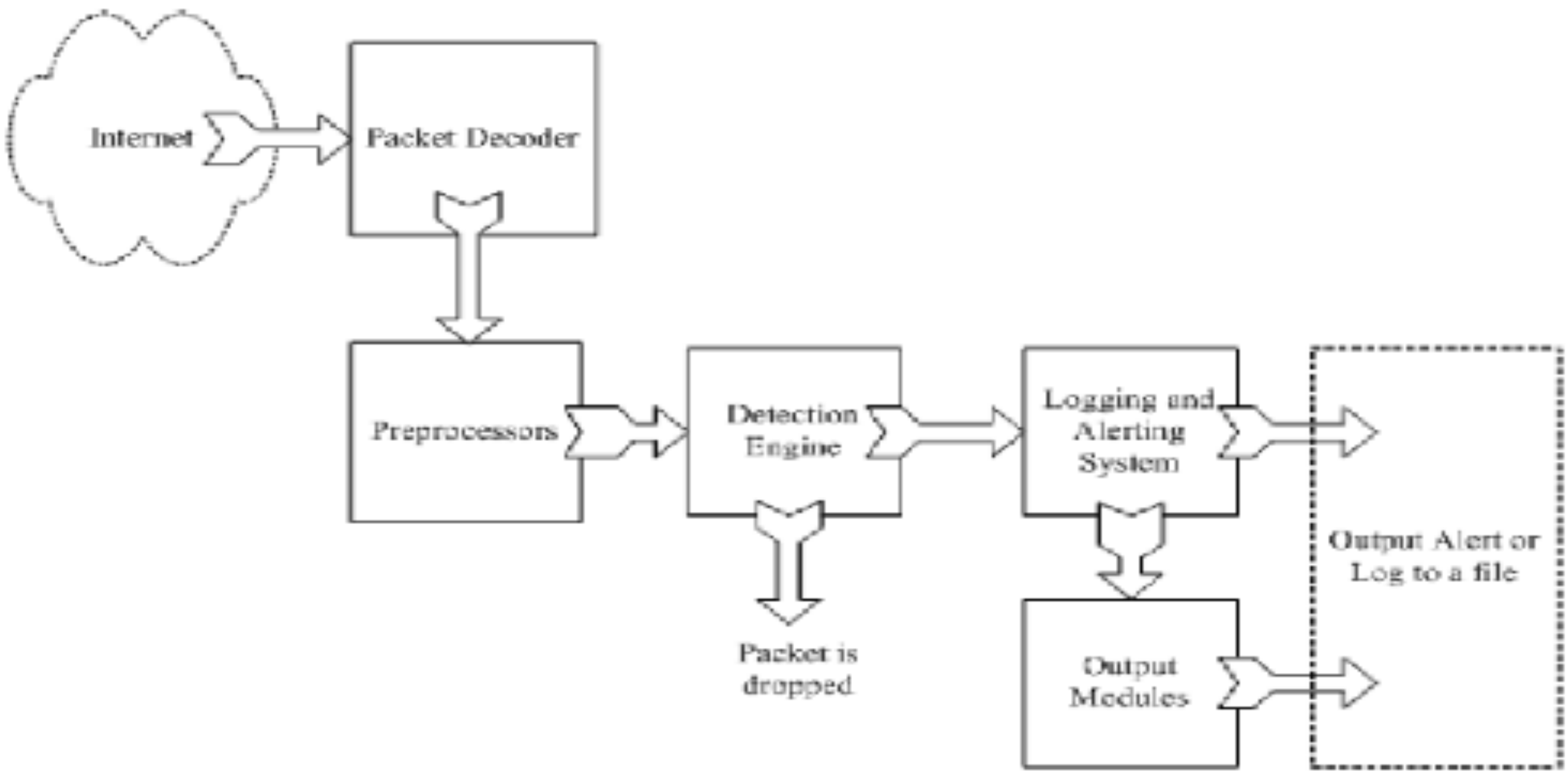

DANG...I KNEW WE SHOULD'VE STORMED THE CASTLE BEFORE IT GOT TRENDY...
7-17

Intrusion detection

- Many intrusion detection systems
  - Network-based, host-based, or combination
- Two basic models
  - Misuse detection model
    - Maintain data on known attacks
    - Look for activity with corresponding signatures
  - Anomaly detection model
    - Try to figure out what is "normal"
    - Report anomalous behavior
- Fundamental problem: too many false alarms

Example: Snort

http://www.snort.org/

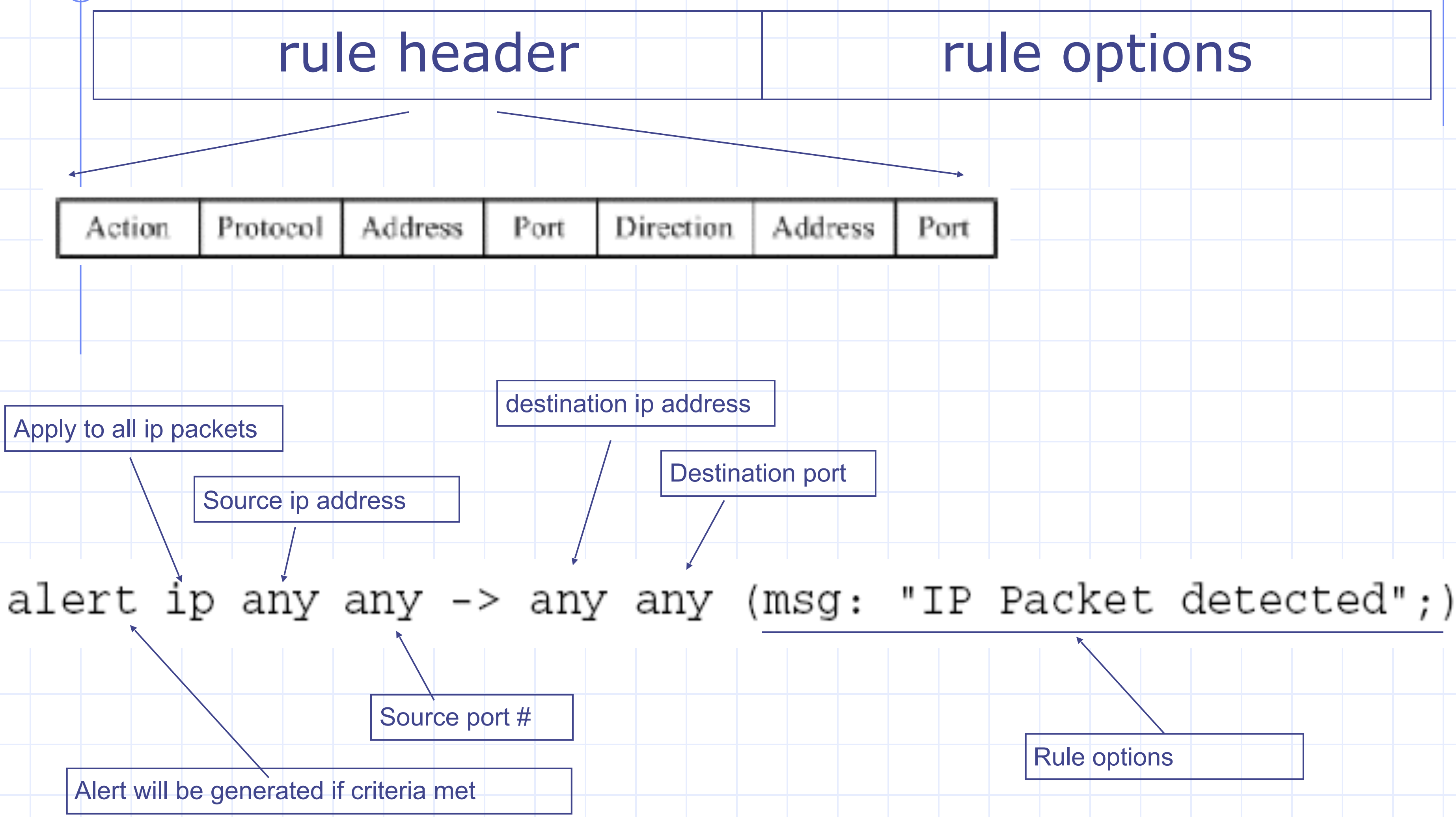


From: Rafeeq Ur Rehman, *Intrusion Detection Systems with Snort: Advanced IDS Techniques with Snort, Apache, MySQL, PHP, and ACID.*

Snort components

- Packet Decoder
  - input from Ethernet, SLIP, PPP…
- Preprocessor:
  - detect anomalies in packet headers
  - packet defragmentation
  - decode HTTP URI
  - reassemble TCP streams
- Detection Engine: applies rules to packets
- Logging and Alerting System
- Output Modules: alerts, log, other output

Snort detection rules



Additional examples

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

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

! = negation operator in address

content - match content in packet

192.168.1.0/24 - addr from 192.168.1.1 to 192.168.1.255

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

Snort challenges

- Misuse detection – avoid known intrusions
  - Database size continues to grow
    - Snort version 2.3.2 had 2,600 rules
  - Snort spends 80% of time doing string match
- Anomaly detection – identify new attacks
  - Probability of detection is low

Difficulties in anomaly detection

- Lack of training data
  - Lots of "normal" network, system call data
  - Little data containing realistic attacks, anomalies
- Data drift
  - Statistical methods detect changes in behavior
  - Attacker can attack gradually and incrementally
- Main characteristics not well understood
  - By many measures, attack may be within bounds of "normal" range of activities
- False identifications are very costly
  - Sys Admin spend many hours examining evidence

Summary of this section

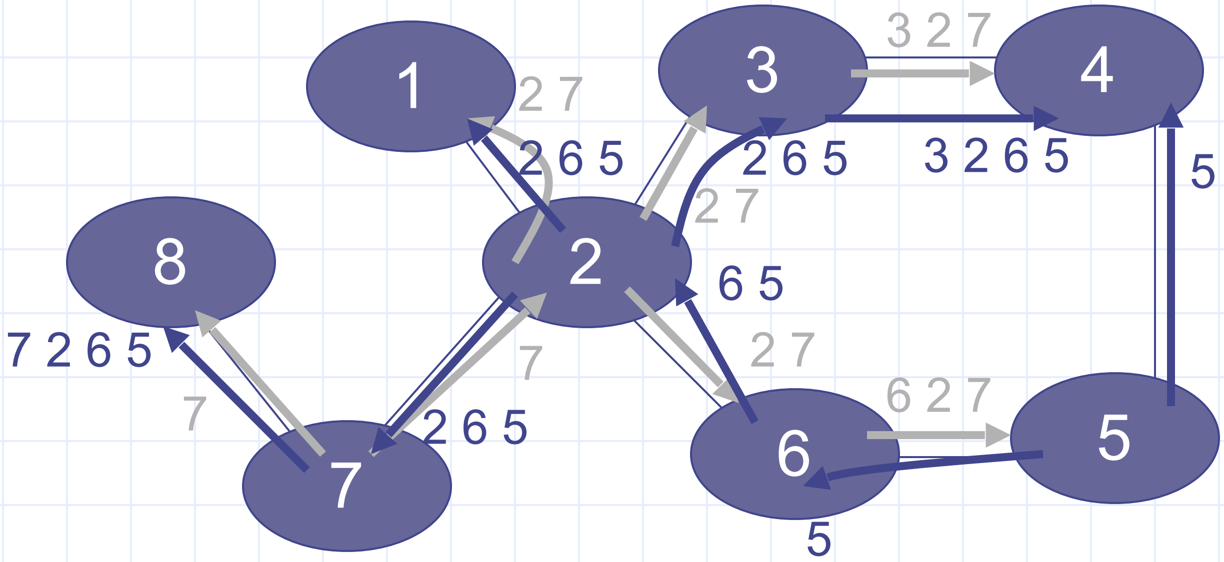
- Perimeter defenses for local networks
  - Firewall
    - Packet filter (stateless, stateful), Application layer proxies
  - Intrusion detection
    - Anomaly and misuse detection

Last section of today's lecture

- Network infrastructure protocols
  - BGP vulnerabilities and S-BGP
  - DNS security, cache poisoning and rebinding attacks

INFRASTRUCTURE PROTOCOLS: BGP, DNS

BGP example



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

Figure: D. Wetherall

BGP Security Issues

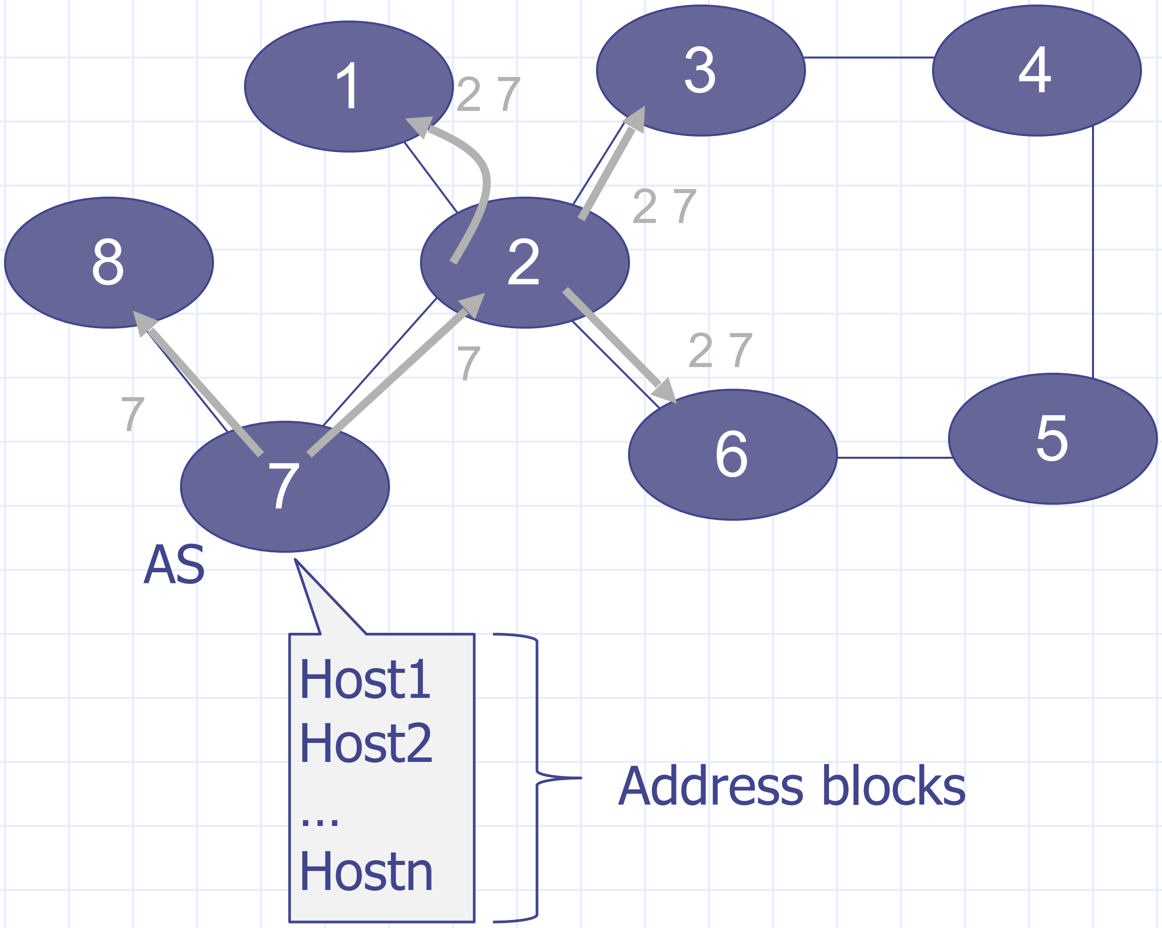
- BGP is used for all inter-ISP routing
- Benign configuration errors affect about 1% of all routing table entries at any time
- Highly vulnerable to human errors, malicious attacks
  - Actual routing policies can be very complicated
- MD5 MAC is rarely used, perhaps due to lack of automated key management,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

S-BGP Design Overview

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

Slide: Steve Kent

BGP example



Address Attestation

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

Route Attestation

- Indicates that the speaker or its AS authorizes the listener's AS to use the route in the UPDATE
- Includes identification of:
  - AS's or BGP speaker's certificate issued by owner of the AS
  - the address blocks and the list of ASes in the UPDATE
  - the neighbor
  - expiration date
- Digitally signed by owner of the AS (or BGP speaker) distributing the UPDATE, traceable to the IANA ...
- Used to protect BGP from erroneous UPDATEs (authenticated but misbehaving or misconfigured BGP speakers)

Validating a Route

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

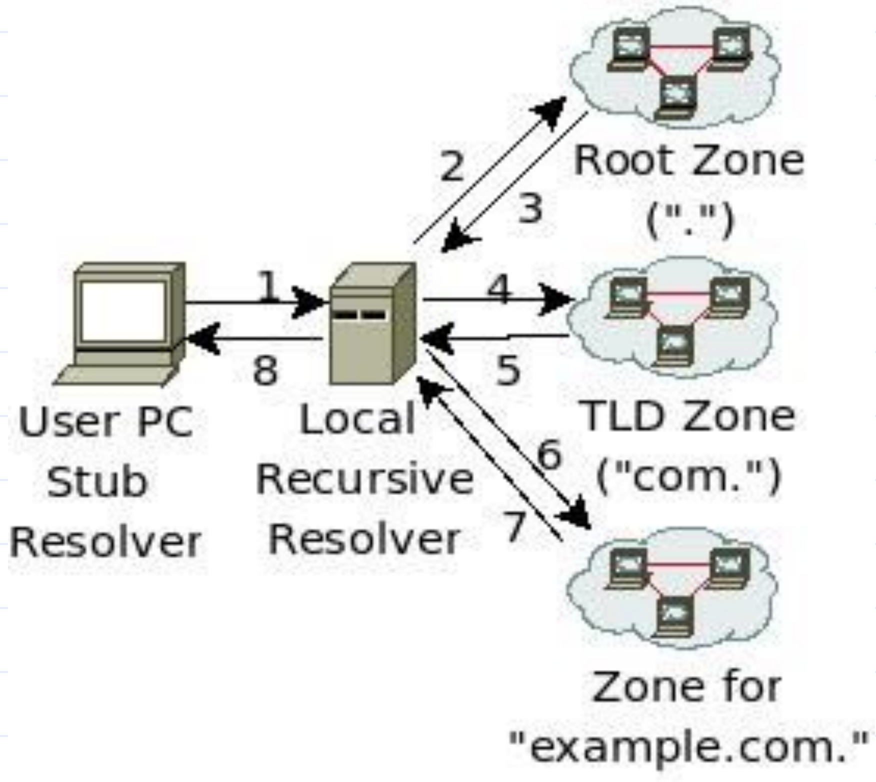
Slide: Kent et al.

INFRASTRUCTURE PROTOCOLS: BGP, DNS

Recall: DNS Lookup

Query: "www.example.com A?"

Reply	Resource Records in Reply
3	"com. NS a.gtld.net" "a.gtld.net A 192.5.6.30"
5	"example.com. NS a.iana.net" "a.iana.net A 192.0.34.43"
7	"www.example.com A 1.2.3.4"
8	"www.example.com A 1.2.3.4"



Local recursive resolver caches these for TTL specified by RR

DNS is Insecure

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

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

DNSSEC Goal

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

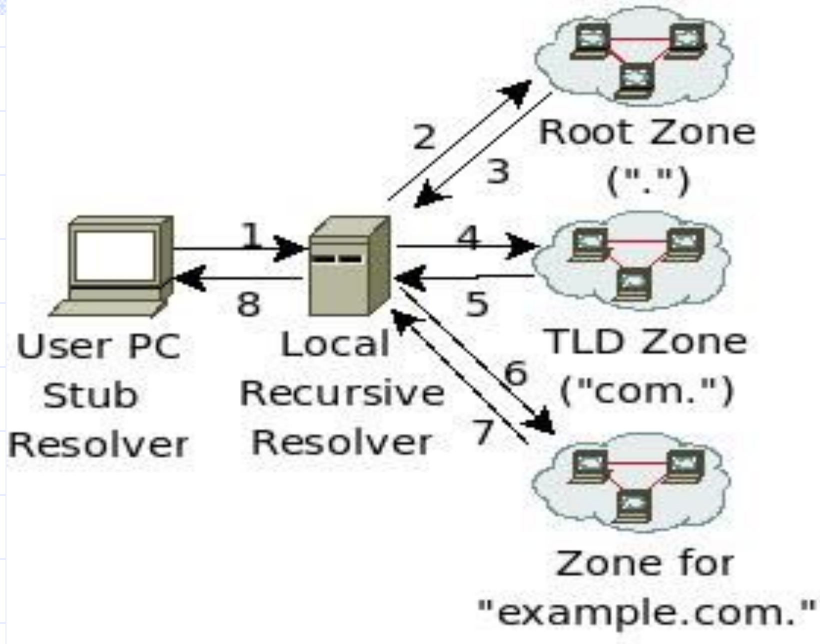
-RFC 4033

DNSSEC

- Basically no change to packet format
  - Goal is security of DNS data, not channel security
- New Resource Records (RRs)
  - RRSIG : signature of RR by private zone key
  - DNSKEY : public zone key
  - DS : crypto digest of child zone key
  - NSEC / NSEC3 authenticated denial of existence
- Lookup referral chain (unsigned)
- Origin attestation chain (PKI) (signed)
  - Start at pre-configured trust anchors
    - DS/DNSKEY of zone (should include root)
  - DS → DNSKEY → DS forms a link

DNSSEC Lookup

Query: "www.example.com A?"



Reply	RRs in DNS Reply	Added by DNSSEC
3	"com. NS a.gtld.net" "a.gtld.net A 192.5.6.30"	"com. DS" "RRSIG(DS) by ."
5	"example.com. NS a.iana.net" "a.iana.net A 192.0.34.43"	"com. DNSKEY" "RRSIG(DNSKEY) by com." "example.com. DS" "RRSIG(DS) by com."
7	"www.example.com A 1.2.3.4"	"example.com DNSKEY" "RRSIG(DNSKEY) by example.com." "RRSIG(A) by example.com."
8	"www.example.com A 1.2.3.4"	Last Hop?

Authenticated Denial-of-Existence

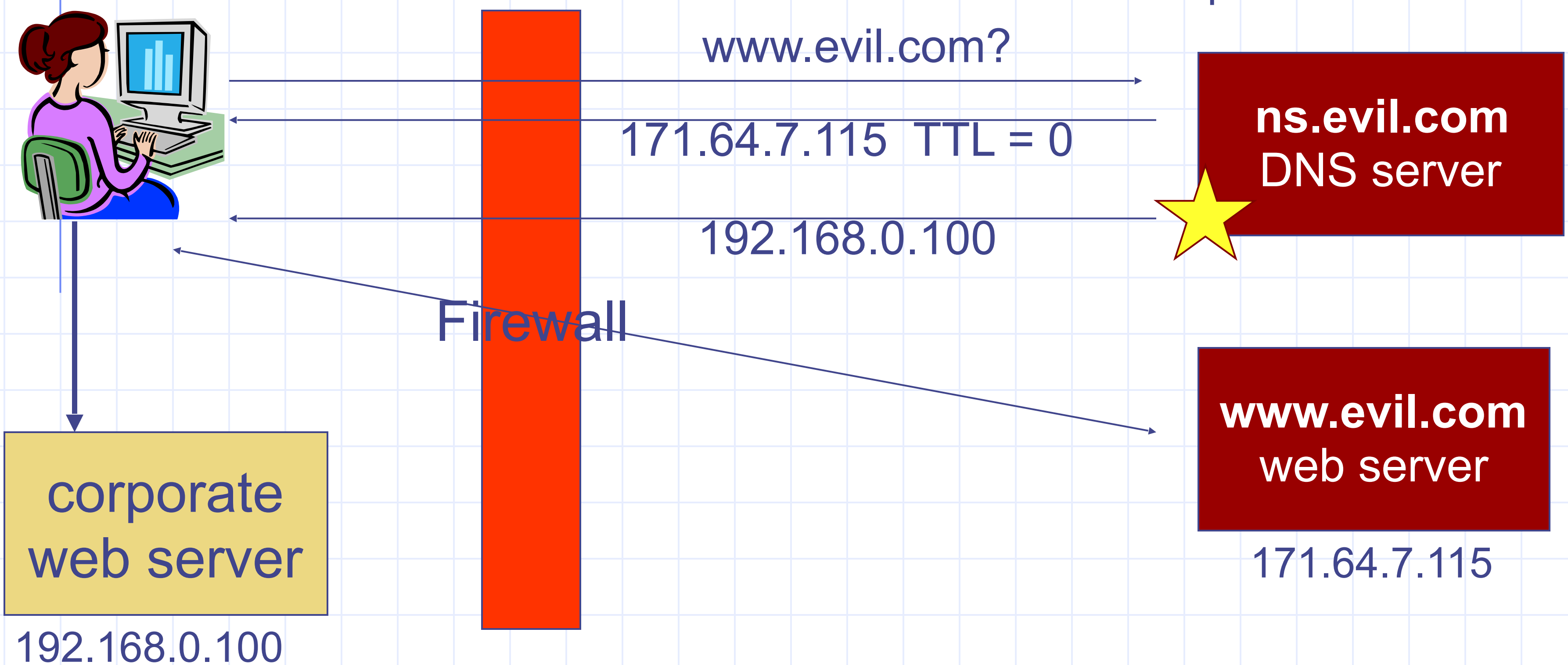
- Most DNS lookups result in denial-of-existence
- NSEC (Next SECure)
  - Lists all extant RRs associated with an owner name
  - Easy zone enumeration
- NSEC3
  - Hashes owner names
    - Public salt to prevent pre-computed dictionaries
  - NSEC3 chain in hashed order

[DWF'96, R'01]

DNS Rebinding Attack

<iframe src="**http://www.evil.com**">

DNSSEC cannot stop this attack



Read permitted: it's the "same origin"

DNS Rebinding Defenses

- Browser mitigation: DNS Pinning
  - Refuse to switch to a new IP
  - Interacts poorly with proxies, VPN, dynamic DNS, …
  - Not consistently implemented in any browser
- Server-side defenses
  - Check Host header for unrecognized domains
  - Authenticate users with something other than IP
- Firewall defenses
  - External names can’t resolve to internal addresses
  - Protects browsers inside the organization

Summary of this section

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

Summary

- Protecting network connections
  - Wireless security – 802.11i/WPA2
  - IPSEC
- Perimeter network perimeter defenses
  - Firewall
    - Packet filter (stateless, stateful),
    - Application layer proxies
  - Intrusion detection
    - Anomaly and misuse detection
- Network infrastructure security
  - BGP vulnerability and S-BGP
  - DNSSEC, DNS rebinding