Network vulnerabilities

INGI2347: COMPUTER SYSTEM SECURITY (Spring 2015)

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Lecture slides adapted from Upenn CSE331 by Steve Zdancewic and UC Berkeley CS161 by Vern Paxson
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Plan for today

Lecture 6

- Networking basics
- Networking attacks
  - Eavesdropping, sniffing
  - Spoofing
  - Session Hijacking
  - Cache poisoning
- Denial of Service (DoS)
  - SYN flooding

DARPA Internet Design Goals

"to develop an effective technique for multiplexed utilization of existing interconnected network" – D. Clark, The Design Philosophy of the DARPA Internet Protocols

- Secondary goals:
  - Tolerate loss of networks or gateways
  - Support multiple types of communications service
  - Accommodate a variety of networks
  - Permit distributed management of its resources
  - Be cost effective
  - Permit host attachment with a low level of effort
  - Used resources must be accountable
- Primarily designed for a benign and trustworthy environment

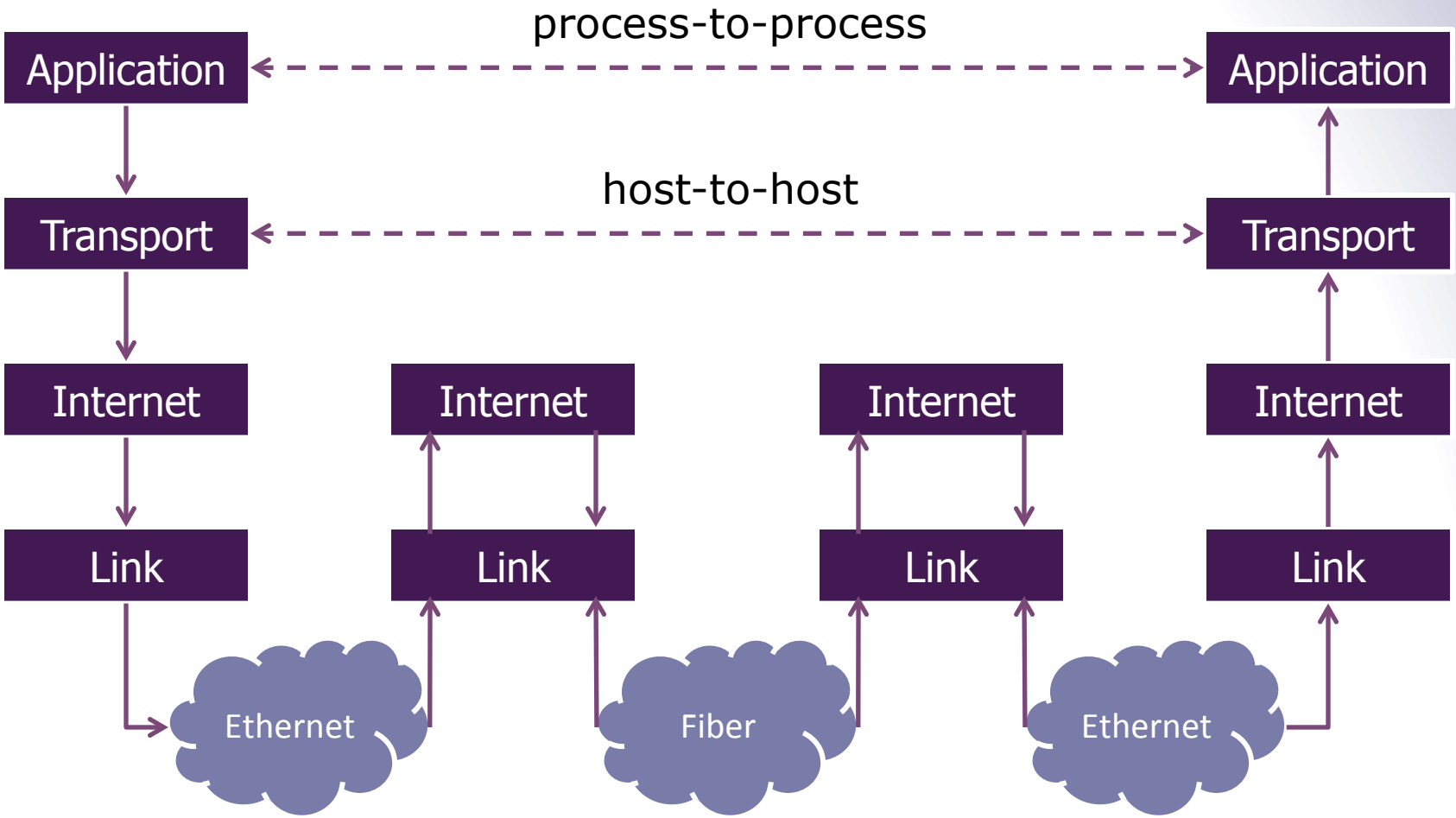
Layering

A result of abstraction in network design

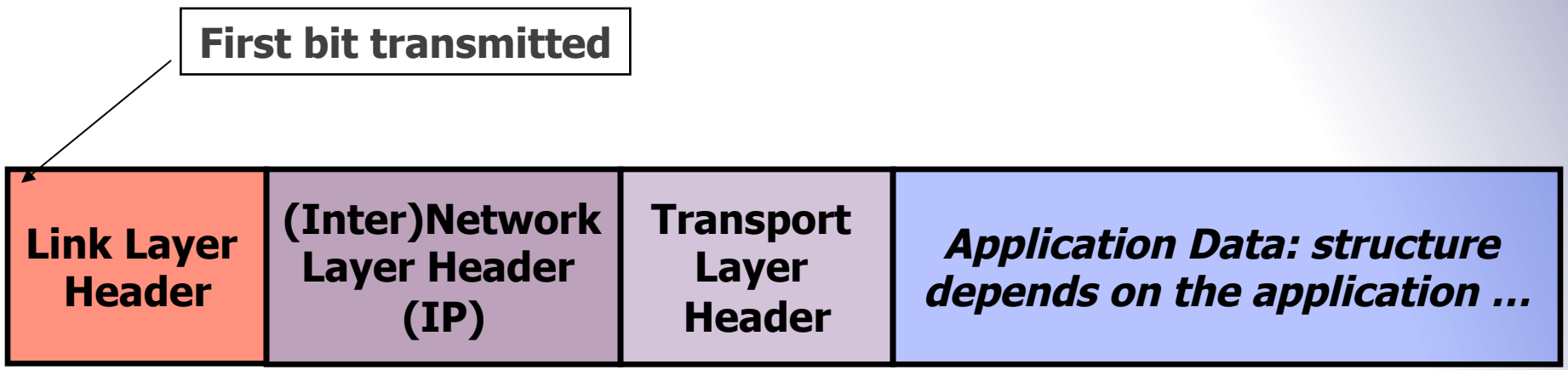
- Higher level services are implemented by using services at lower levels
- Advantages
  - Decompose problems
  - Modular changes

TCP/IP Layered Model	OSI Layered Model	
Application (e.g. SMTP, HTTP, Telnet)	Application	7
	Presentation	6
	Session	5
Transport (e.g. TCP, UDP)	Transport	4
Internet (e.g. IP, ARP, ICMP)	Network	3
Link (e.g. Ethernet, PPP, X25)	Data Link	2
	Physical	1

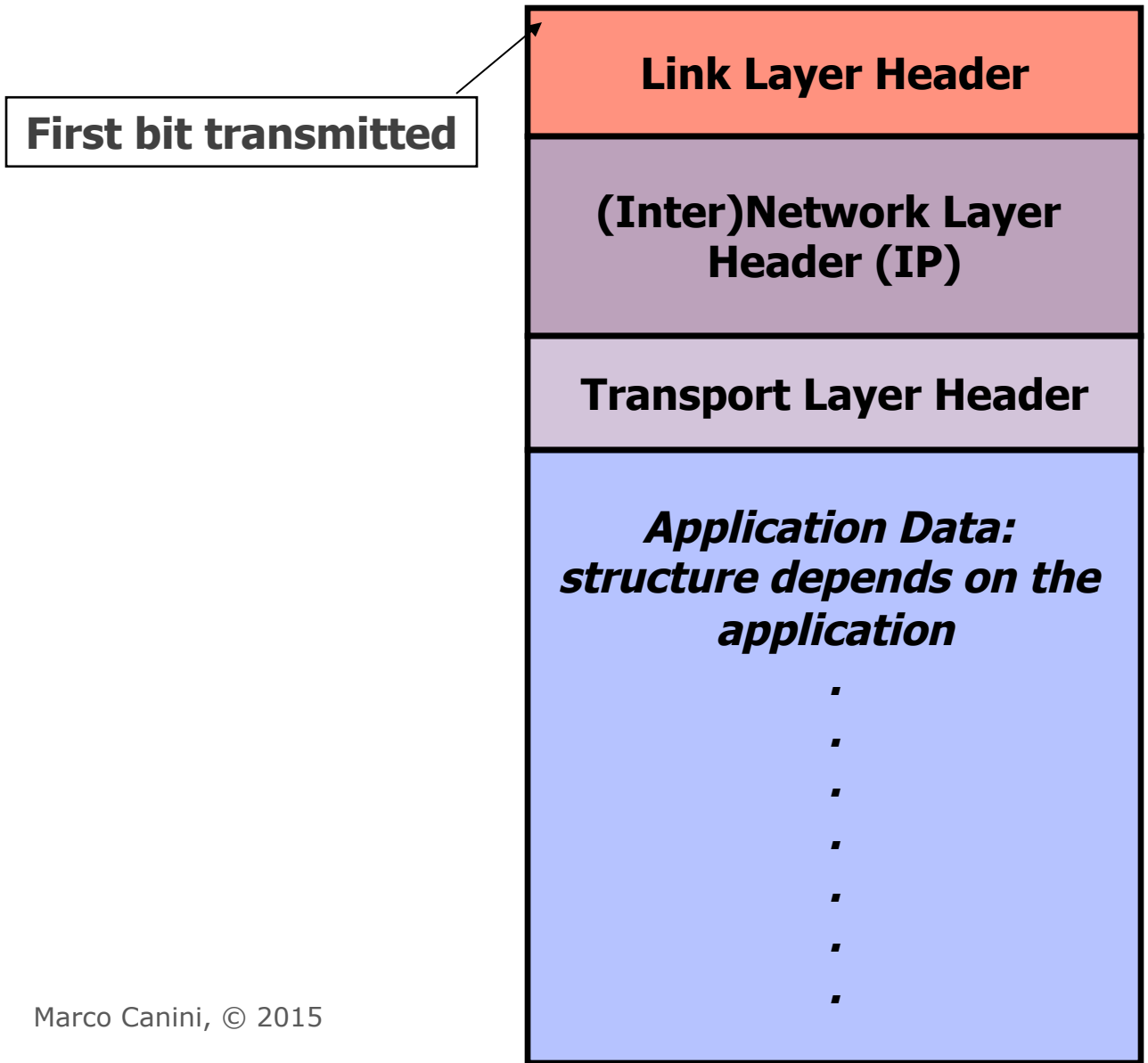
Data Flow


process-to-process
Application
Application
host-to-host
Transport
Transport
Internet
Internet
Internet
Internet
Link
Link
Link
Link
Ethernet
Fiber
Ethernet

Horizontal View of a Single Packet



Vertical View of a Single Packet

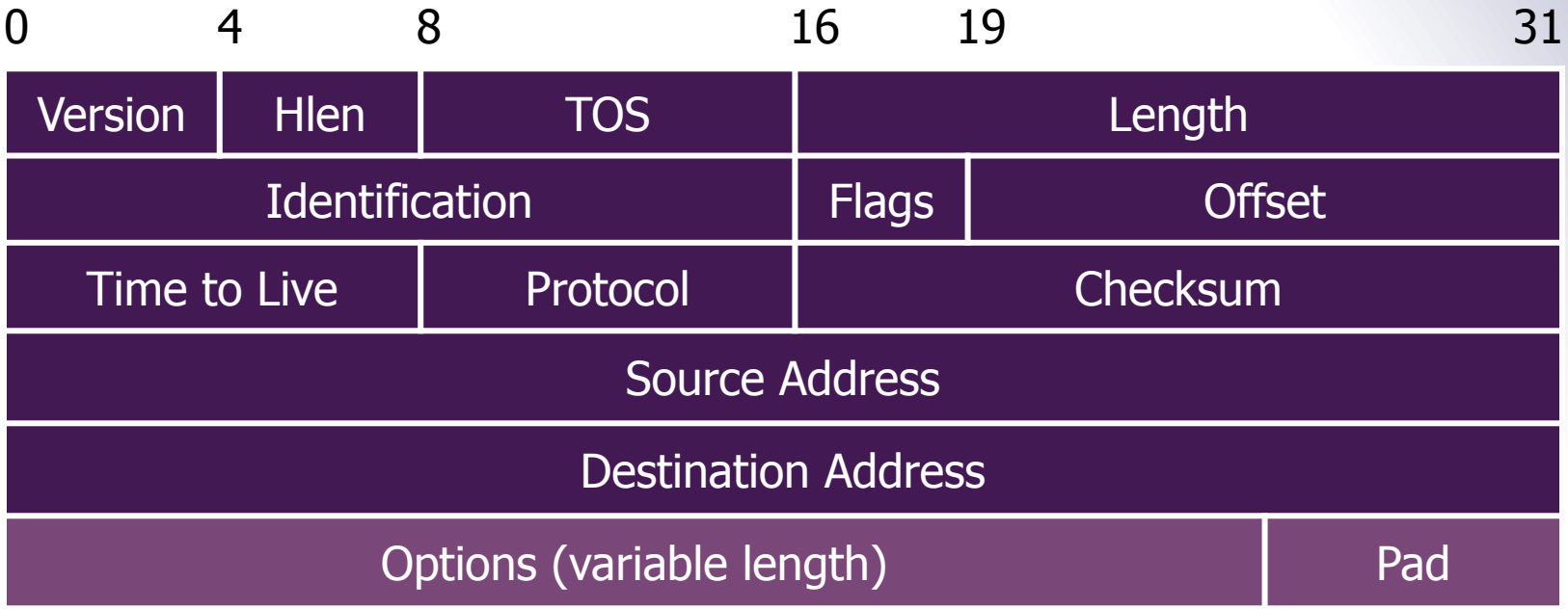


Recall IP

How does the router know where to forward a packet?

- IP adopts a datagram approach
  - Every packet (datagram) contains the destination IP address
  - Packets can be sent at anywhere at any time
  - Best-effort delivery (unreliable)

Recall IP



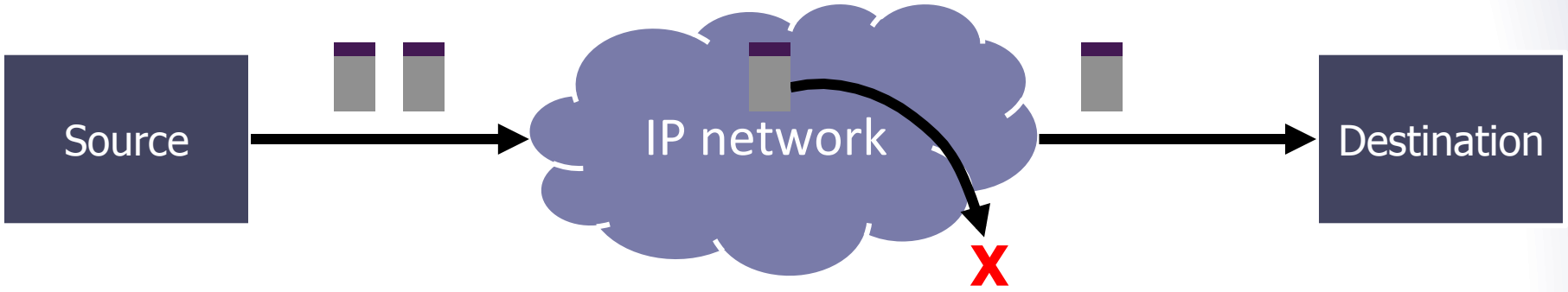
- Can you trust the contents?

Recall IP

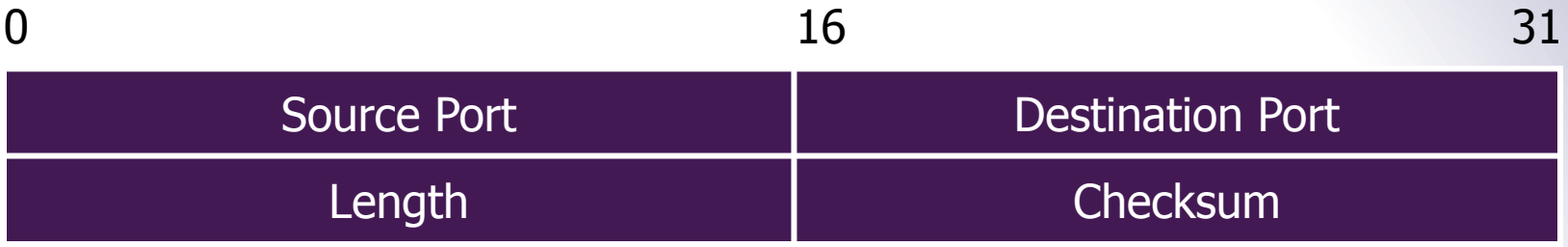
- Two IP addresses
  - Source IP address (32 bits)
  - Destination IP address (32 bits)
- Destination address
  - Unique identifier/locator for the receiving host
  - Allows each node to make forwarding decisions
- Source address
  - Unique identifier/locator for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send a reply back to source

IP: "Best Effort" Packet Delivery

- Routers inspect destination address, locate "next hop" in forwarding table
  - Address = ~unique identifier/locator for the receiving host
- Only provides a " *I'll give it a try* " delivery service:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order

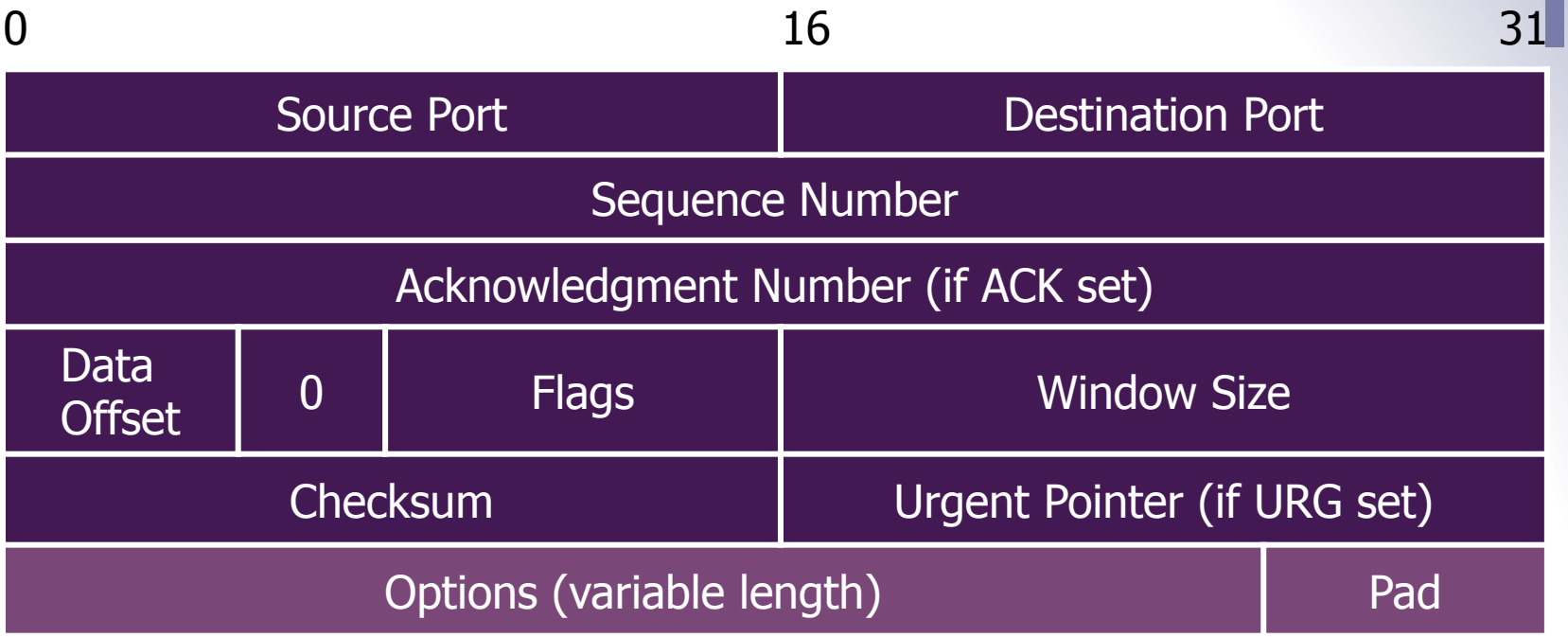


Recall UDP



- Minimal message-oriented transport protocol
- Provide no guarantees for message delivery
- Port numbers to perform application demultiplexing
  - e.g., port 53 is DNS, port 2049 is NFS, port 138 is Netbios

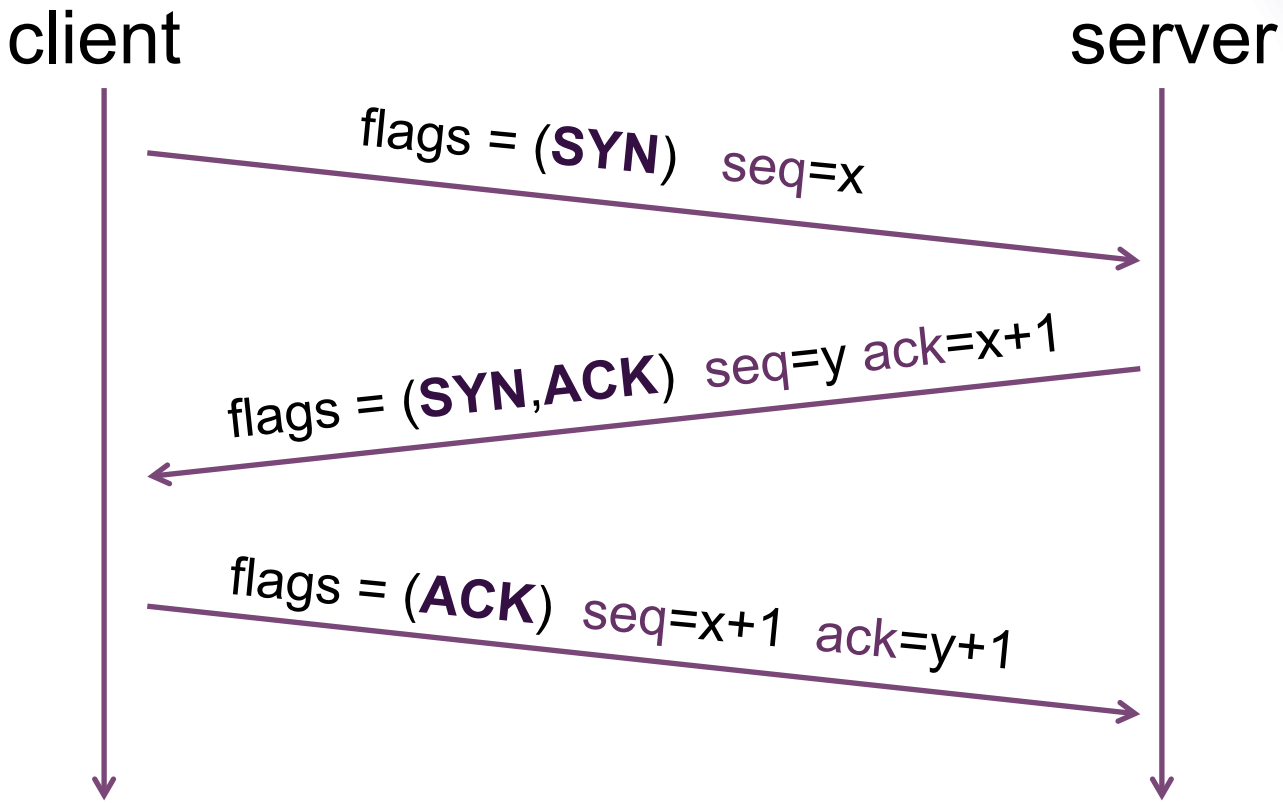
Recall TCP



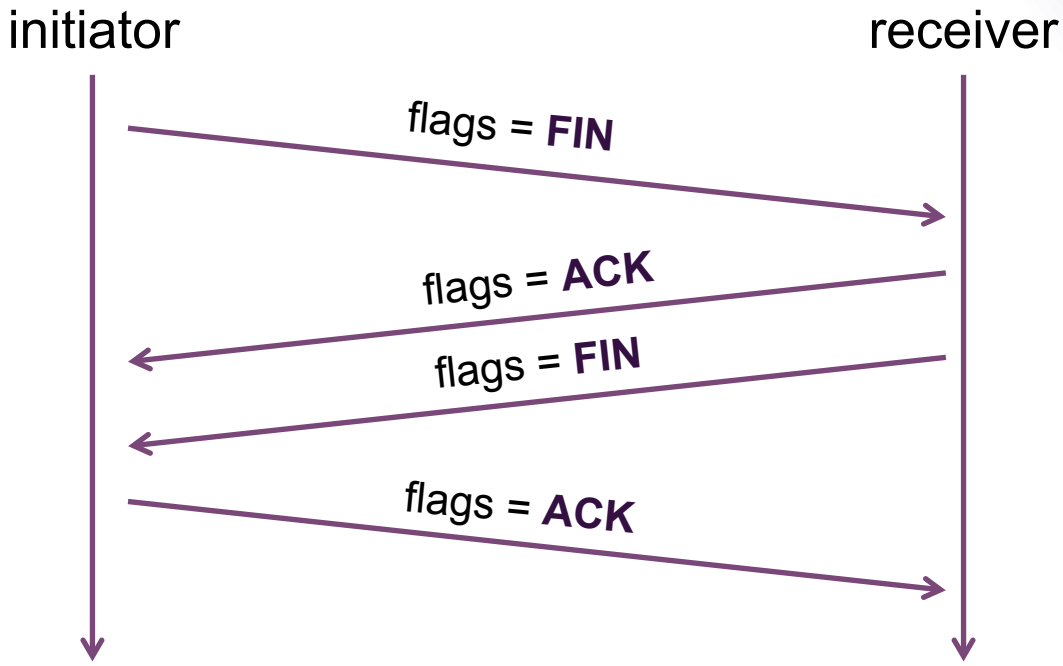
- Reliable, in-order message delivery
  - Sequence numbers identify the order of the bytes sent
  - Ack number specify the sequence number of the next expected byte
  - Sliding window flow control to not overflow receiver

TCP Connection Establishment

- 3-way handshake: SYN ; SYN + ACK ; ACK



TCP Connection Termination



- Each side of the connection terminates independently
  - A connection can be "half-open", in which case one side has terminated, but the other has not

Recall ARP (Address Resolution Protocol)

Problem:

- Need mapping between IP addresses and hardware addresses

- Solution: ARP
  - Every host maintains IP-HW address mapping table (cache)
  - Timeout associate with cached info (15 min)

- Sender
  - Broadcasts "Who is IP address X?"
  - Broadcast message includes sender's IP and HW addresses

- Receivers
  - Any host with sender in cache "refreshes" timeout
  - Host with IP address X replies "IP X has HW address Y"
  - Target host adds sender (if not already in cache)

Mapping Names to Addresses

- Domain Name System (DNS)
  - Hierarchical name space divided into sub-trees ("*zones*")
  - Zones distributed over collection of DNS *name servers*
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers (e.g. for *uclouvain.be*)

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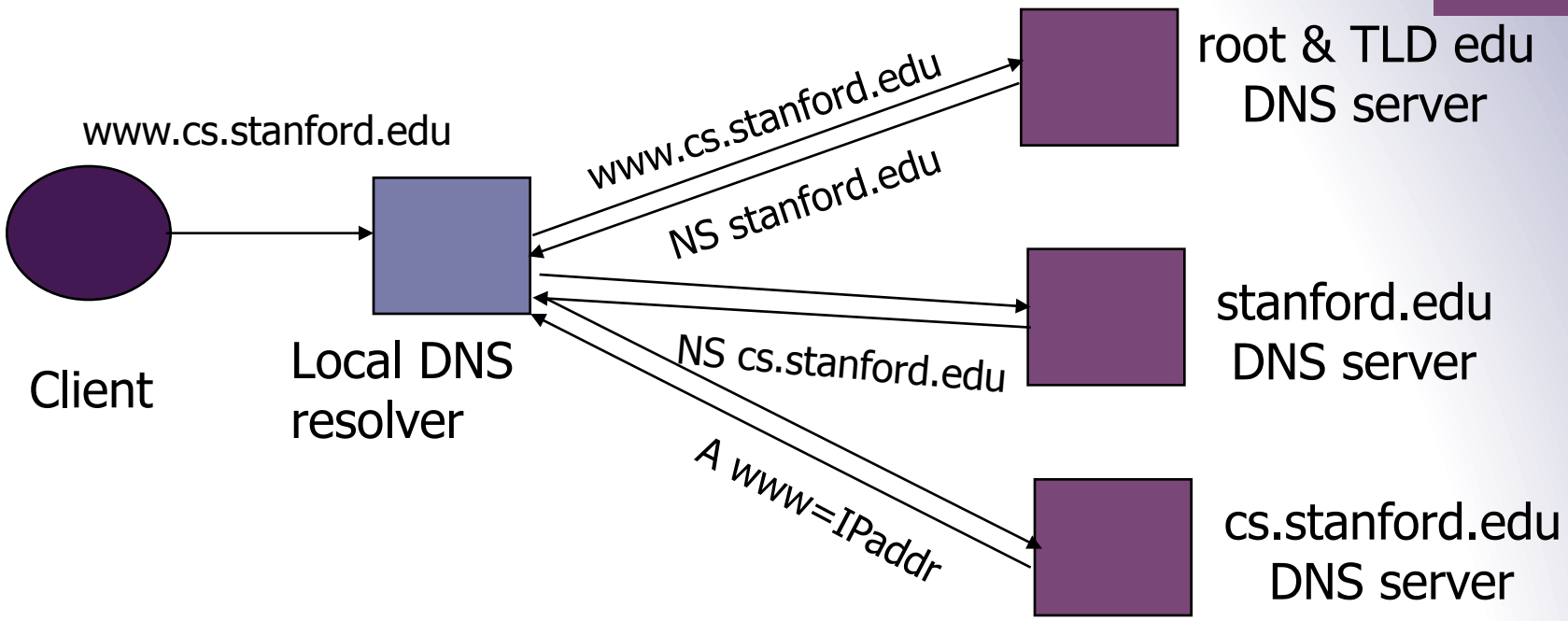
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers (e.g. for *uclouvain.be*)
- Performing the translations
  - Each computer configured to contact a *resolver*

DNS Lookup Example



DNS record types (partial list):

- NS: name server (points to other server)
- A: address record (contains IP address)
- MX: address in charge of handling email
- TXT: generic text (e.g. used to distribute site public keys)

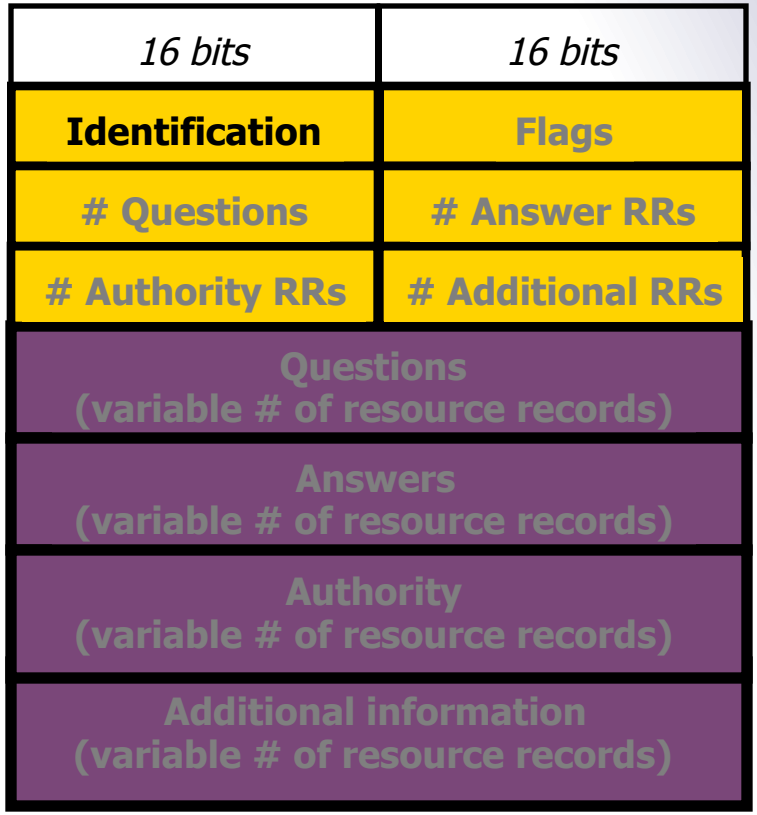
DNS Protocol

DNS protocol: *query* and *reply* messages, both with same *message format*

(Mainly uses UDP transport rather than TCP)

Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Replies can include "Authority" (name server responsible for answer) and "Additional" (info client is likely to look up soon anyway)
- Replies have a Time To Live (in seconds) for caching

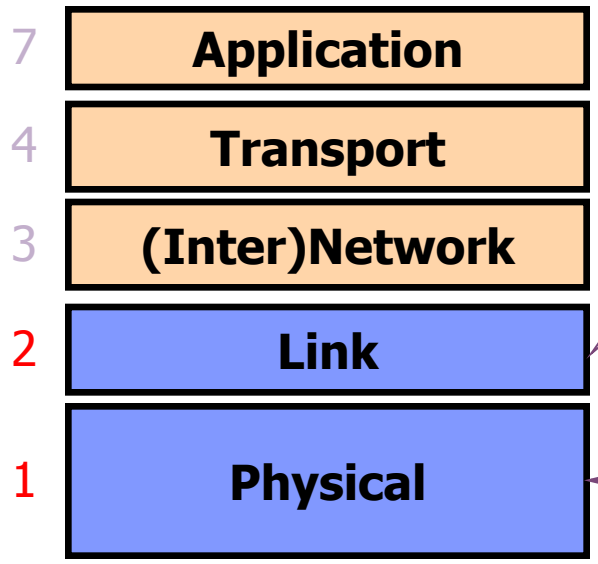


Network attacks

General Communication Security Goals: CIA

- Confidentiality:
  - No one can *read* our data / communication unless we want them to
- Integrity
  - No one can *manipulate* our data / processing / communication unless we want them to
- Availability
  - We can *access* our data / conduct our processing / use our communication capabilities when we want to
- Also: no *additional* traffic other than ours …

Layers 1 & 2: General Threats?



Framing and transmission of a collection of bits into individual messages sent across a single "subnetwork" (one physical technology)

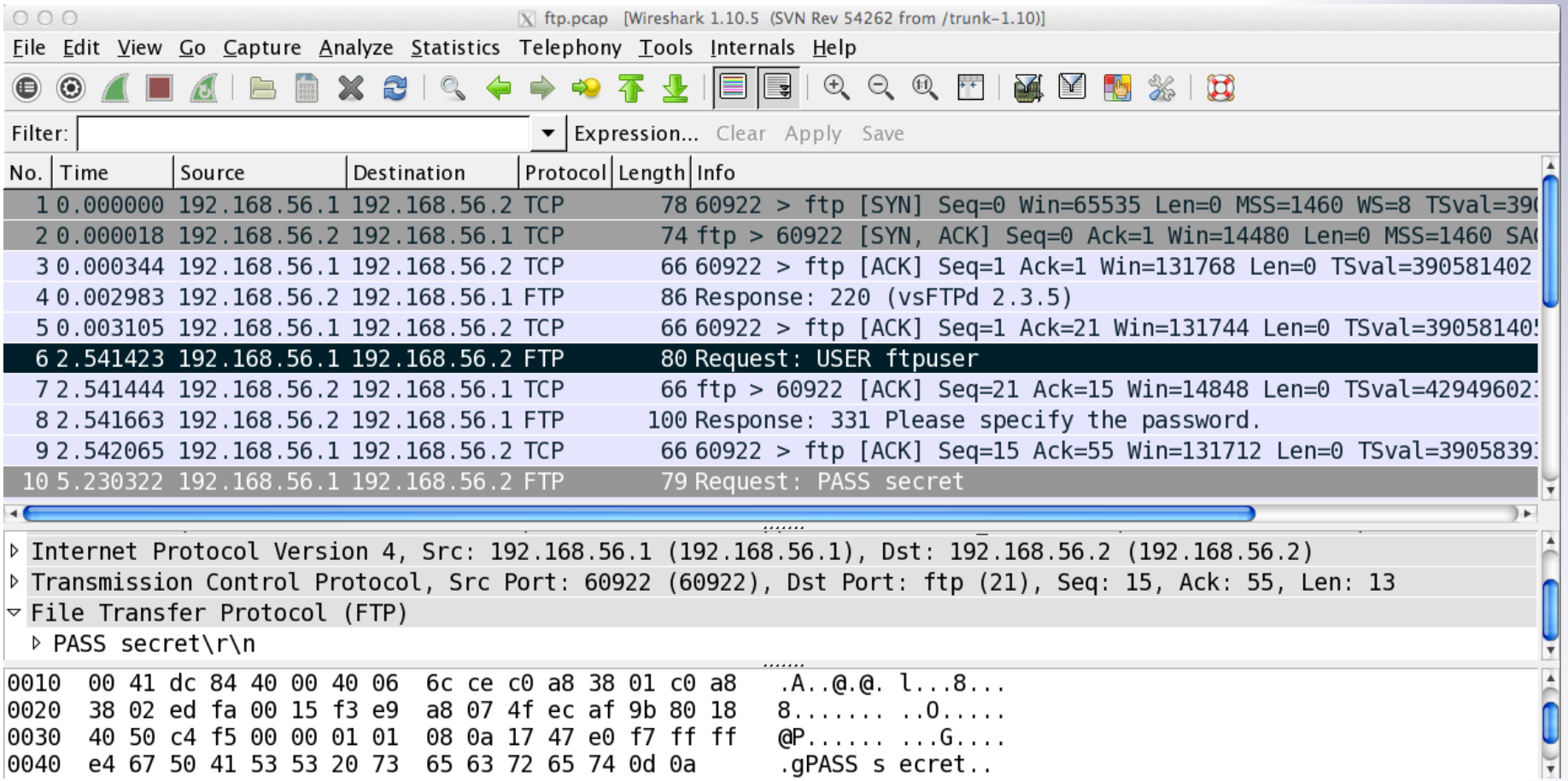
Encoding bits to send them over a single physical link

e.g. patterns of *voltage levels / photon intensities / RF modulation*

Physical/Link-Layer Threats: *Eavesdropping*

- Also termed *sniffing*
- For subnets using broadcast technologies (e.g., WiFi, some types of Ethernet), get it for "free"
  - Each attached system's NIC (= Network Interface Card) can capture any communication on the subnet
  - Some handy tools for doing so
    - tcpdump / windump (low-level ASCII printout)
    - Wireshark (GUI for displaying 800+ protocols)

Sniffing Tool: Wireshark



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  - Some handy tools for doing so
    - tcpdump / windump (low-level ASCII printout)
    - Wireshark (GUI for displaying 800+ protocols)
- For any technology, routers (and internal "switches") can look at / export traffic they forward
- You can also "tap" a link
  - Insert a device to mirror physical signal
    - Or: just steal it!

Physical/Link-Layer Threats: Disruption

- With physical access to a subnetwork, attacker can
  - Overwhelm its signaling
    - E.g., jam WiFi's RF
  - Send messages that violate the protocol's rules
    - E.g., send messages > maximum allowed size, sever timing synchronization, ignore fairness rules
- Routers & switches can simply "drop" traffic
- There's also the heavy-handed approach …

Sabotage attacks knock out phone service

Nanette Asimov, Ryan Kim,Kevin Fagan, Chronicle Staff Writers
Friday, April 10, 2009

PRINT E-MAIL SHARE COMMENTS (477) FONT | SIZE:

(04-10) 04:00 PDT SAN JOSE --

Police are hunting for vandals who chopped fiber-optic cables and killed landlines, cell phones and Internet service for tens of thousands of people in Santa Clara, Santa Cruz and San Benito counties on Thursday.

IMAGES

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The sabotage essentially froze operations in parts of the three counties at hospitals, stores, banks and police and fire departments that rely on 911 calls, computerized medical records, ATMs and credit and debit cards.

The full extent of the havoc might not be known for days, emergency officials said as they finished repairing the damage late Thursday.

Whatever the final toll, one thing is certain: Whoever did this is in a world of trouble if he, she or they get caught.

"I pity the individuals who have done this," said San Jose Police Chief Rob Davis.

Ten fiber-optic cables carrying were cut at four locations in the predawn darkness. Residential and business customers quickly found that telephone service was perhaps more laced into their everyday needs than they thought. Suddenly they couldn't draw out money, send text messages, check e-mail or Web sites, call anyone for help, or even check on friends or relatives down the road.

Several people had to be driven to hospitals because they were unable to summon ambulances. Many businesses lapsed into idleness for hours, without the ability to contact associates or customers.

More than 50,000 landline customers lost service - some were residential, others were business lines that needed the connections for ATMs, Internet and bank card transactions. One line alone could affect hundreds of users.

UPDATE LOOK Vancouver's Venues Shine Update

NEWS | LOCAL BEAT

$250K Reward Out for Vandals Who Cut AT&T Lines

Local emergency declared during outage

By LORI PREUITT

Updated 2:12 PM PST, Fri, Apr 10, 2009

PRINT EMAIL SHARE BUZZ UP! TWITTER FACEBOOK

AT&T is now offering a $250,000 reward for information leading to the arrest of whoever is responsible for severing lines fiber optic cables in San Jose tha left much of the area without phone or cell service Thursday.

John Britton of AT&T said the reward is the largest ever offered by the company.

Marco Cantù, © 2015

Physical/Link-Layer Threats: Spoofing

- With physical access to a subnetwork, attacker can create any message they like
  - When with a bogus source address: spoofing
- When using a typical computer, may require root/ administrator to have full freedom
- Particularly powerful when combined with eavesdropping
  - Because attacker can understand exact state of victim's communication and craft their spoofed traffic to match it
  - Spoofing w/o eavesdropping = blind spoofing

ARP Spoofing

- Recall: ARP maps between IP addresses and hardware addresses
- ARP is very simple and insecure
  - client: who knows the Ethernet address of 1.2.3.4?
  - anybody: 1.2.3.4 has Ethernet address 01:02:03:04:05:06
- It is easy to forge responses (even non-solicited) to redirect traffic!

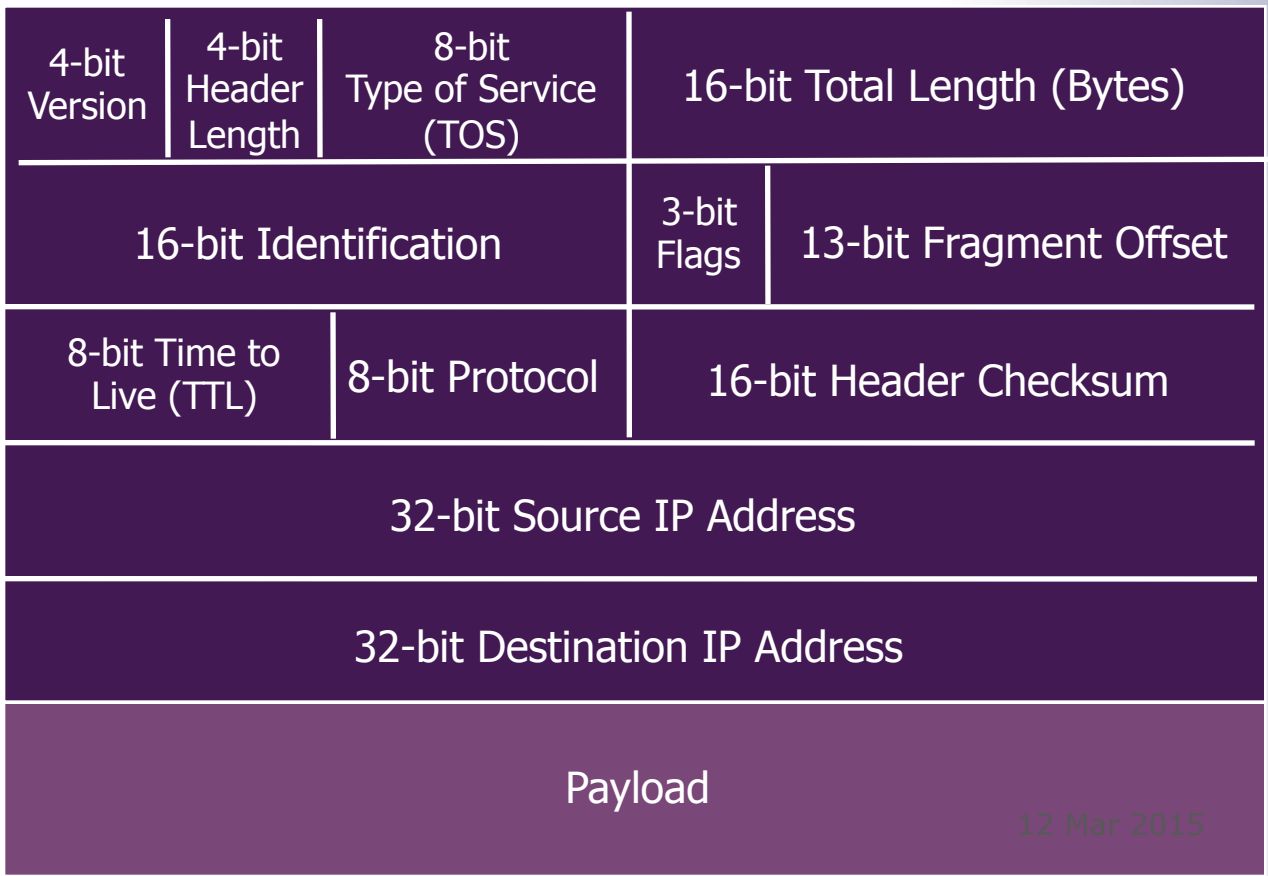
Spoofing Considerations

- "On path" attackers can see victim's traffic ⇒ spoofing is easy
- "Off path" attackers can't see victim's traffic
  - They have to resort to blind spoofing
  - Often must guess/infer header values to succeed
    - We then care about work factor: how hard is this
  - But sometimes they can just brute force
    - E.g., 16-bit value: just try all 65,536 possibilities!
- When we say an attacker "can spoof", we usually mean "with reasonable chance of success"

Layer 3: General Threats?

7	**Application**
4	**Transport**
3	**(Inter)Network**
2	**Link**
1	**Physical**

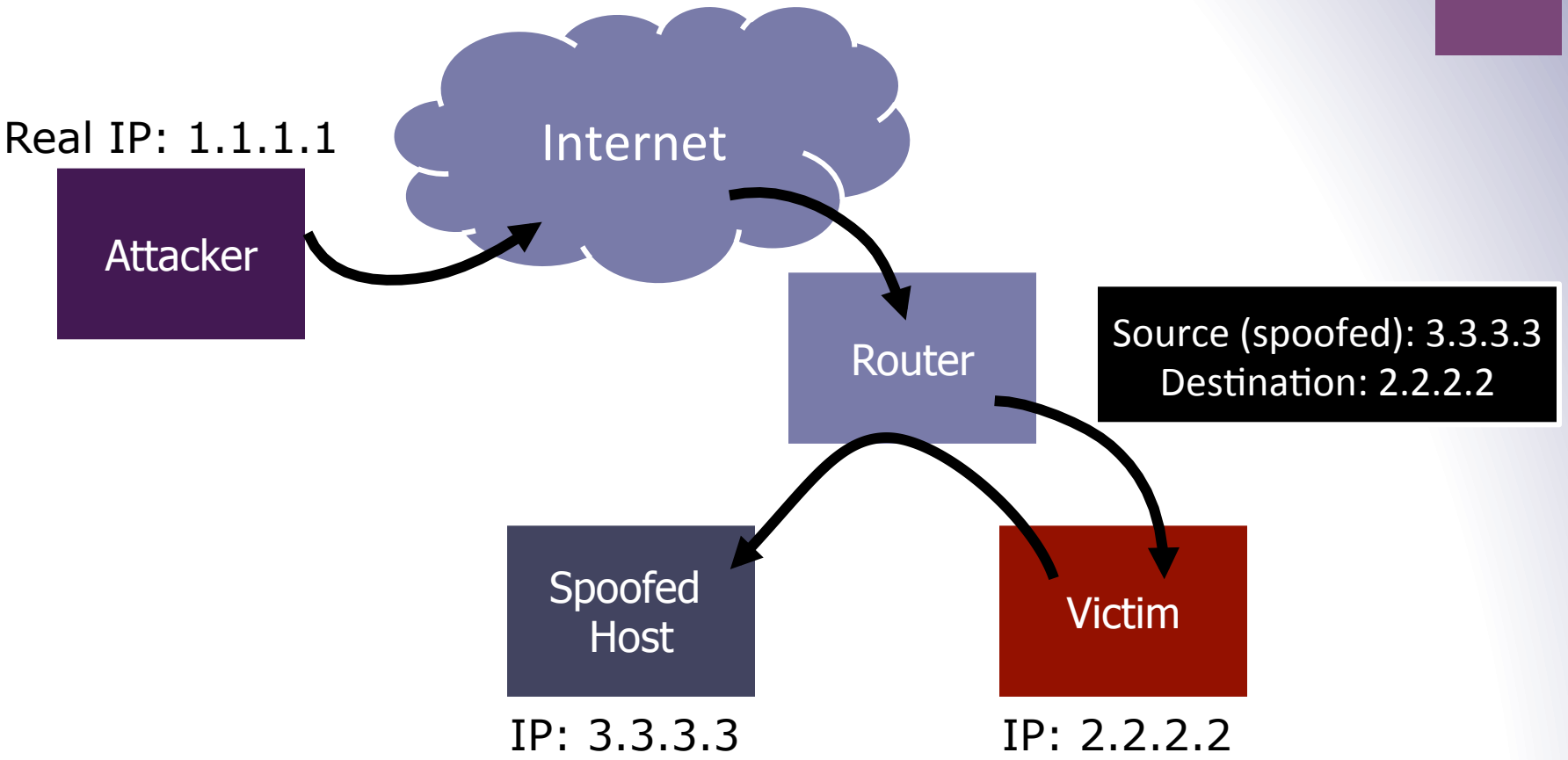
Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes



Network-Layer (IP) Threats

- Can set arbitrary source address
  - "Spoofing" – receiver has no idea who you are
  - Could be blind, or could be coupled with sniffing
  - Note: many attacks require two-way communication
    - So successful off-path/blind spoofing might not suffice
- Can set arbitrary destination address
  - Enables "scanning" – brute force searching for hosts
- Can send like crazy (flooding)
  - IP has no general mechanism for tracking overuse
  - IP has no general mechanism for tracking consent
  - Very hard to tell where a spoofed flood comes from!
- **If** attacker can manipulate routing, can bring traffic to themselves for eavesdropping (viewed as hard)

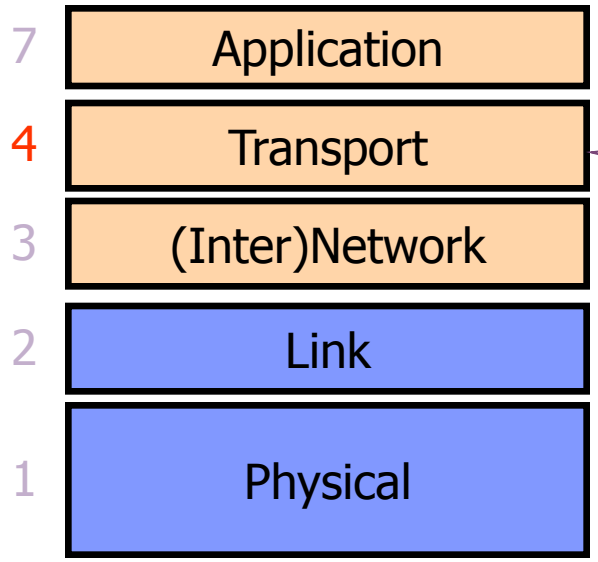
IP Spoofing Example



IP Spoofing

- The response to a forged message is sent to the forged source address
  - Spoofing mainly used when an attacker does not care about response
  - The LAN is a special case as the attacker can observe the response
- Easy to use with protocols based on UDP
- Spoofing a TCP connection is more difficult
  - Recall 3-way handshake: SYN ; SYN + ACK ; ACK

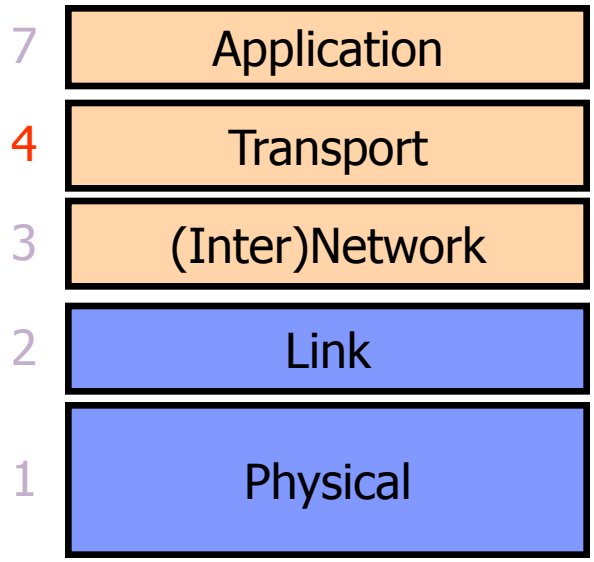
Layer 4: General Threats?



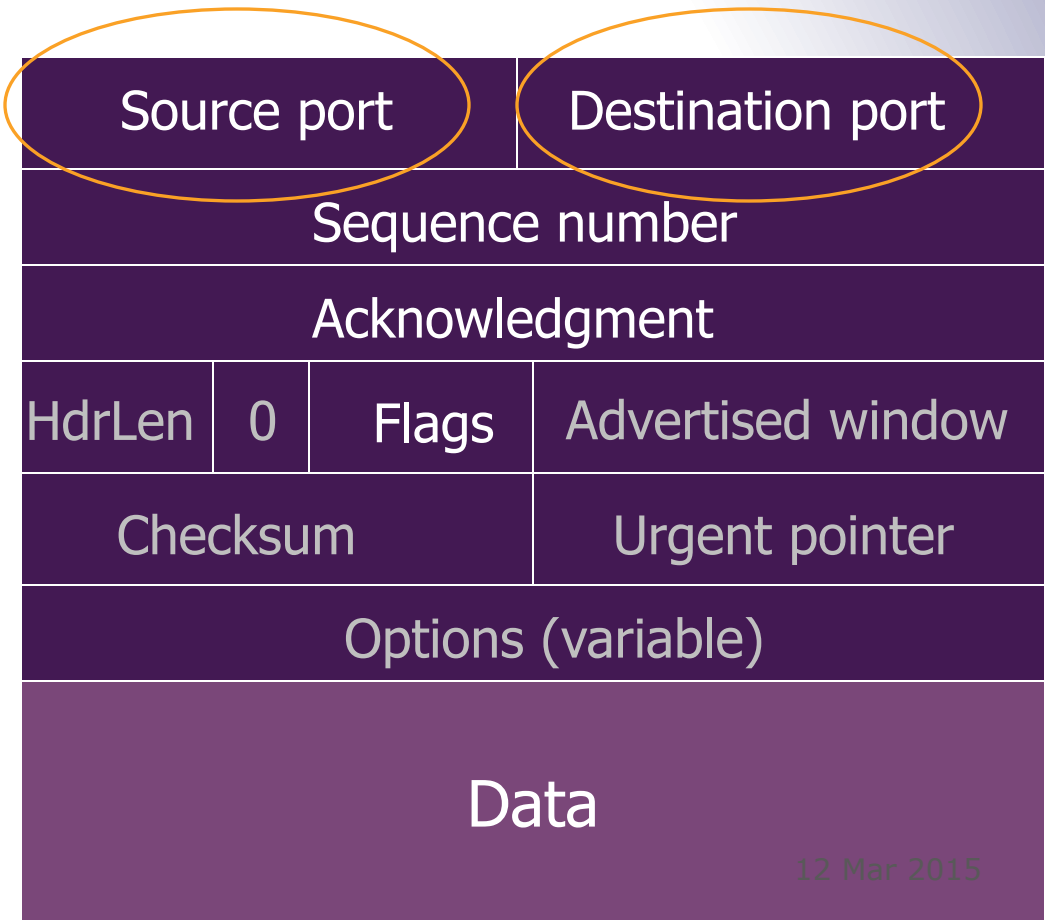
End-to-end communication between processes (TCP, UDP)

Source port	Destination port
Sequence number	
Acknowledgment	
HdrLen | 0 | Flags	Advertised window
Checksum	Urgent pointer
Options (variable)	
Data	

Layer 4: General Threats?



These plus IP addresses define a given connection



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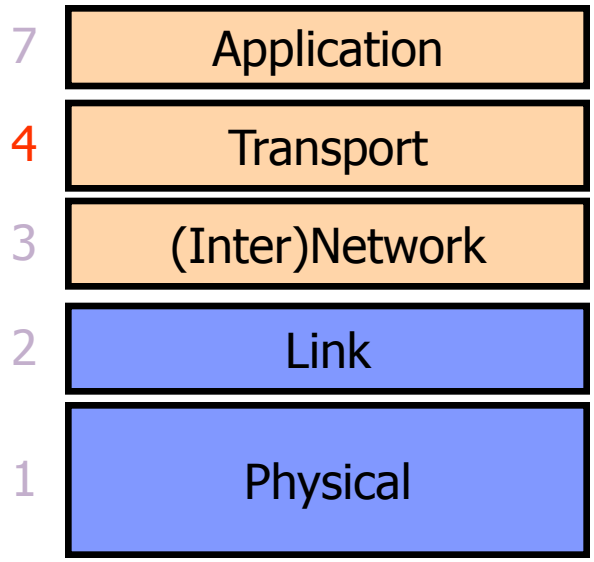
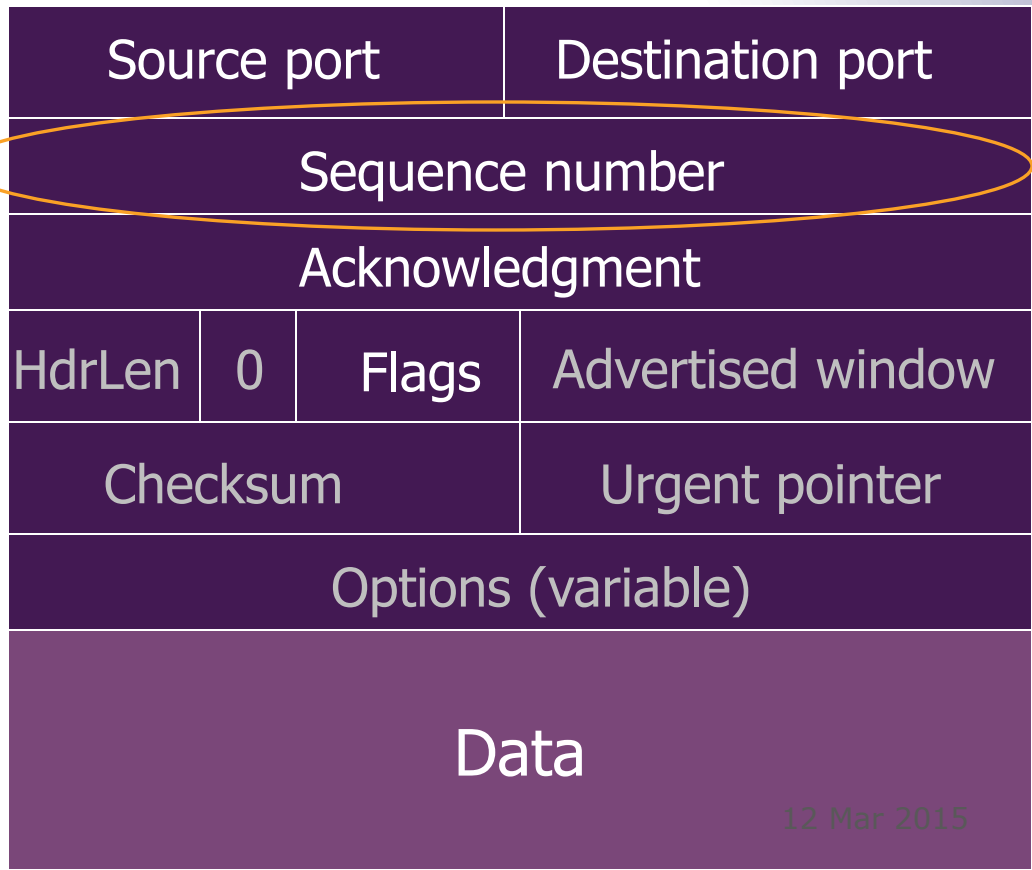
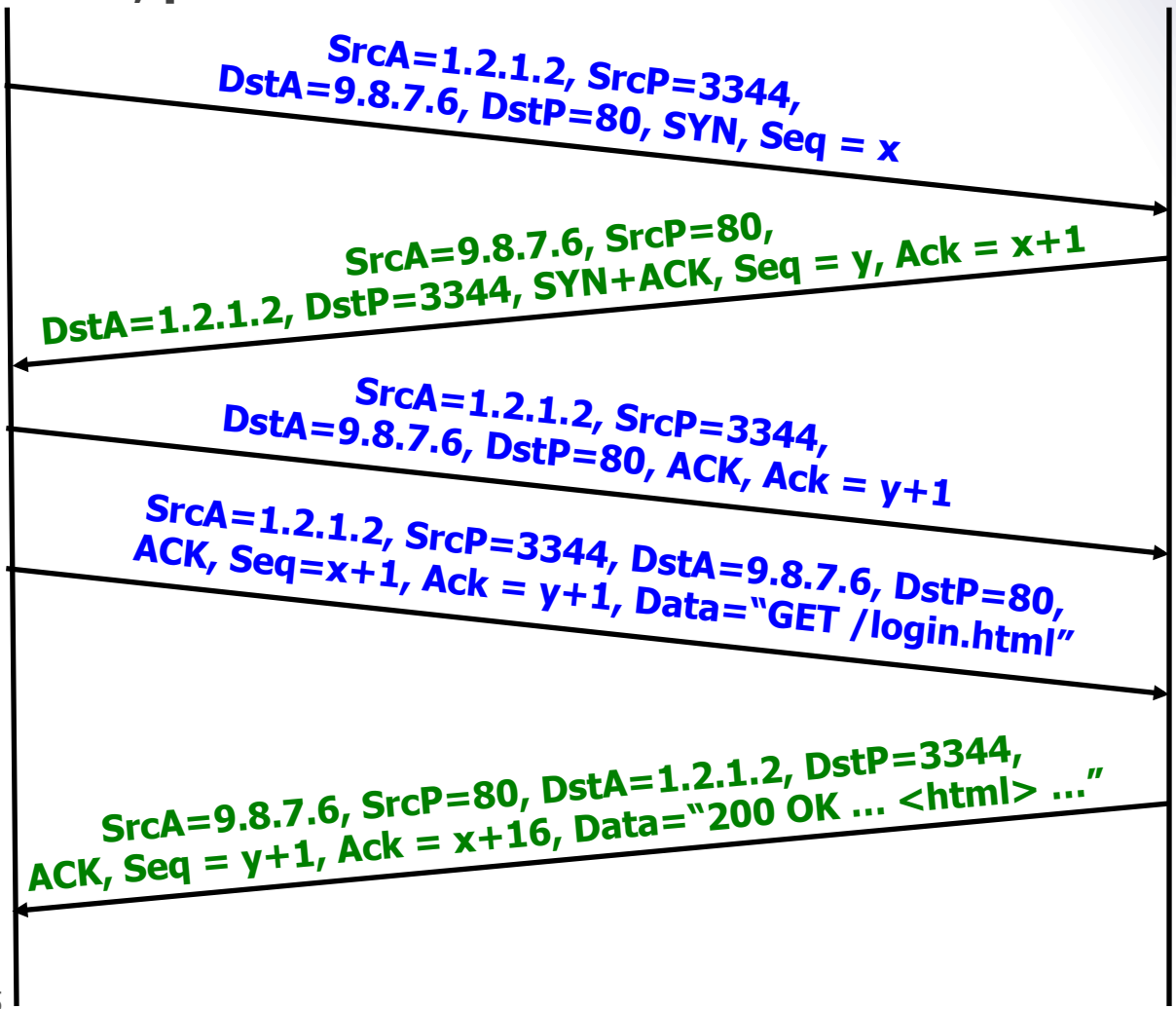


Defines where this packet fits within the sender's bytestream

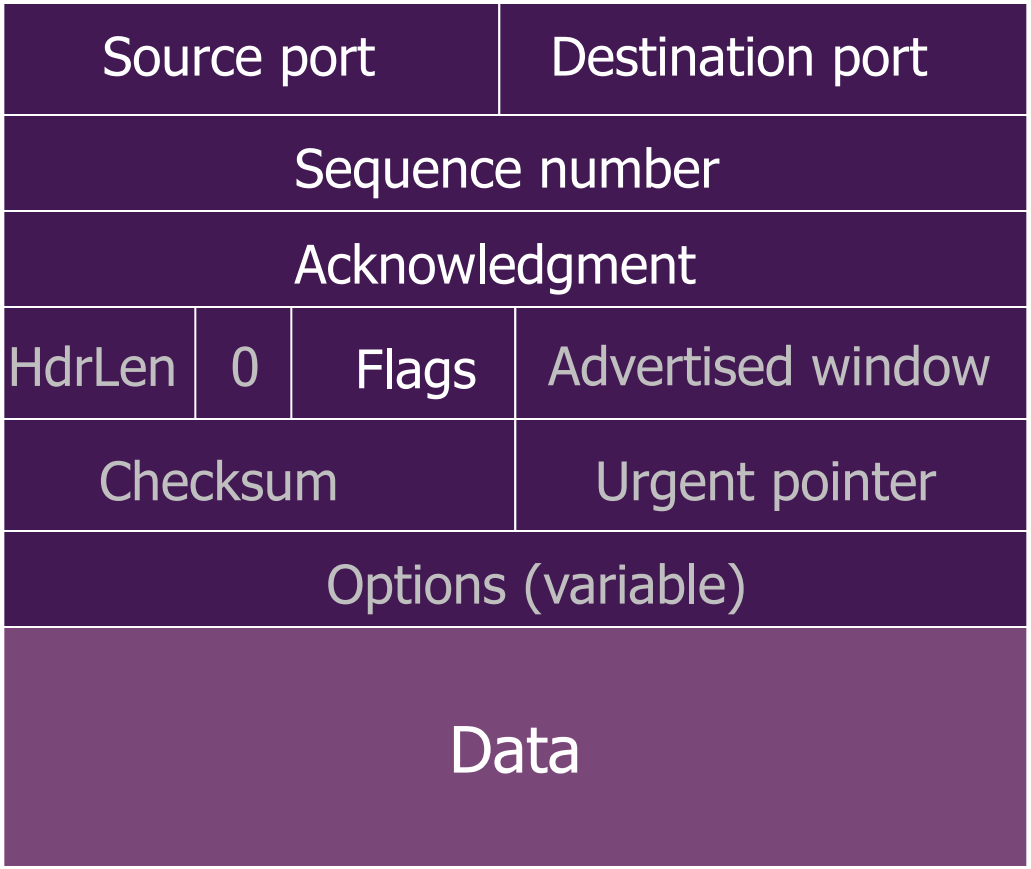


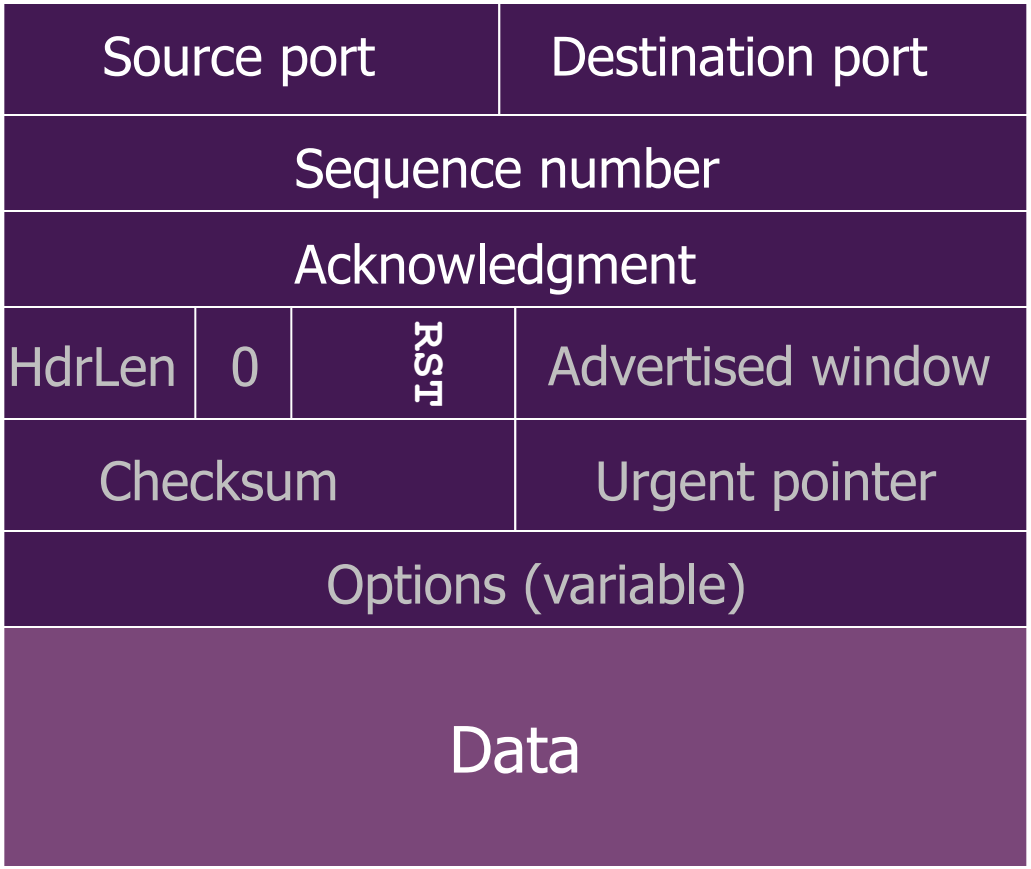
TCP Conn. Setup & Data Exchange



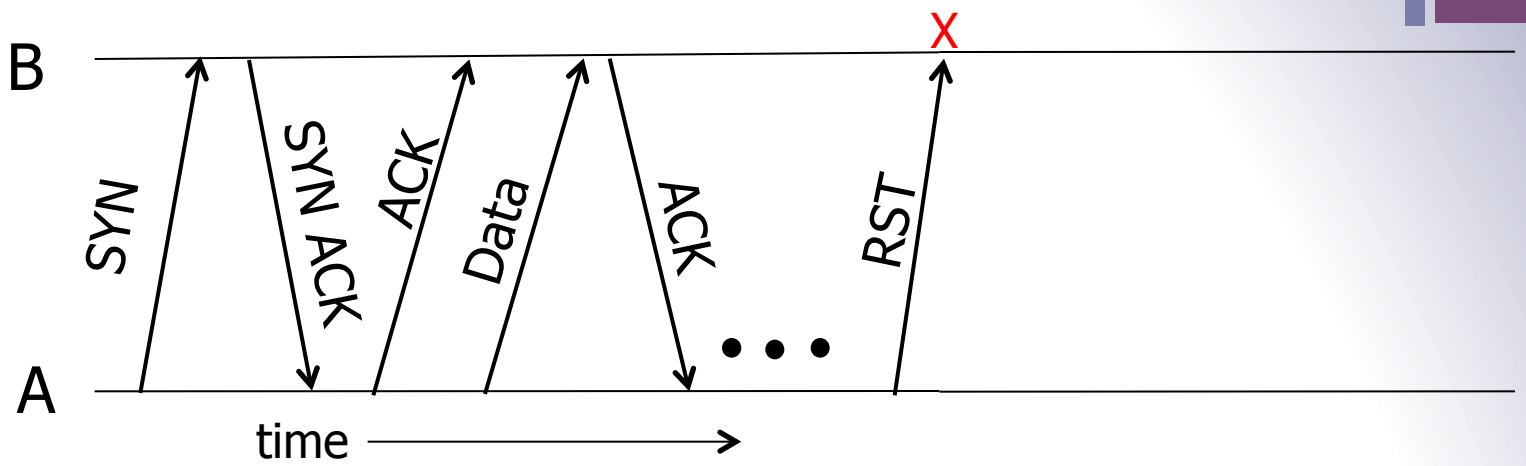
TCP Threat: Disruption

- Normally, TCP finishes ("closes") a connection by each side sending a FIN control message
  - Reliably delivered, since other side must ack
- But: if a TCP endpoint finds unable to continue (process dies; info from other "peer" is inconsistent), it abruptly terminates by sending a RST control message
  - Unilateral
  - Takes effect immediately (no ack needed)
  - Only accepted by peer if has correct sequence number


Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data


Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
RST
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

Abrupt Termination



- A sends a TCP packet with RESET (**RST**) flag to B
  - E.g., because app. process on A crashed
  - (Could instead be that B sends a RST to A)
- Assuming that the sequence numbers in the **RST** fit with what B expects, That's It:
  - B's user-level process receives: ECONNRESET
  - No further communication on connection is possible

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- But: if a TCP endpoint finds unable to continue (process dies; info from other "peer" is inconsistent), it abruptly terminates by sending a RST control message
  - Unilateral
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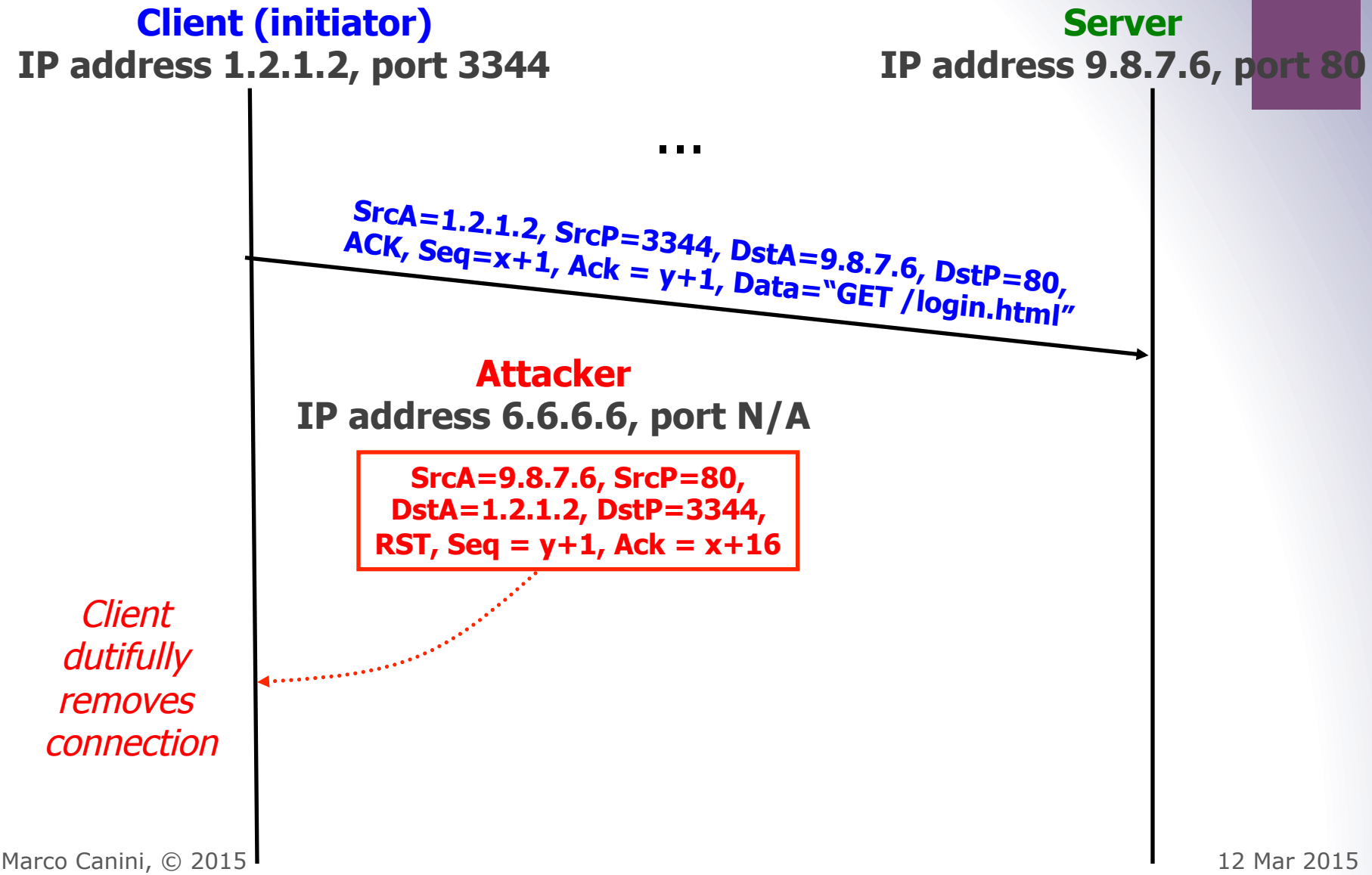
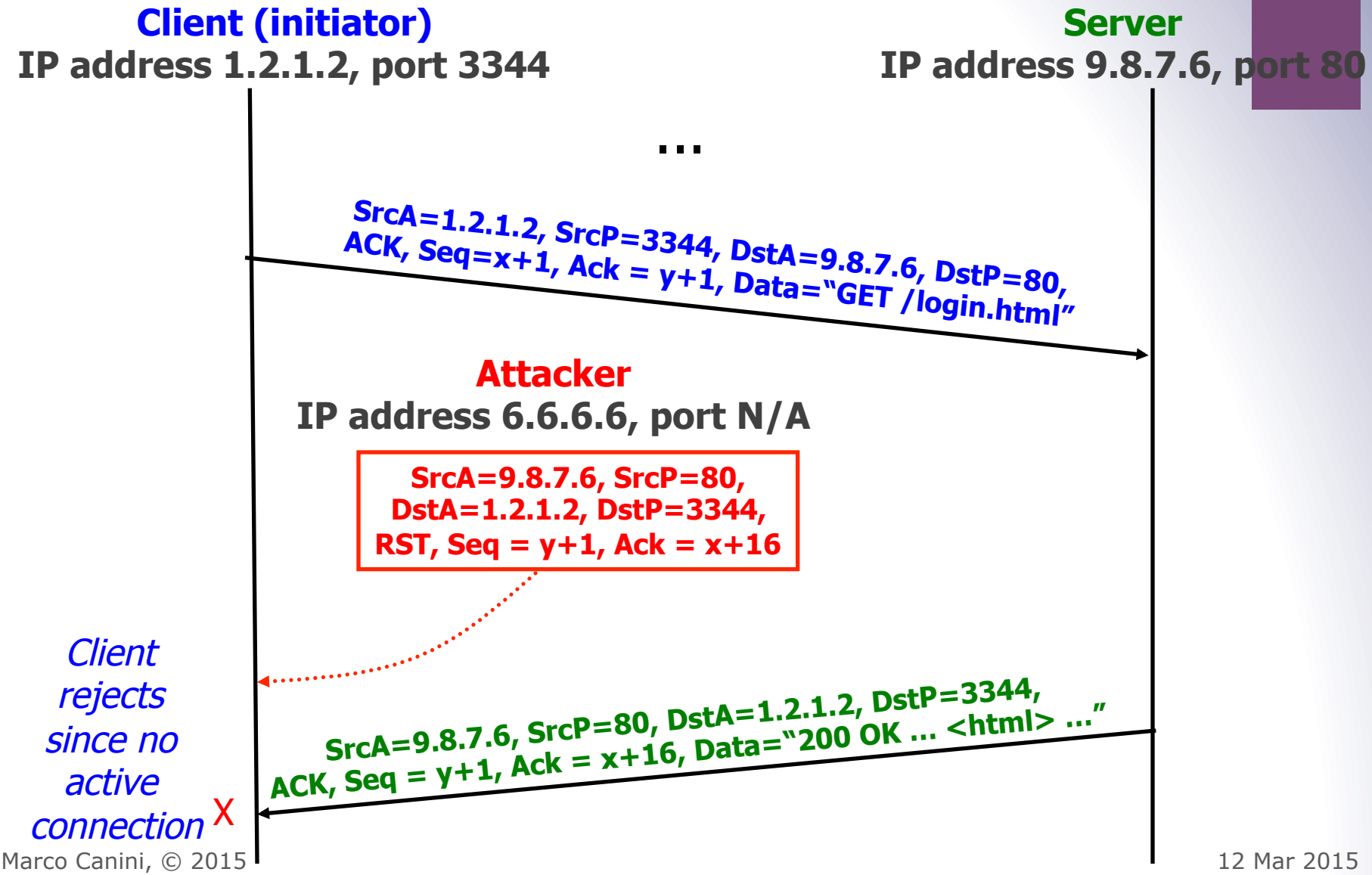
  - Only accepted by peer if has correct sequence number
- So: if attacker knows ports & sequence numbers, can disrupt any TCP connection

TCP RST Injection



TCP RST Injection

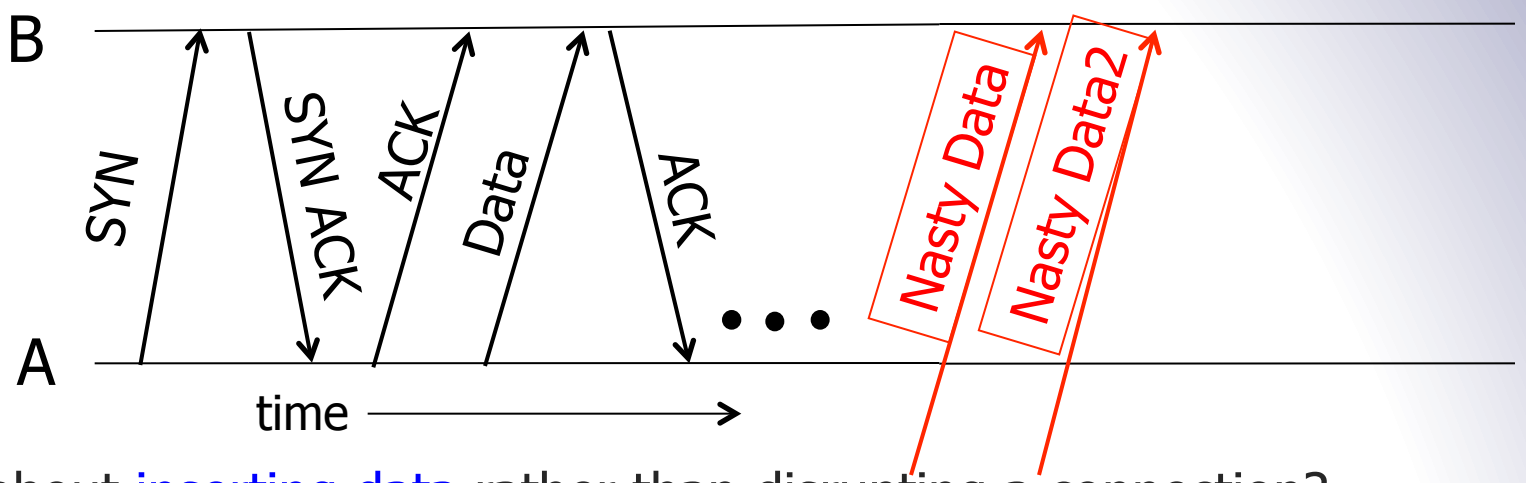


Example DoS: RST Injection

- Attacker sends a RST packet to an open socket at s
  - If correct SN_S then connection will close ⇒ DoS
  - Naively, success prob. is $1/2^{32}$ (32-bit seq. #'s).
    - … but, many systems allow for a large window of acceptable seq. #. Much higher success probability.
  - Attacker can flood with RST packets until one works

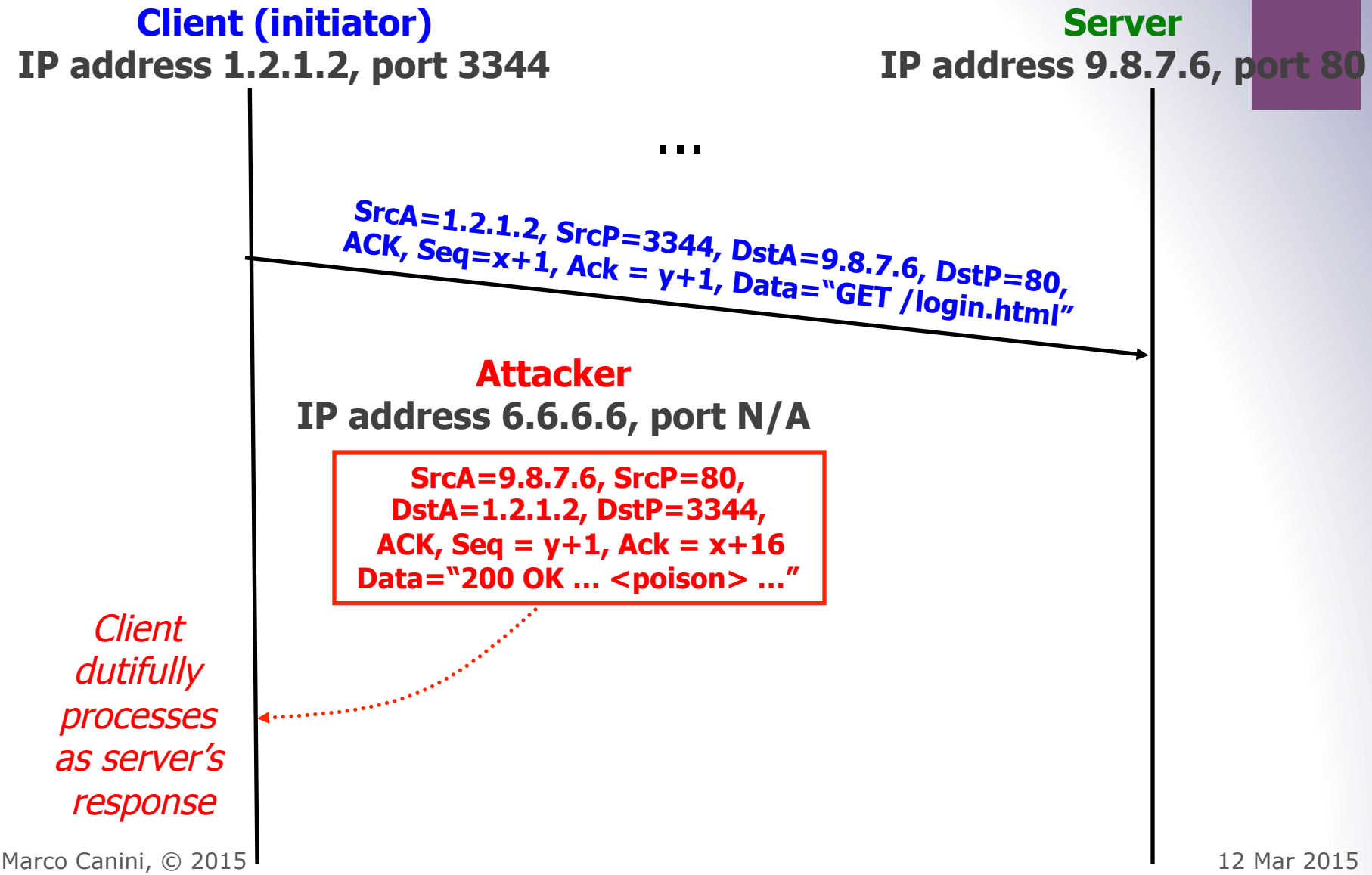
- Most effective against long lived connections
  - E.g. BGP

TCP Threat: Data Injection

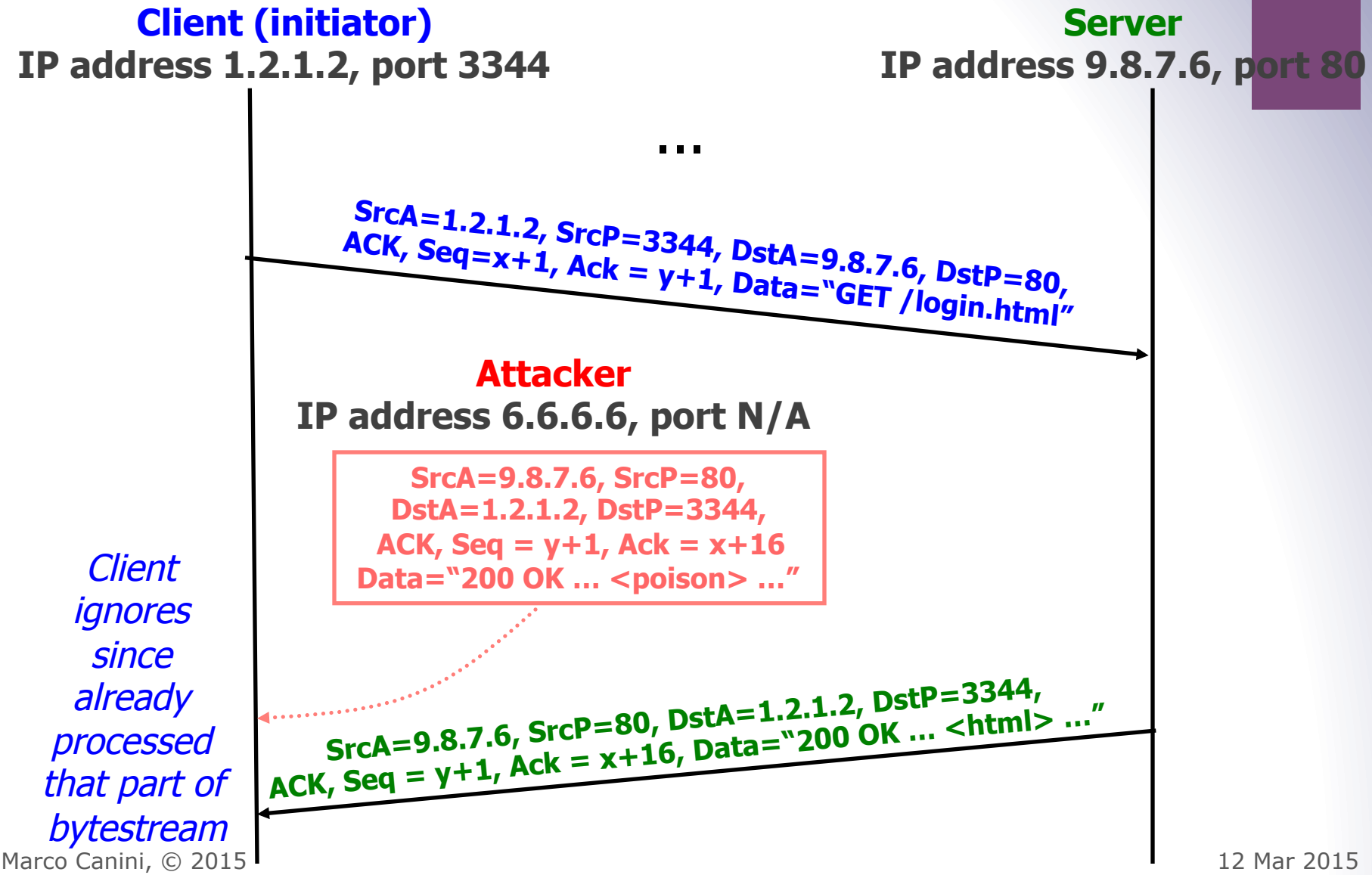


- What about inserting data rather than disrupting a connection?
  - Again, all that's required is attacker knows correct ports, seq. numbers
  - Receiver B is *not any wiser!*
- Termed TCP connection hijacking (or "*session hijacking*")
  - A general means to take over an already-established connection!
- We are toast if an attacker can see our TCP traffic!
  - Because then they immediately know the port & sequence numbers

TCP Data Injection



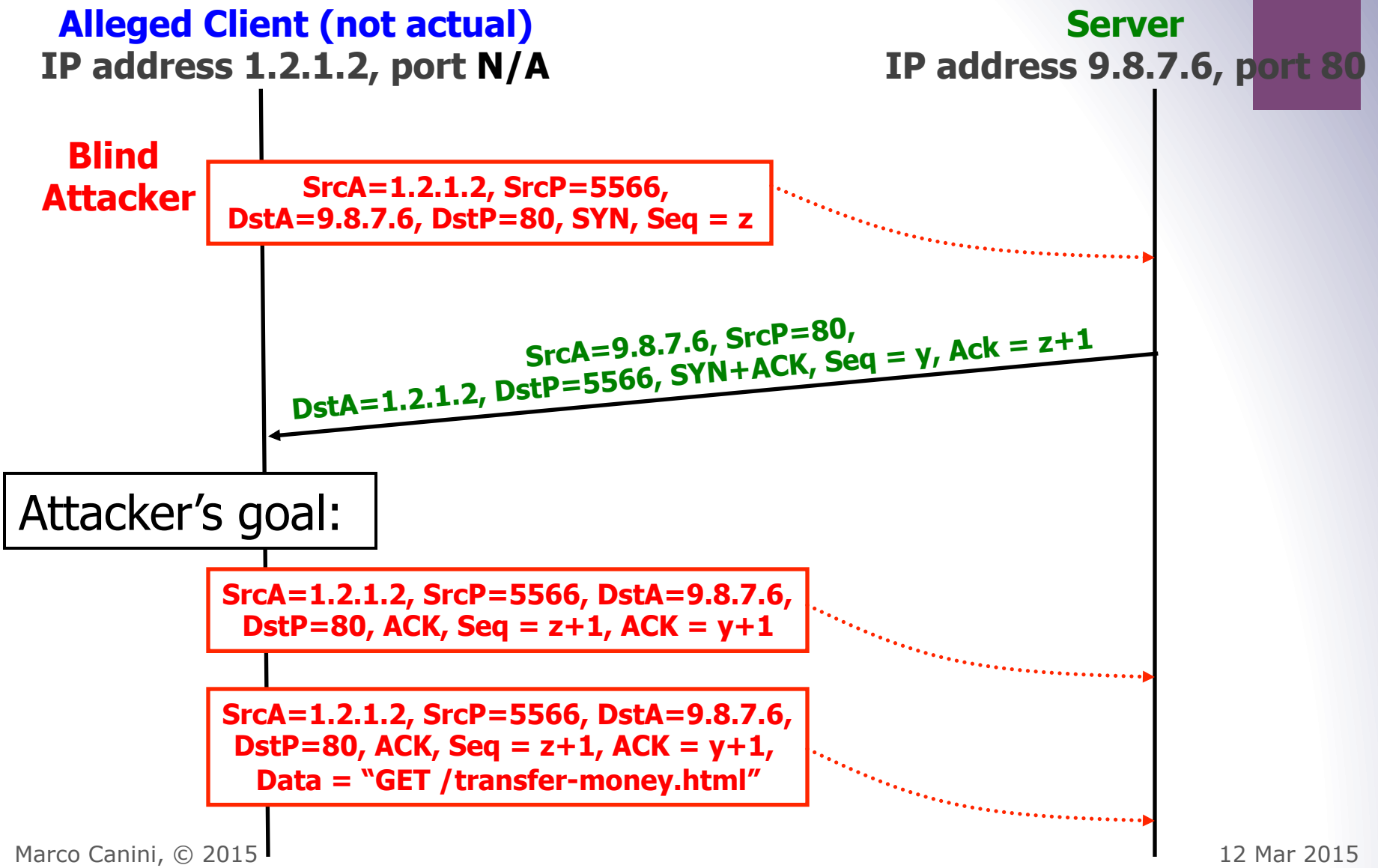
TCP Data Injection



TCP Threat: Blind Spoofing

- Is it possible for an attacker to inject into a TCP connection even if they can't see our traffic?
- YES: if somehow they can infer or guess the port and sequence numbers
- Let's look at a simpler related attack where the goal of the attacker is to create a fake connection, rather than inject into a real one
  - Why?
  - Perhaps to leverage a server's trust of a given client as identified by its IP address
  - Perhaps to frame a given client so the attacker's actions during the connections can't be traced back to the attacker

Spoofing an Entire TCP Connection



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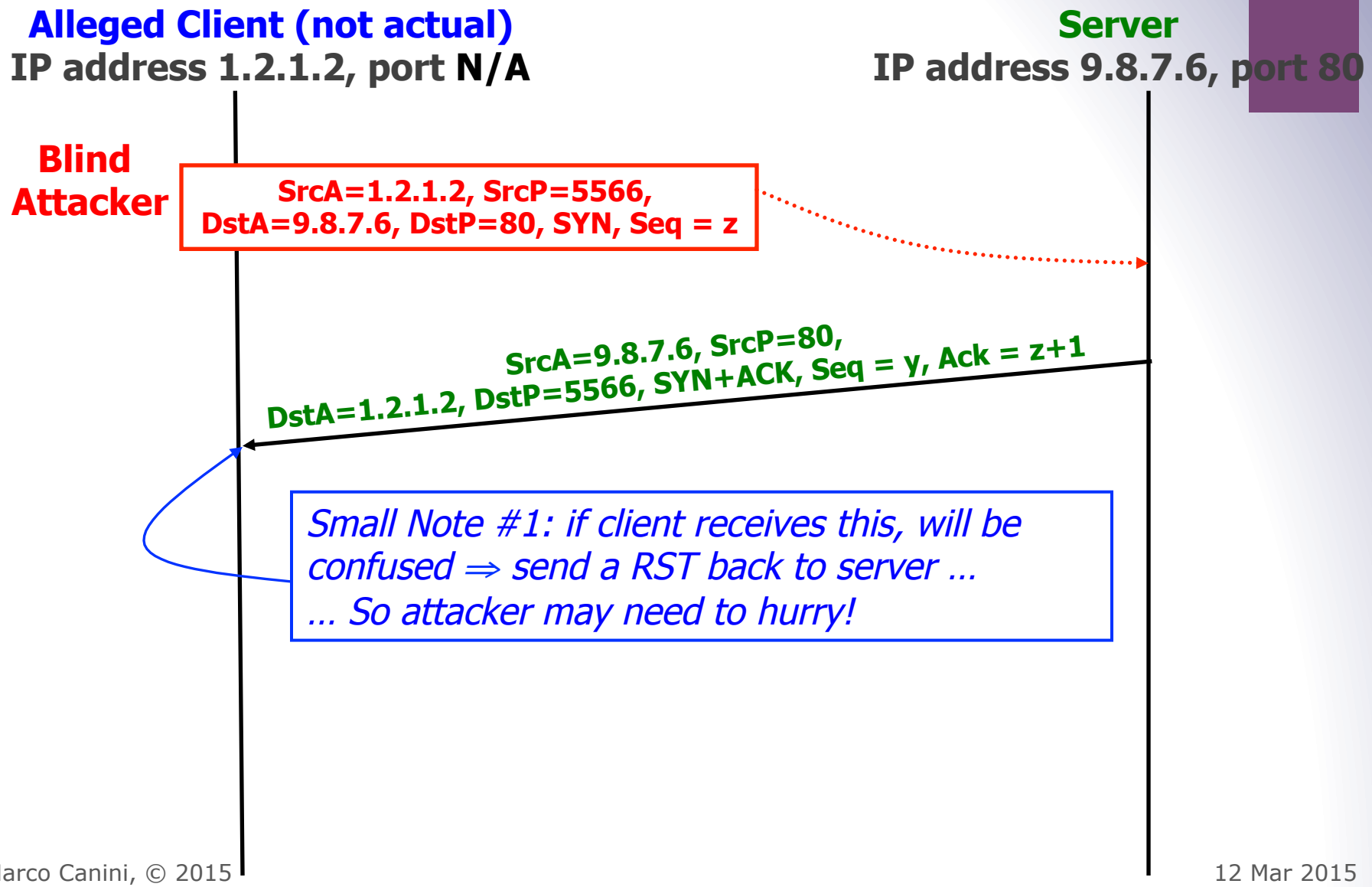

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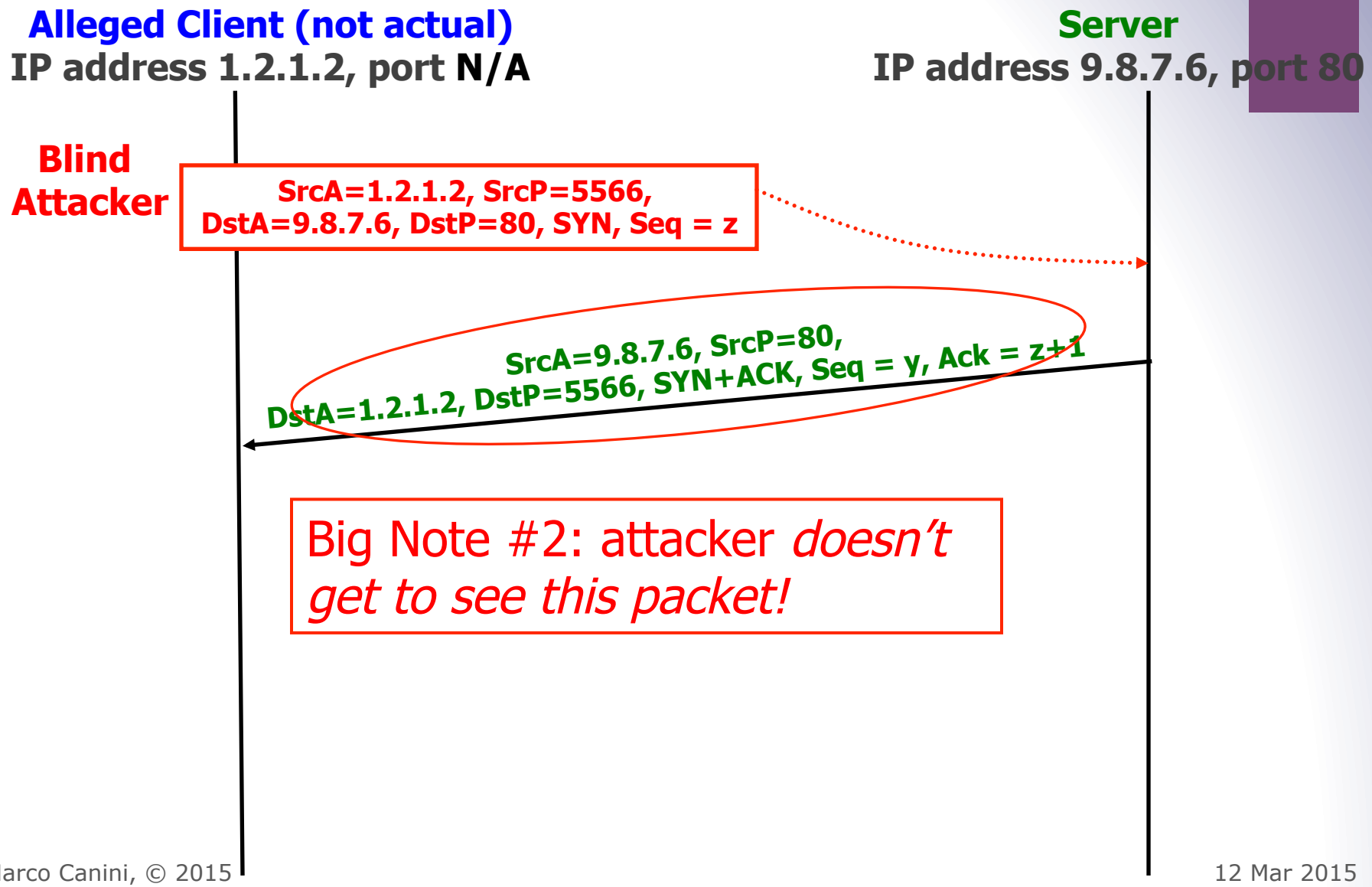

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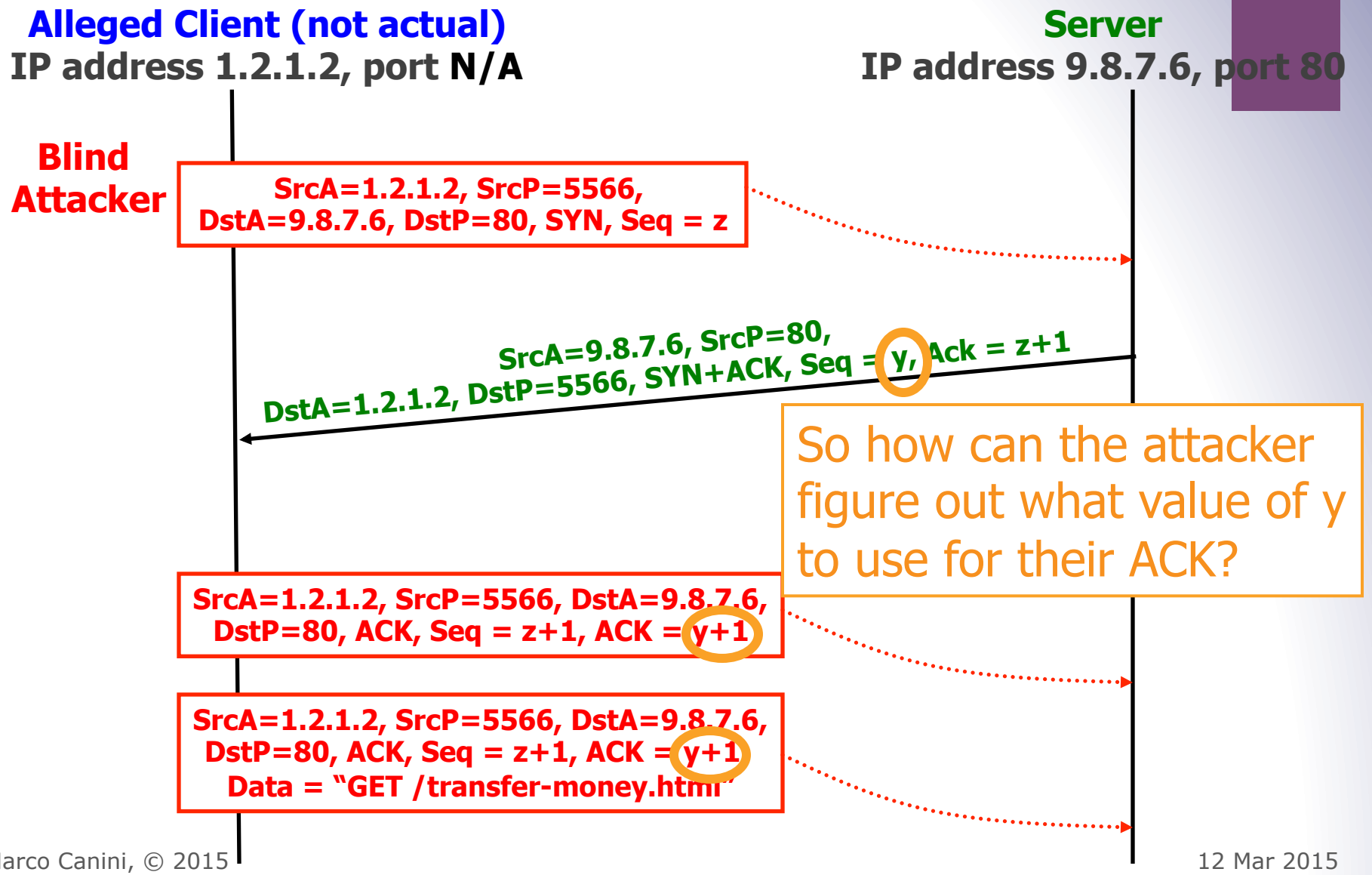
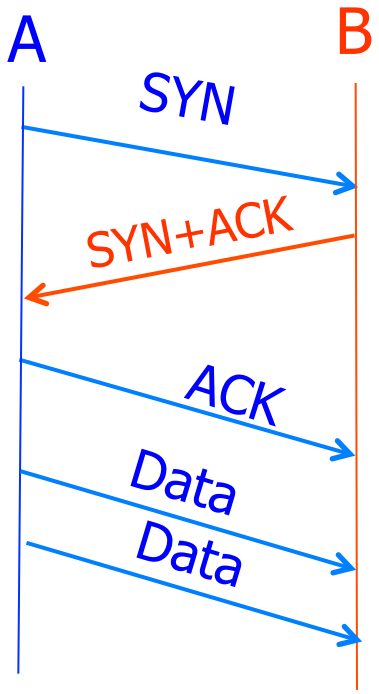


Recall: Establishing TCP Connection



Each host tells its *Initial Sequence Number* (ISN) to the other host

(Spec says to pick based on local clock)

Hmm, any way for the attacker to know ***this?***

How Do We Fix This?

Use a (Pseudo)-*Random* ISN

Sure - make a non-spoofed connection *first*, and see what server used for ISN y then!

Summary of TCP Security Issues

- An attacker who can observe your TCP connection can manipulate it:
  - Forcefully **terminate** by forging a RST packet
  - **Inject** (*spoof*) data into either direction by forging data packets
  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - *Remains a major threat today (will see later how SSL helps)*

Summary of TCP Security Issues

- An attacker who can observe your TCP connection can manipulate it:
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  - Works because they can include in their spoofed traffic the correct sequence numbers (both directions) and TCP ports
  - *Remains a major threat today (will see later how SSL helps)*
- An attacker who can predict the ISN chosen by a server can "blind spoof" a connection to the server
  - Makes it appear that host ABC has connected, and has sent data of the attacker's choosing, when in fact it hasn't
  - *Undermines any security based on trusting ABC's IP address*
  - Allows attacker to "frame" ABC or otherwise avoid detection
  - **Fixed** (mostly) today by choosing random ISNs

Threats to Comm. Security Goals

- Attacks can subvert each type of goal
  - Confidentiality: eavesdropping / theft of information
    - Especially easy when attacker controls a machine close to victim (e.g. WiFi routers)
  - Integrity: altering data, manipulating execution (e.g., code injection)
    - TCP state easily obtained by eavesdropping
  - Availability: *denial-of-service*

- Attackers can also combine different types of attacks towards an overarching goal
  - E.g. use eavesdropping (confidentiality) to construct a spoofing attack (integrity) that tells a server to drop an important connection (denial-of-service)

Basic DNS Vulnerabilities

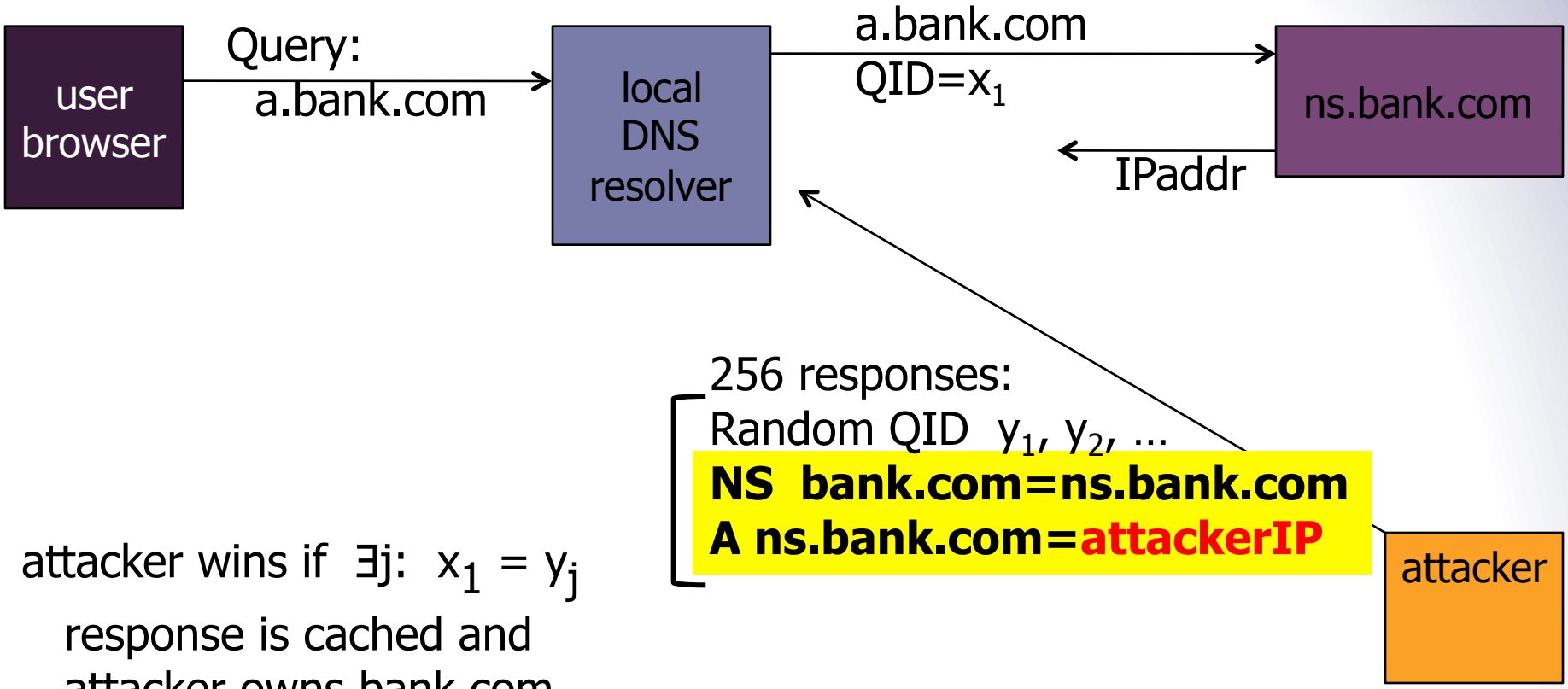
- Users/hosts trust the host-address mapping provided by DNS:
  - Used as basis for many security policies:

    Browser same origin policy, URL address bar

- Obvious problems
  - Interception of requests or compromise of DNS servers can result in incorrect or malicious responses
    - e.g.: malicious access point in a cafe
  - Solution – authenticated requests/responses
    - Provided by DNSsec … but few use DNSsec

DNS cache poisoning (a la Kaminsky'08)

- Victim machine visits attacker's web site, downloads Javascript



attacker wins if $\exists j$: $x_1 = y_j$

response is cached and attacker owns bank.com

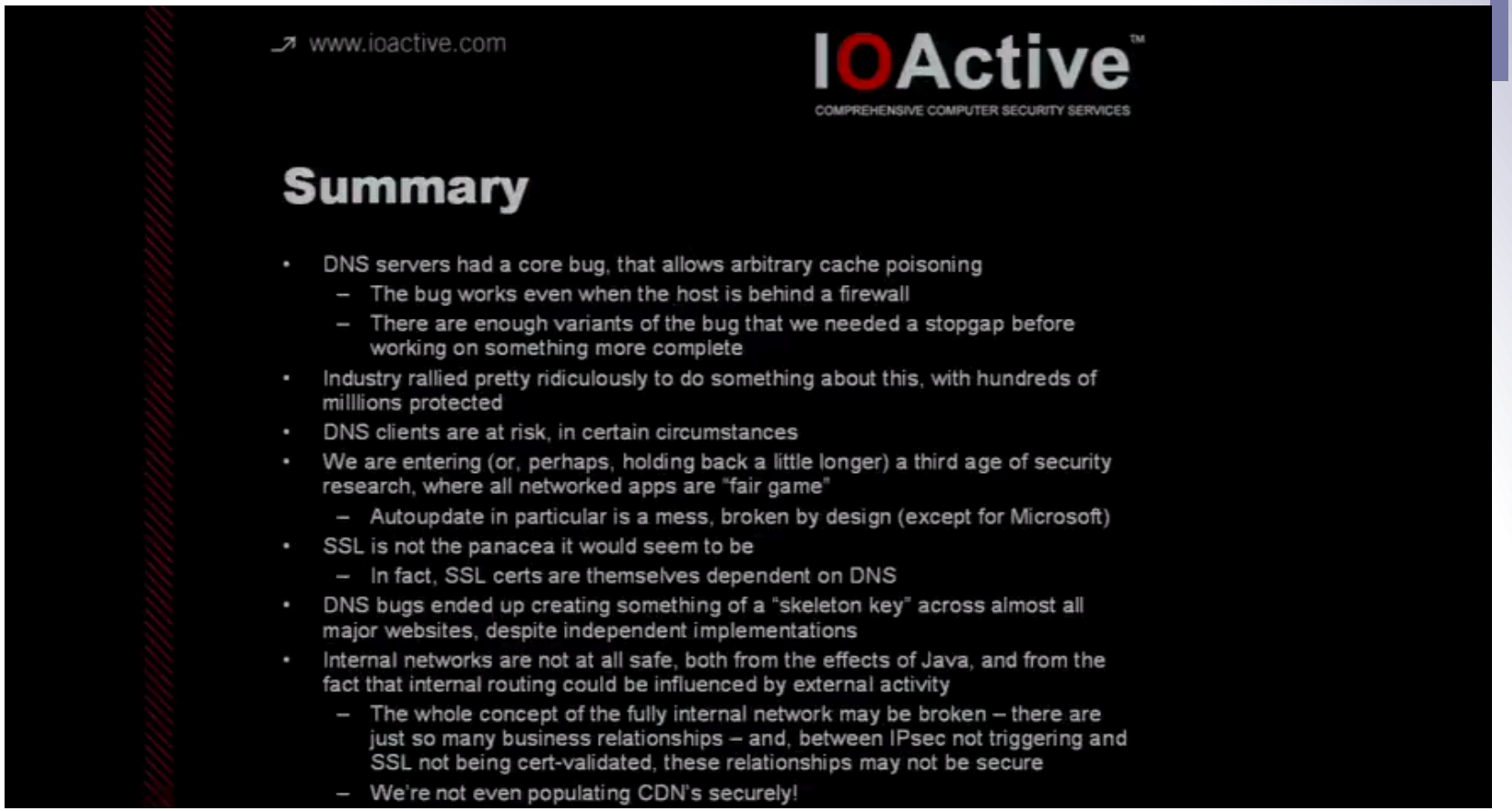
Defenses

- Increase Query ID size. How?

- Randomize client source port, additional 11 bits
  - Now attack takes several hours

- Ask every DNS query twice:
  - Attacker has to guess Query ID correctly twice (32 bits)
  - … but can DNS system handle the additional load?

Extra



- Watch Dan Kaminsky's 2008 talk on this serious vulnerability in DNS https://vimeo.com/17247507

Denial of Service

Denial of Service (DoS)

- An attempt to make a machine or network resource unavailable to its intended users, either temporarily or indefinitely
- Many methods of attack exist, classifiable as:
  - Consumption of computation resources (e.g. CPU, memory, bandwidth)
  - Disruption of configuration (e.g. routing information)
  - Disruption of state information (e.g. sending TCP RST packets)
  - Disruption of physical components
  - Obstructing communication media between the victim and its users
- DoS attacks typically involve forged IP addresses

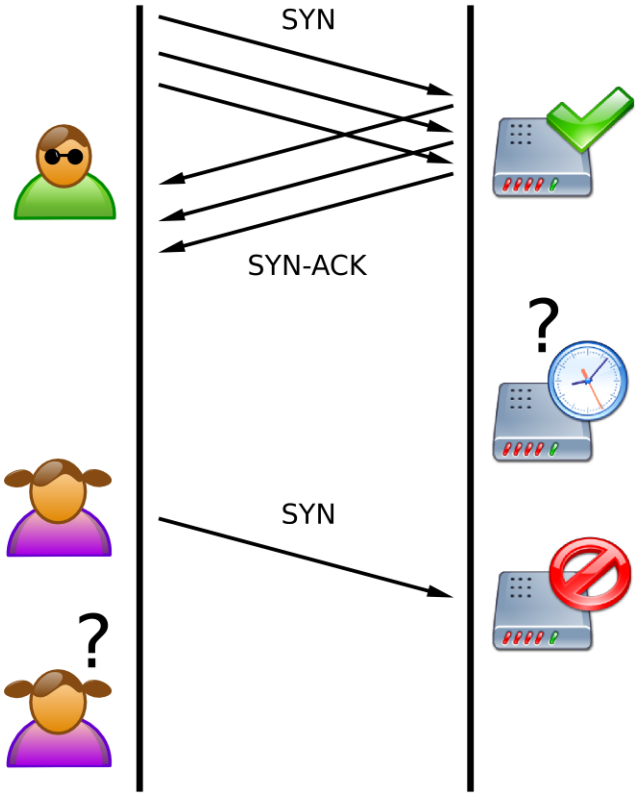
Historical example

Ping of death (PoD)

- One of the earliest denial of service attack
  - Up to 1997, affected Unix, Linux, Mac, Windows, printers, and routers
- Attack based on sending a malformed ICMP packet
  - Send a ping larger than the maximum IPv4 packet size (65,535 bytes) could crash a target
  - Exploit fragmentation (problem has nothing to do with ICMP)
  - When packet is reassembled, a buffer overflow can occur, which often causes a system crash

SYN Flooding

- Send a large number TCP/SYN packets
  - Recall 3-way handshake: SYN ; SYN + ACK ; ACK



Source: Wikipedia

SYN Flooding

- On receiving the SYN packet, the server allocates necessary memory for the connection and enters it in a queue of half open connections
- Once the queue overflows, the server cannot accept any new connection
- The attacker can forge the source address of his SYN packets to remain anonymous
- Recent versions of operating systems (Windows, Unix, Linux) are protected against such attacks

Protections Against SYN Flooding

- Increase the size of the queue
- Reduce timeout while server is waiting for an ACK
- Drop the oldest SYN in the queue
- Filtering e.g. on IP addresses
- SYN Cache
  - Allocate minimal state on the server, reply with SYN + ACK and complete the connection creation once the ACK is received
  - Host compute a hash based on some secret bits, IP addresses and transport ports that determines the location in a global hash table where the incomplete connection information is stored
  - Still must be prepared to overflow

Protections Against SYN Flooding

SYN cookies

- Once the connection queue is almost filled up, the server uses SYN cookies
- Upon reception of a SYN:
  - The server sends a SYN + ACK containing a SYN cookie
  - The server erases the SYN entry
- Upon reception of an ACK:
  - The server checks whether it contains a valid cookie
  - If so this highly likely means that the client has already sent a SYN and so it is an honest client

SYN Cookie Content

SYN cookies are specific Initial Sequence Numbers:

- *t* is a counter incremented every 64 s modulo 32
- *m* is the Maximum Segment Size encoded on 3 bits
- *s* is the result of a cryptographic hash function computed on t and the IP address and port number of the server and client

ISN =

t **mod** 32	*m*	*s*
5 bits	3 bits	24 bits

32 bits

SYN Cookie Check

Upon reception of an ACK, the server carries out the following operations:

- Check that the received value *t* is valid with respect to the current time
  - Otherwise, this means the connection is expired
- Recompute *s* to check its validity
- Decode the value *m*, which allows the server to reconstruct the SYN queue entry

Any questions?

Stay tuned

Next time you will learn about

Network defense tools