CS 772/872: **Advanced**
Computer and Network Security
Fall 2025

Course Link:
https://shhaos.github.io/courses/CS872/netsec-fall25.html

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OLD DOMINION
UNIVERSITY

CS 772/872: Advanced Computer and Network Security

- **Network Security** (including Crypto foundations and applications)
- **Web and Browser Security**
- **Cloud Security**
- **System/Software Security**
- **AI/LLM Security** (by papers)

Network Security

- TCP/IP
- (D)DoS Attacks
- DNS
- BGP
- CDN
- Applied Cryptography
- PKI
- SSL/TLS and HTTPS
- DNSSEC/RPKI

Network Security

- **Confidentiality: only sender, intended receiver should "understand" message contents**
  - sender encrypts message
  - receiver decrypts message
- **Integrity: sender, receiver want to ensure message not altered (in transit, or afterwards)**
- **Authentication: sender, receiver want to confirm identity of each other**

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  - sender encrypts message
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- **Integrity: sender, receiver want to ensure message not altered (in transit, or afterwards)**
- **Authentication: sender, receiver want to confirm identity of each other**
- **Accessibility and Availability: services must be accessible and available to users**

Network Security

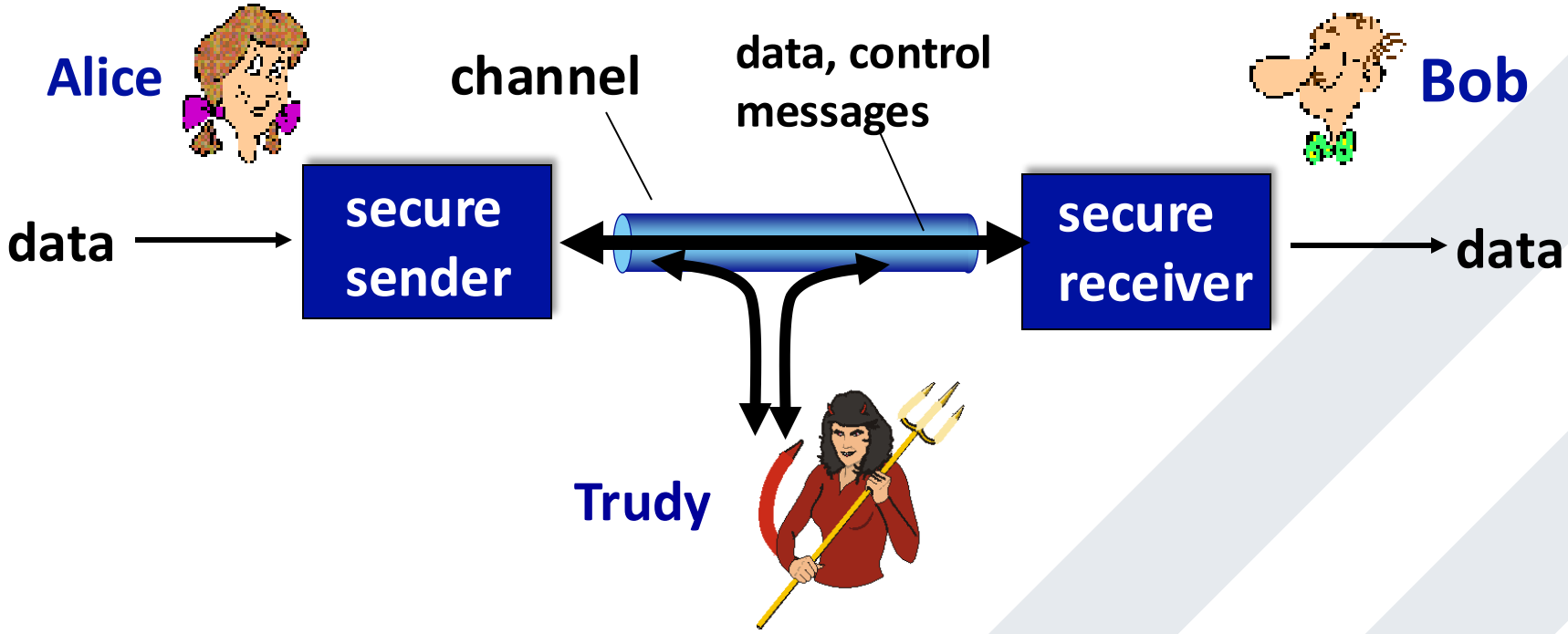
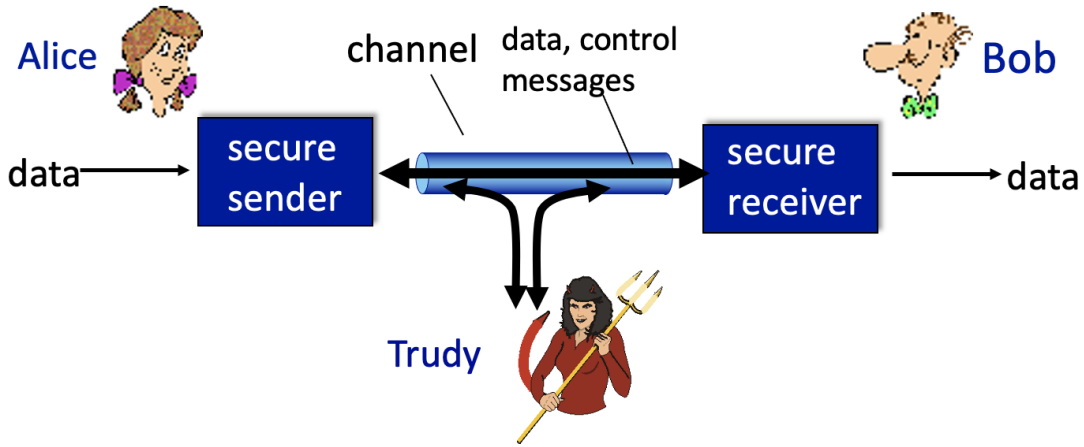


Image: Computer Networking: A Top Down Approach, J. Kurose and K. Ross

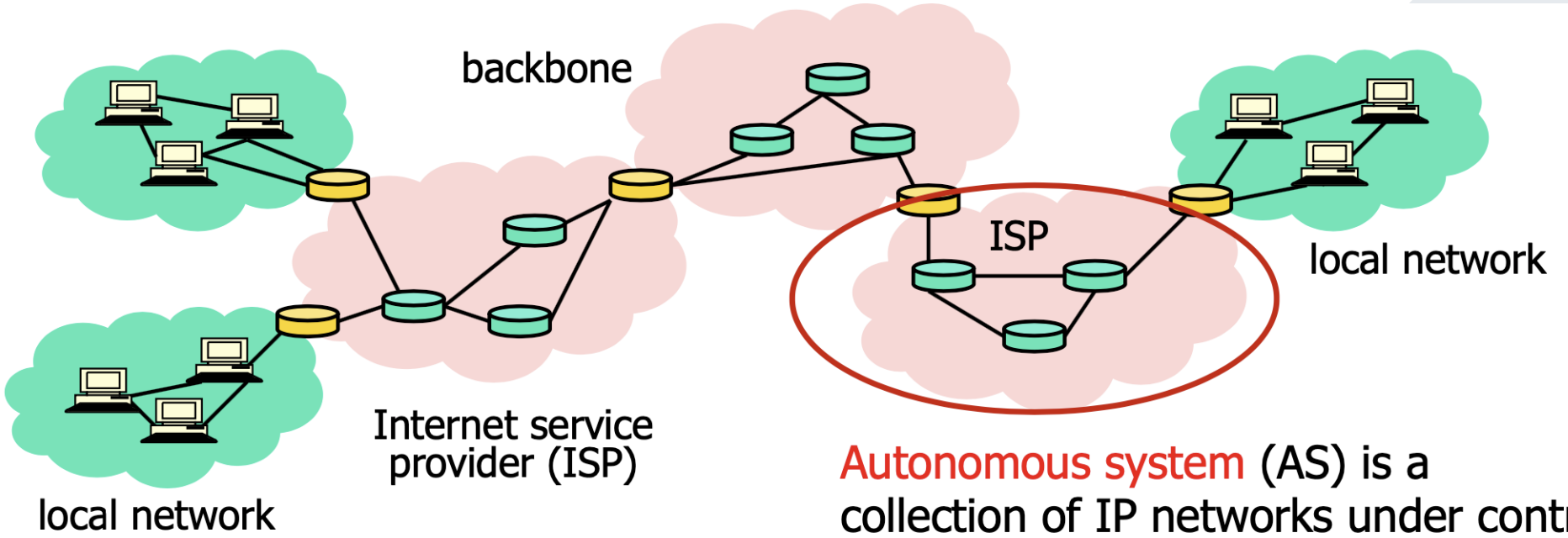
Network Security

- **Eavesdrop**: Intercept messages
- **Impersonation**: fake/spoof source address of packets
- **Hijacking**: “take over” ongoing connection by inserting himself in place
- **Denial of service**: prevent service from being used by others



Network Security

- **Internet: a Network of Network**



Autonomous system (AS) is a collection of IP networks under control of a single administrator (e.g., ISP)

Network Security

- **OSI Protocol Stack**

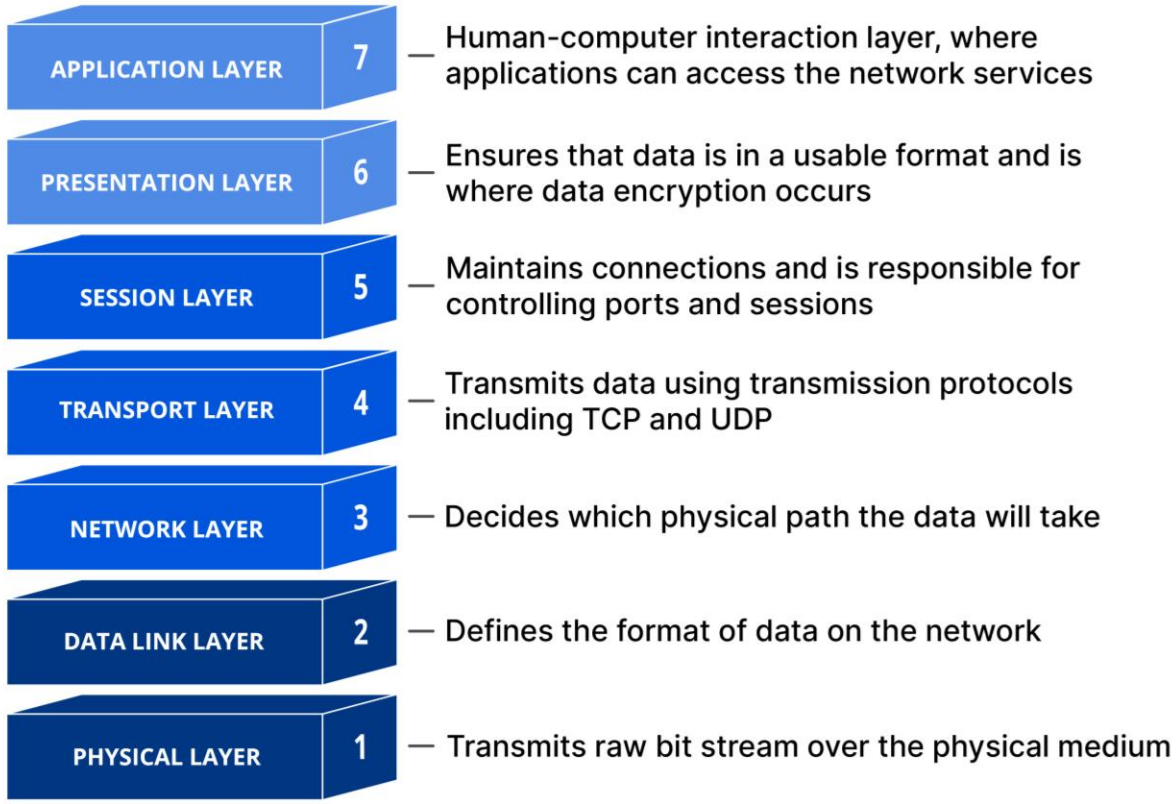
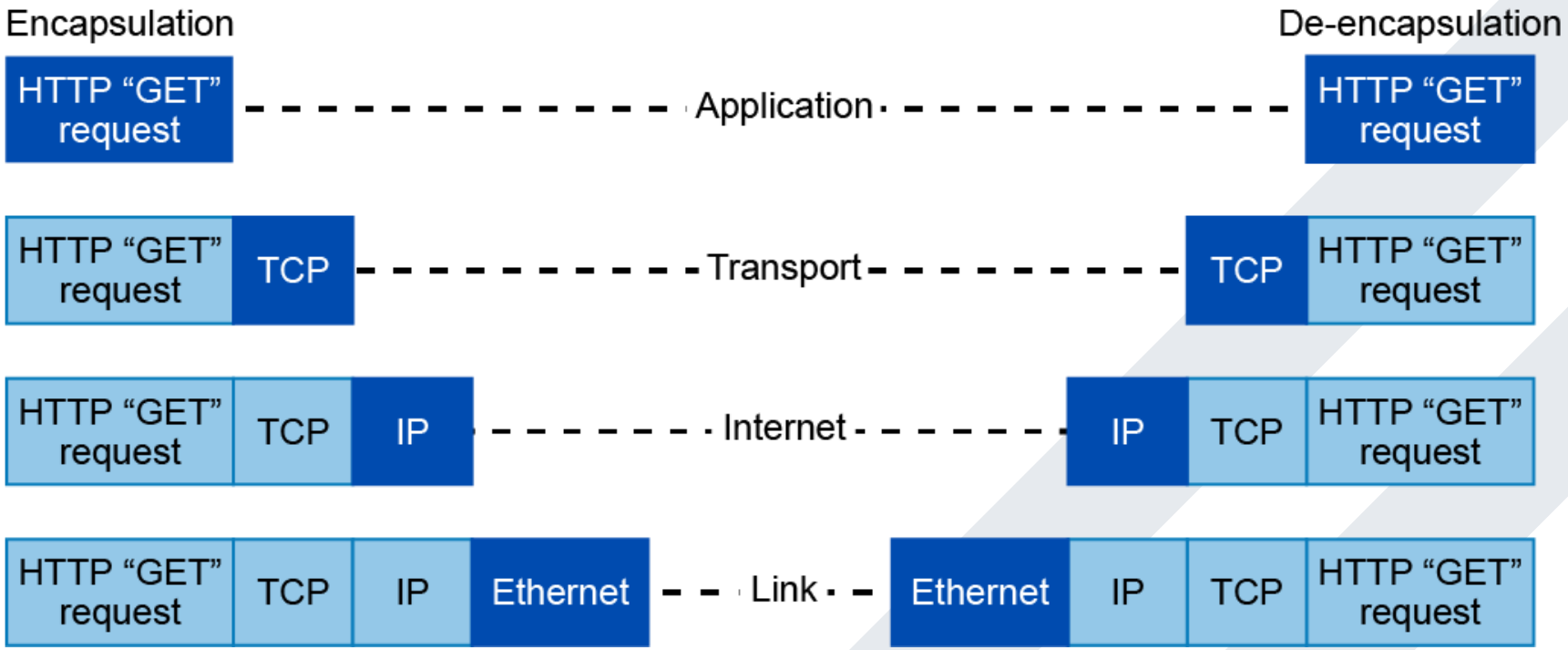


Image: Cloudflare

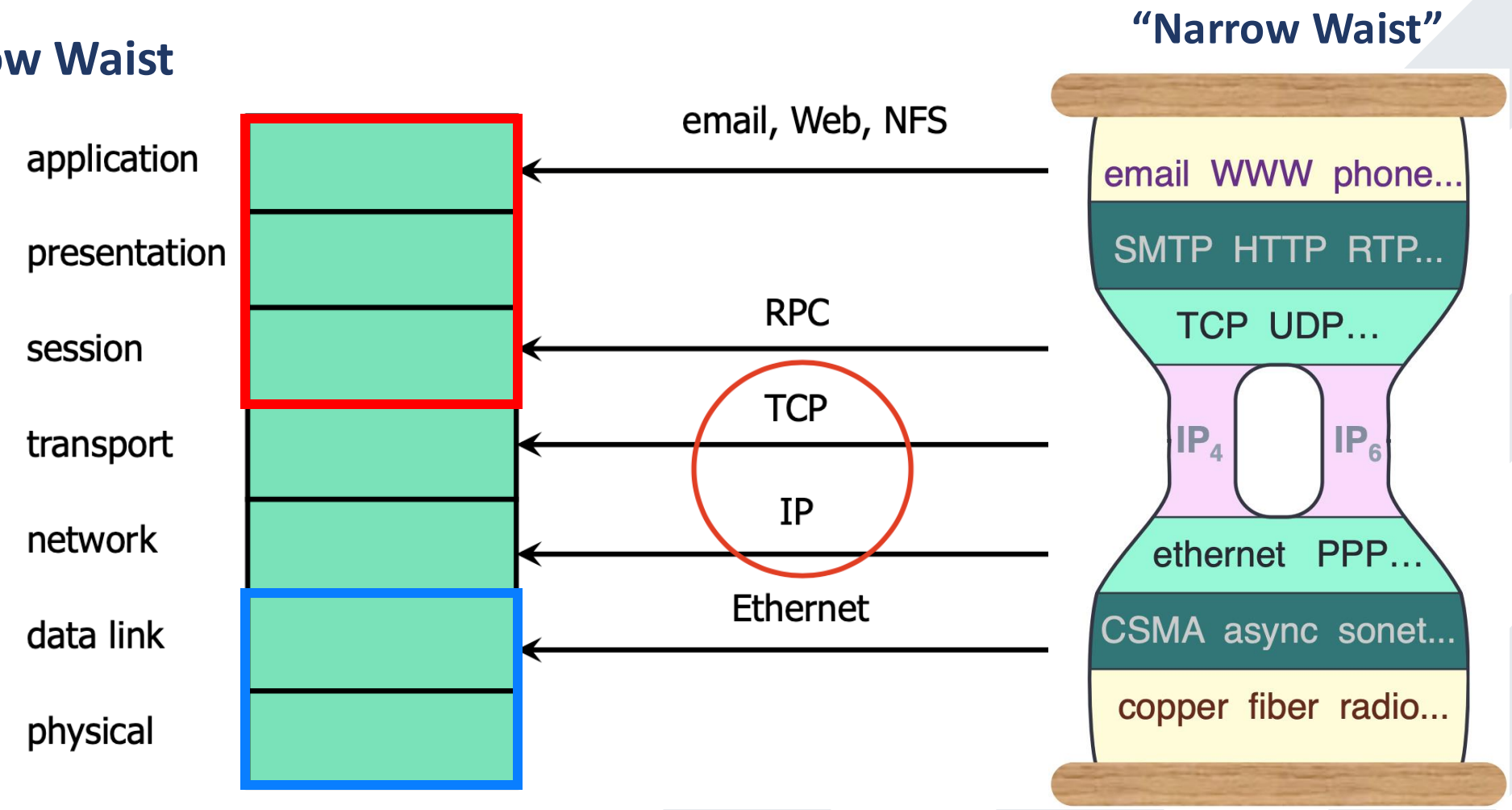
Network Security

- **Encapsulation: end-to-end connectivity**



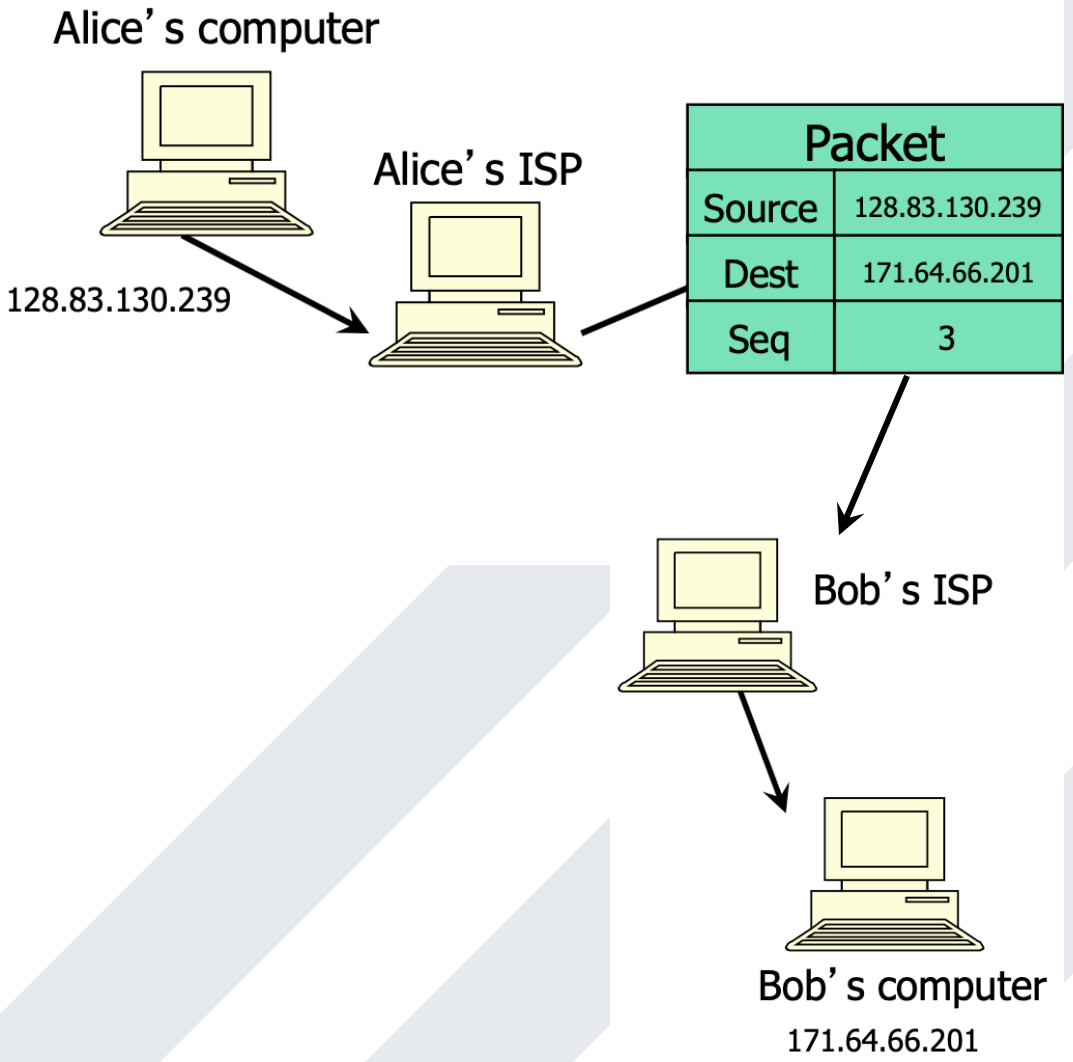
Network Security

- Narrow Waist



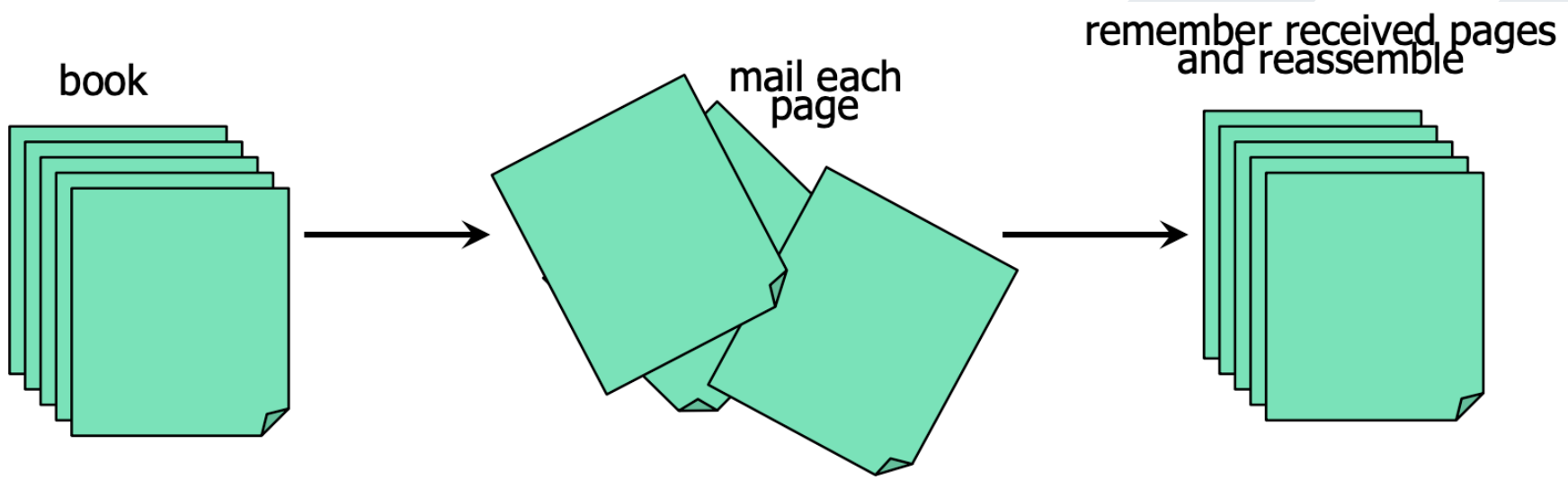
IP – Internet Protocol

- **Connectionless**
  - Unreliable, “best-effort” protocol
- **Packet switching**
  - No states established ahead of time
  - Destination-based Routing
  - Shared resources



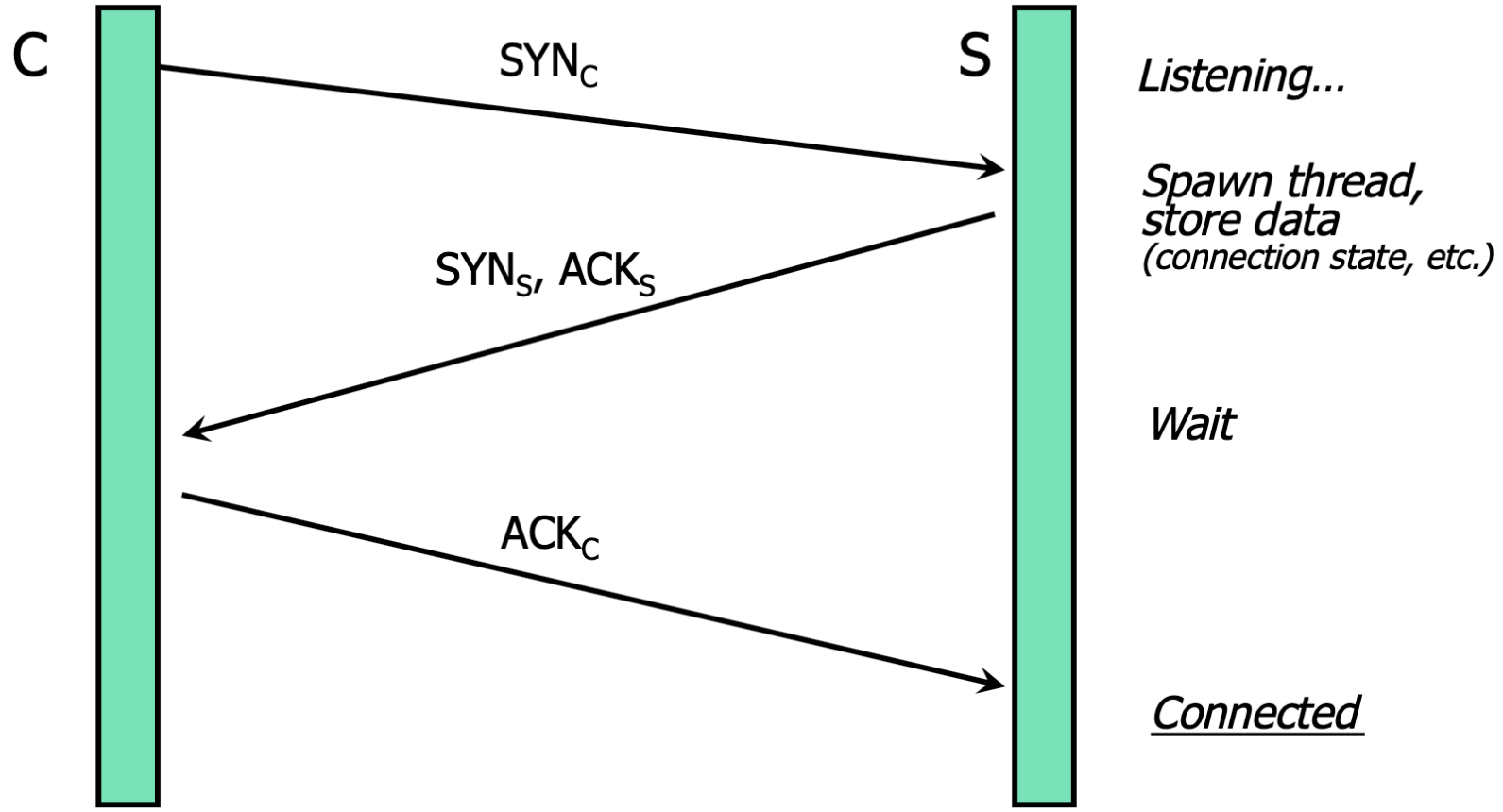
TCP – Transmission Control Protocol

- **Sender: break data into segments**
  - Sequence number is assigned to every segment
- **Receiver: reassemble segments in correct order**
  - Acknowledge receipt; lost segments will be re-sent
- **Connection state maintained on both sides**



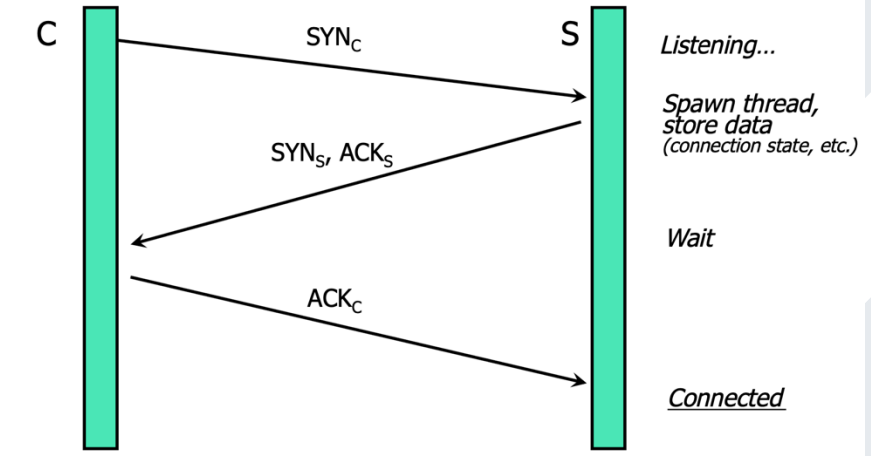
TCP – Transmission Control Protocol

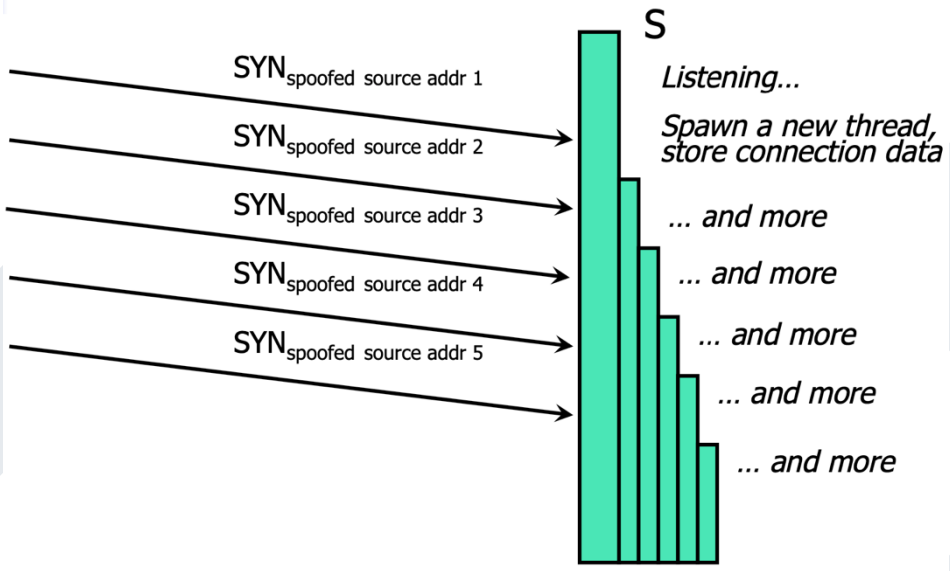
- **TCP Handshake: Connection establishment**



TCP – Transmission Control Protocol

- **SYN Flooding Attack**
  - Attacker sends many connection requests with spoofed source address
  - Victim allocates resources for each request
    - New thread
    - “half-open” connections
  - Once resources exhausted, legitimate requests are dropped
  - **Classic (Distributed-)Denial-of-Service (DDoS) pattern**



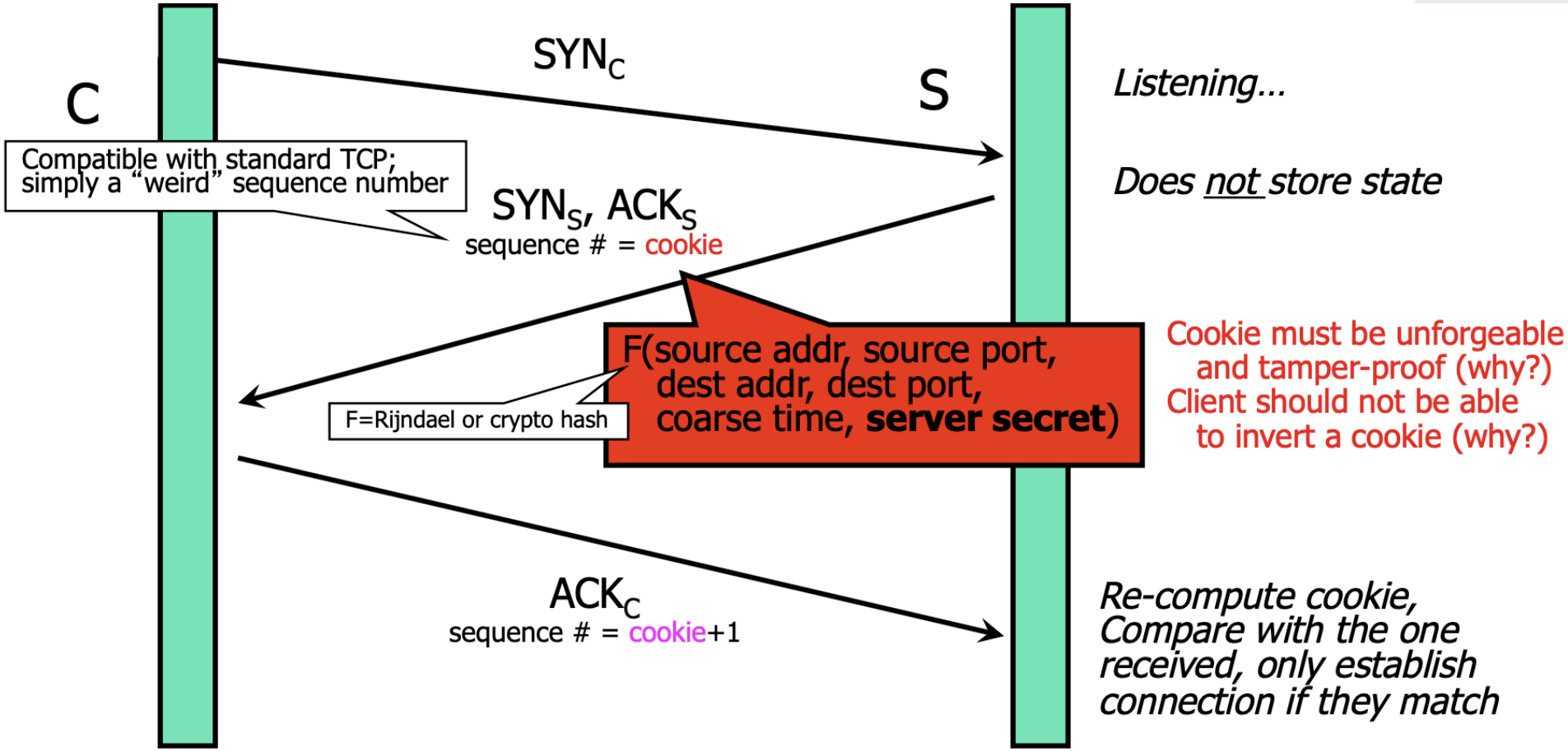


TCP – Transmission Control Protocol

- **Preventing Denial of Service**
  - DoS is caused by asymmetric state allocation
    - If a victim server opens new state for each connection attempt, attacker can initiate thousands of connections from bogus or forged IP addresses
  - **Cookies** ensure that the responder (victim) is stateless until initiator produced at least one acknowledgment
    - Responder's state (IP addresses and ports of the connection) is stored in a cookie and sent to initiator
    - After initiator responds, cookie is regenerated and compared with the cookie returned by the initiator

TCP – Transmission Control Protocol

- **Preventing Denial of Service**

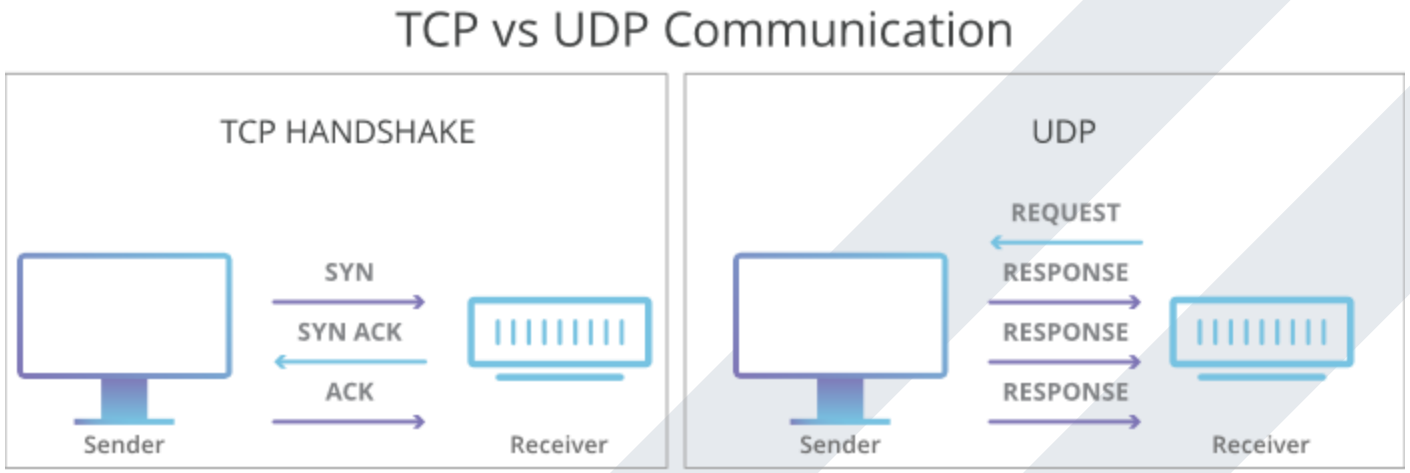


TCP – Transmission Control Protocol

- **Denial of Service by Connection Reset**
  - If attacker can guess/predict/monitor the current sequence number for an existing connection, can send RESET packet to close it
    - Especially effective against long-lived connection
  - Widely used in Internet Censorship

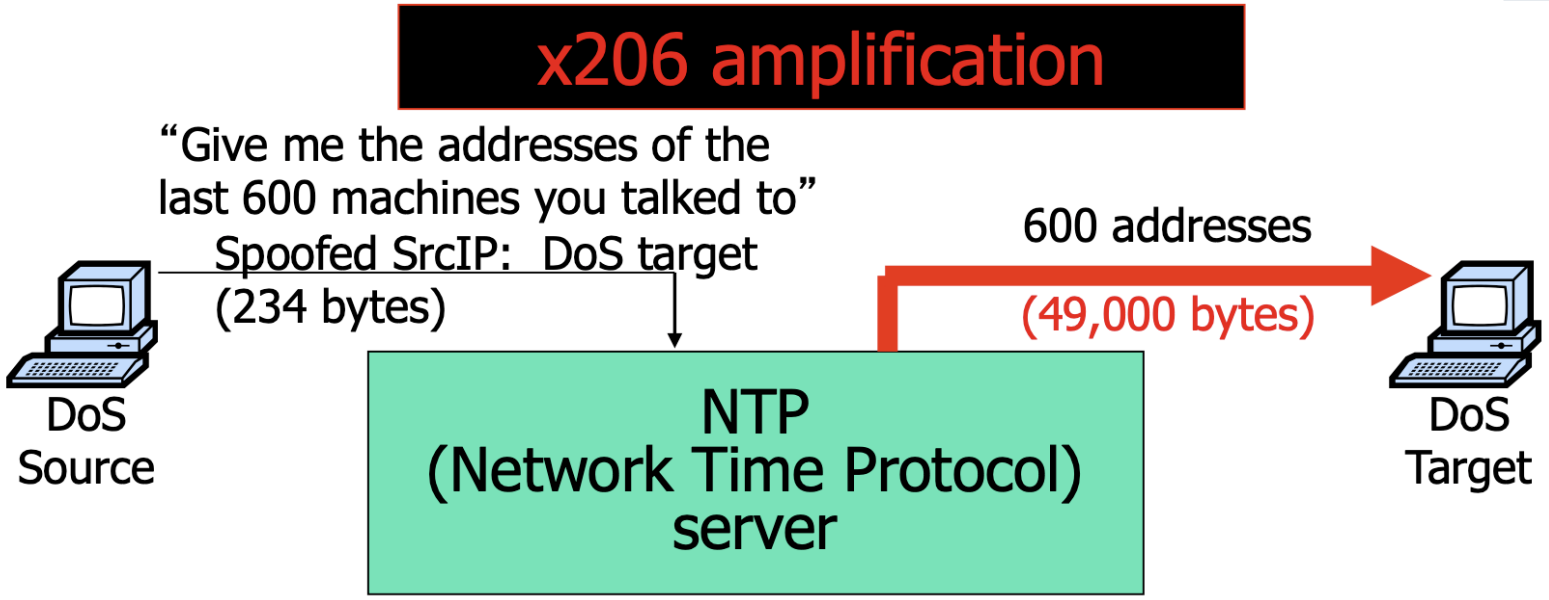
UDP – User Datagram Protocol

- **Connectionless protocol**
  - Simply send datagram to application process at the specified port of the IP address
  - Source port number provides return address
  - Applications: media streaming, broadcast
- **No acknowledgement, no flow control, no message continuation**



UDP – User Datagram Protocol

- **NTP Amplification Attack**
  - "Reflection-and-Amplification" attack



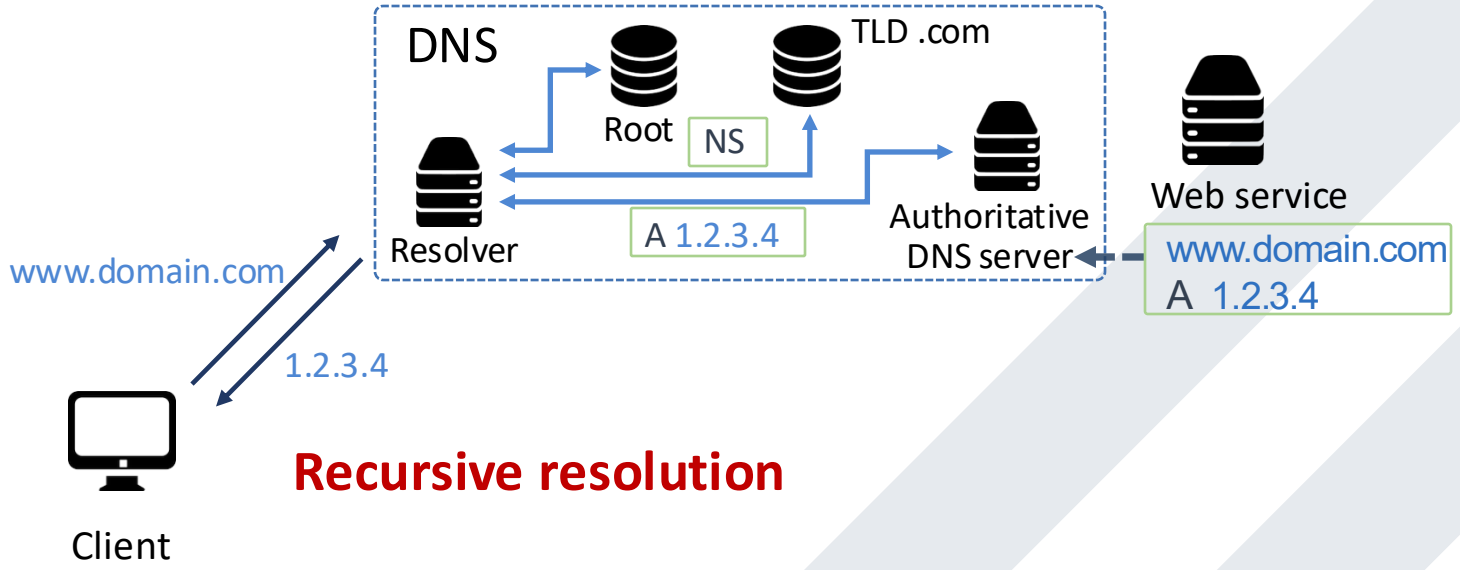
  - Dec. 2013 – Feb. 2014: 400Gbps DDoS attacks involving 4,500+ NTP servers targeting Cloudflare's data center

Network Defenses

- **Rate-limiting**
  - Straightforward but cannot differentiate legitimate traffic from malicious traffic
- **Egress Filtering against IP spoofing**
  - ISPs are lack of motivation to deploy
- **DDoS Protection Service offered by Content Delivery Networks (CDNs)**
  - Re-route the traffic to CDN's highly distributed network infrastructures
  - Must hide the the origin IP address

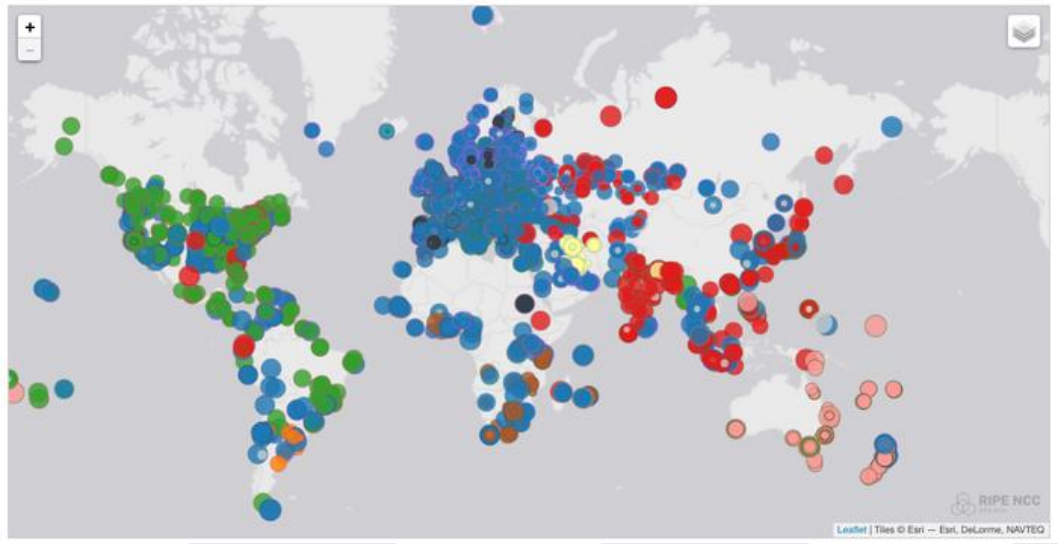
DNS – Domain Name System

- **Internet Dictionary**
  - Maps symbolic names to numeric IP addresses
  - UDP-based protocol



DNS – Domain Name System

- **Hierarchical System Design**
  - Root nameservers for top-level domains (`.com`, `.edu`, `.uk`, etc.)
  - 13 root server systems (A - M)
  - Top-level domain (TLD) nameservers indicate authoritative nameservers
  - Authoritative nameservers (ADNS) resolve subdomains
  - Local resolvers contact authoritative servers for requested domains



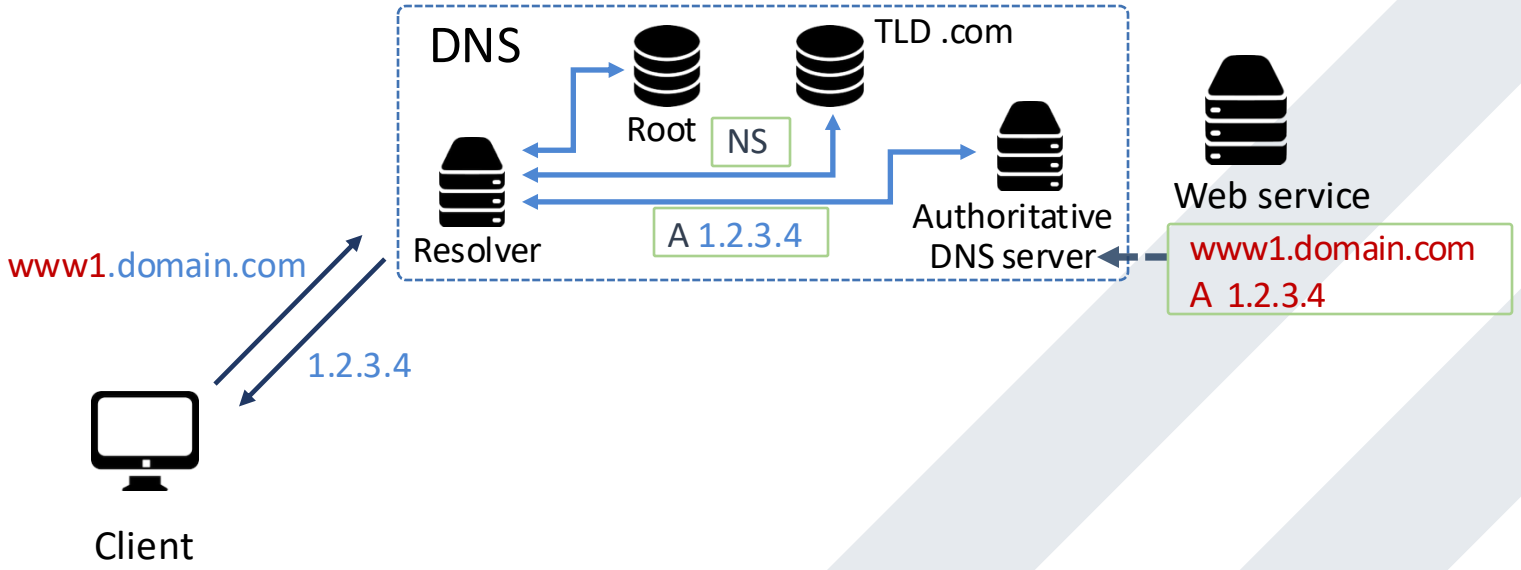
K-root servers

DNS – Domain Name System

- **DNS Caching**
  - DNS responses can be cached (on local resolvers)
    - Quick response for repeated translations
    - Other queries may reuse some parts of lookup
      - NS records identify name servers responsible for a domain
  - DNS negative queries can be cached
    - Don’t have to repeat past mistakes (failed domains, misspellings, etc.)
  - Cached data will periodically time out
    - Lifetime (TTL) of data controlled by owner of data, passed with every record

DNS – Domain Name System

- **DNS Caching**



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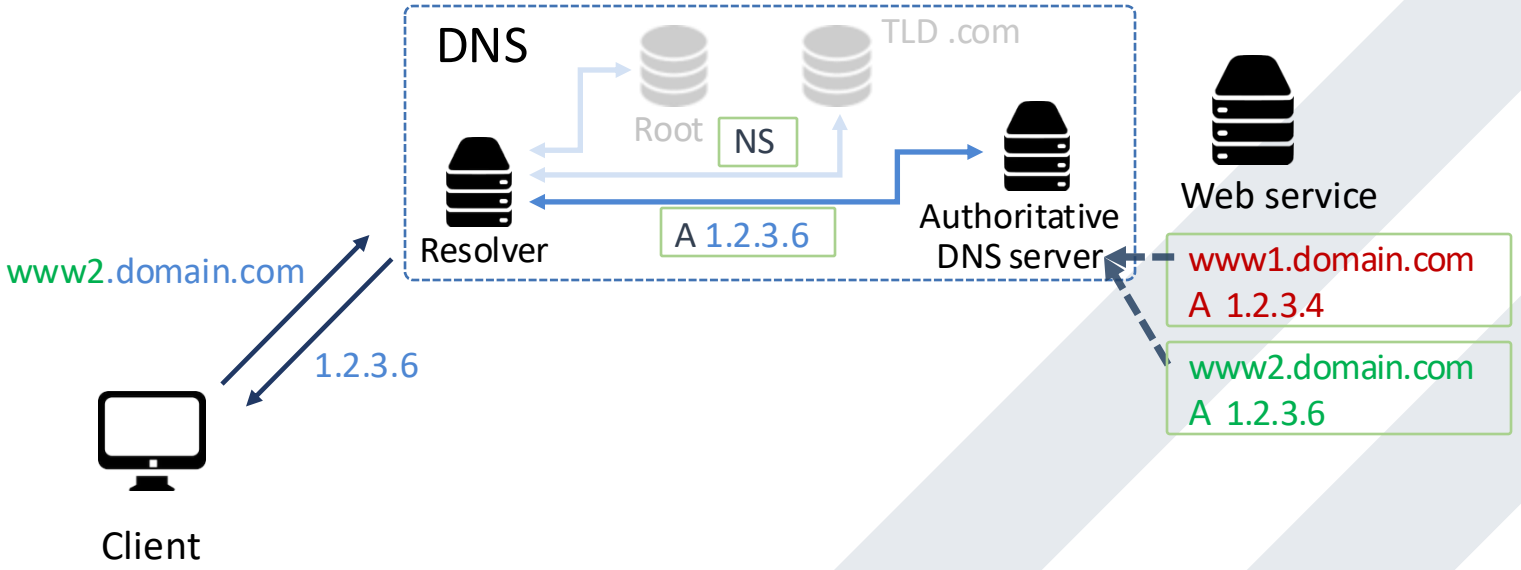
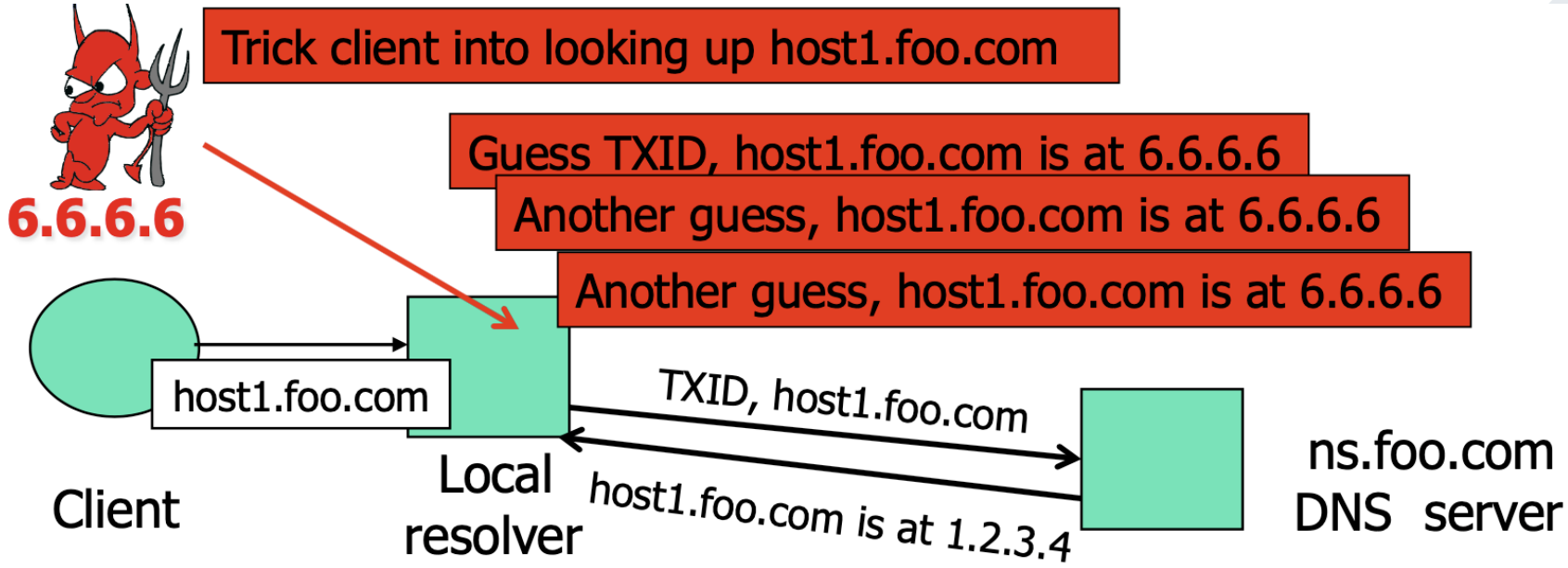


DNS – Domain Name System

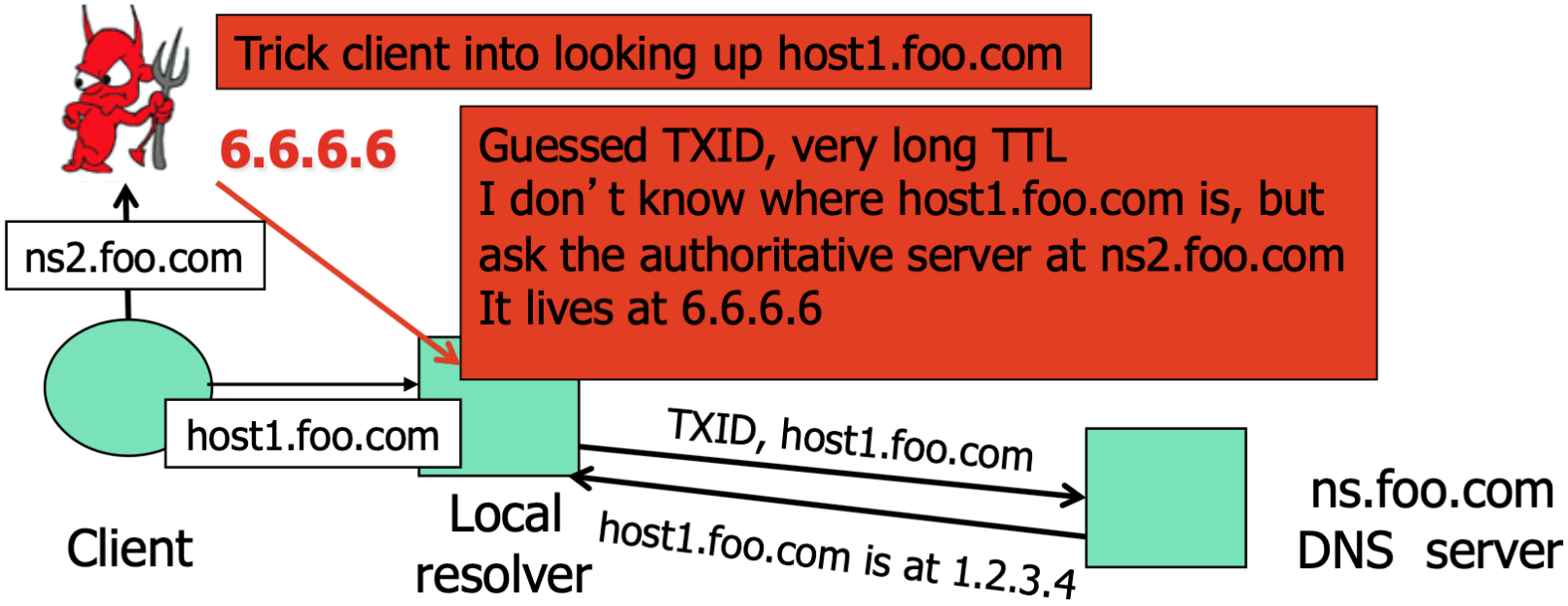
- **DNS Cache Poisoning**



  - Several opportunities to win the race.
  - Here attacker attempts to pollute individual A records

DNS – Domain Name System

- **DNS Cache Poisoning – Kaminsky attack**



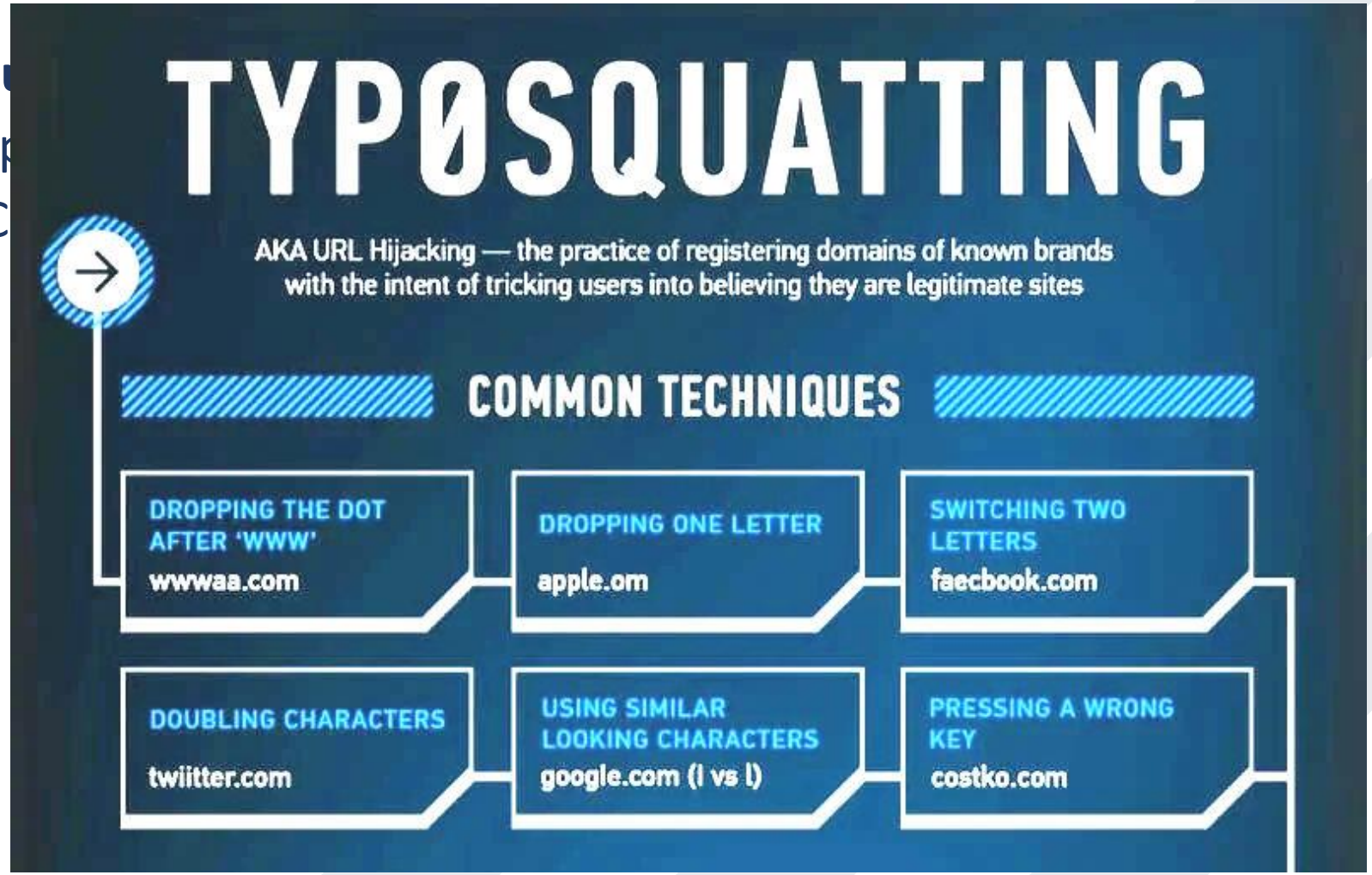
- If win the race, any request for `<XXX>.foo.com` will go to 6.6.6.6. The NS record is poisoned for a very long time
- If lose, try again with `<ANYTHING>.foo.com`

DNS – Domain Name System

- **Defending the DNS Cache Poisoning Problem**
  - Long TTL for legitimate responses?
    - Does it really help?
  - Randomized Transaction ID (TXID – 16 bits)
  - Randomize port in addition to TXID
    - 32 bits of randomness, makes it harder for attacker to guess TXID+port
  - **DNSSEC**
    - **Cryptographic authentication of host-address mappings**

DNS – Domain Name System

- **Other DNS-related Secu**
  - Fast flux in DNS map
    - DNS-based C&C
  - DNS squatting
    - typo-squatting,



DNS – Domain Name System

- **Other DNS-related Security Issues**
  - Fast flux in DNS mappings
    - DNS-based C&C (Control-and-command) in botnets
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DNS – Domain Name System

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  - DNS squatting
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Browser Security Indicators

Convey information about the security of a page

Locks, shields, keys, green bars…

"This page was fetched using SSL" Secure | https://

Page content was not viewed or altered by a network adversary

Certificate is valid (e.g. not expired), issued by a CA trusted by the browser, and the subject name matches the URL's domain

"This page uses an invalid certificate" Not secure | ~~https:~~//

"Parts of the page are not encrypted" https://

"The legal entity operating this web site is known"

Extended Validation (EV) certificates Square, Inc. [US] | https://squ

DNS – Domain Name System

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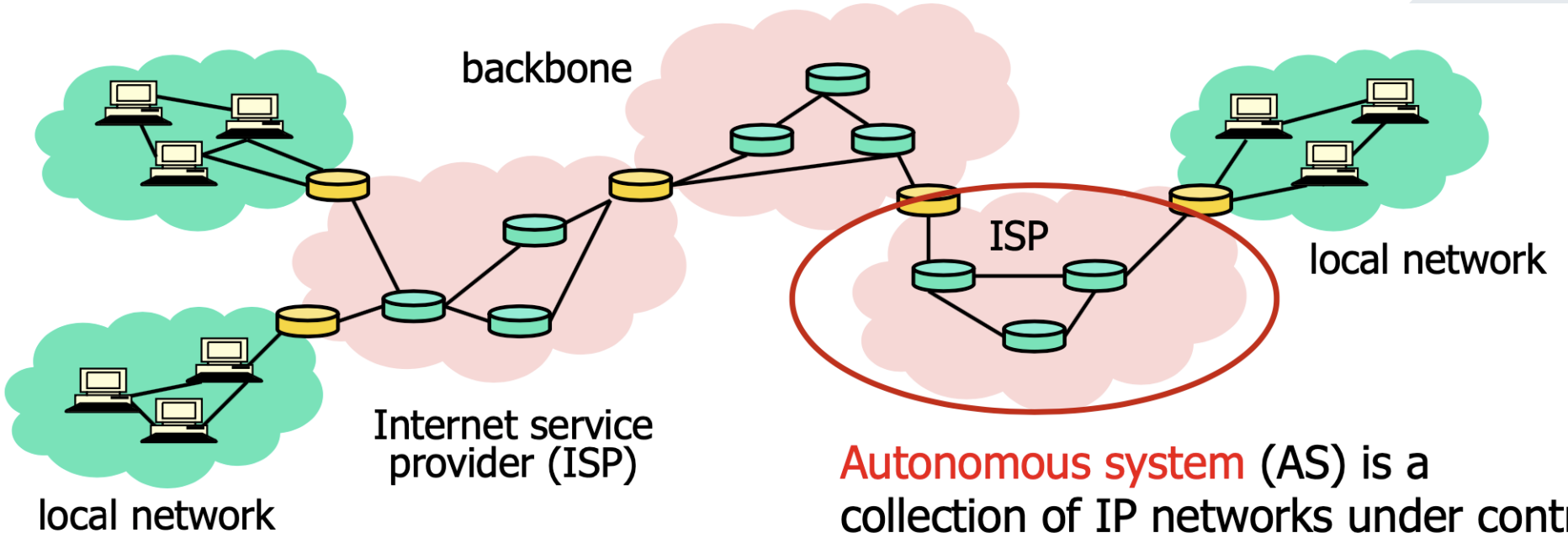
  - Fast flux in DNS mappings
    - DNS-based C&C (Control-and-command) in botnets
  - DNS squatting
    - typo-squatting, combo-squatting
  - Domain/subdomain hijacking
    - Dangling DNS records, domain shadowing
  - DNS Amplification

IP Routing – BGP (Border Gateway Protocol)

- **Internet: a Network of Network**



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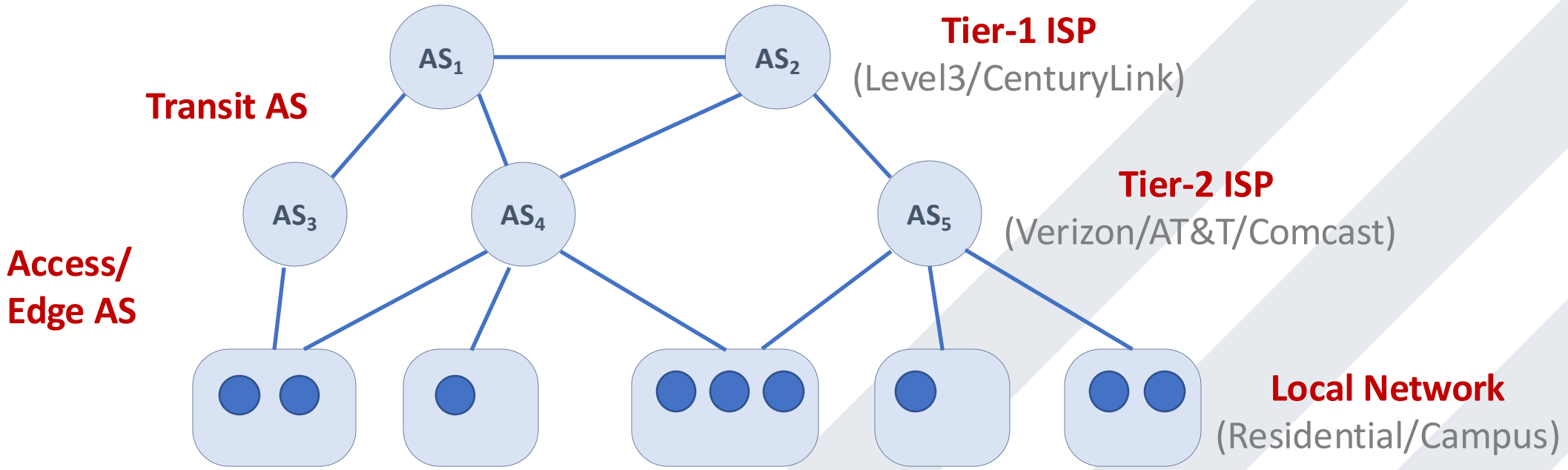

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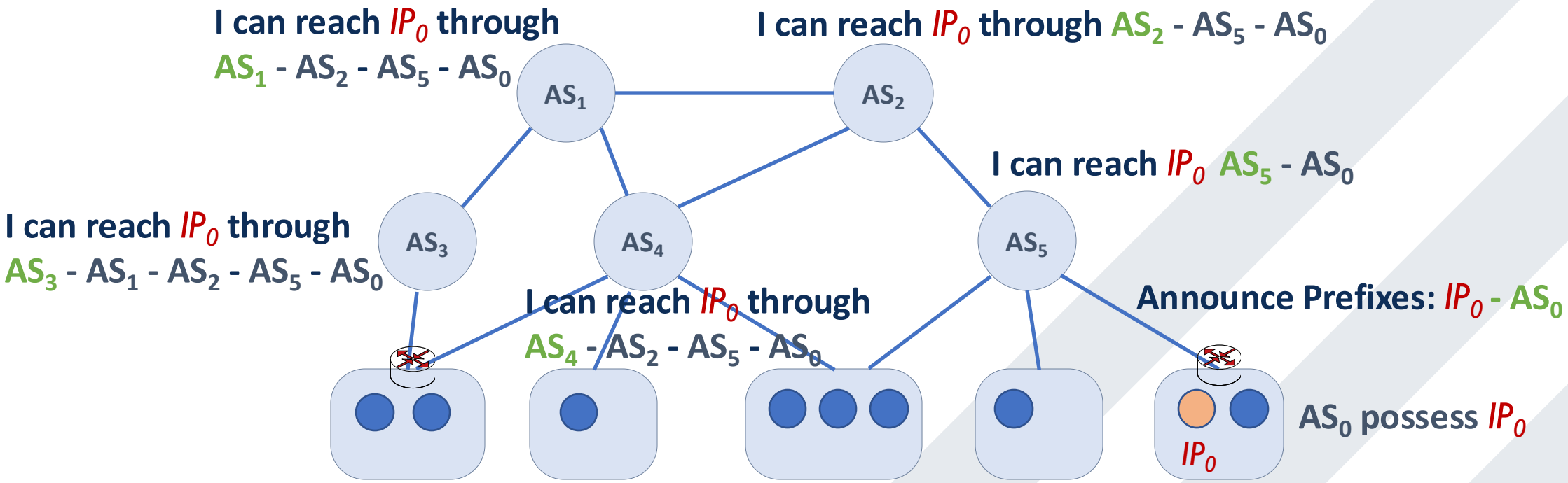

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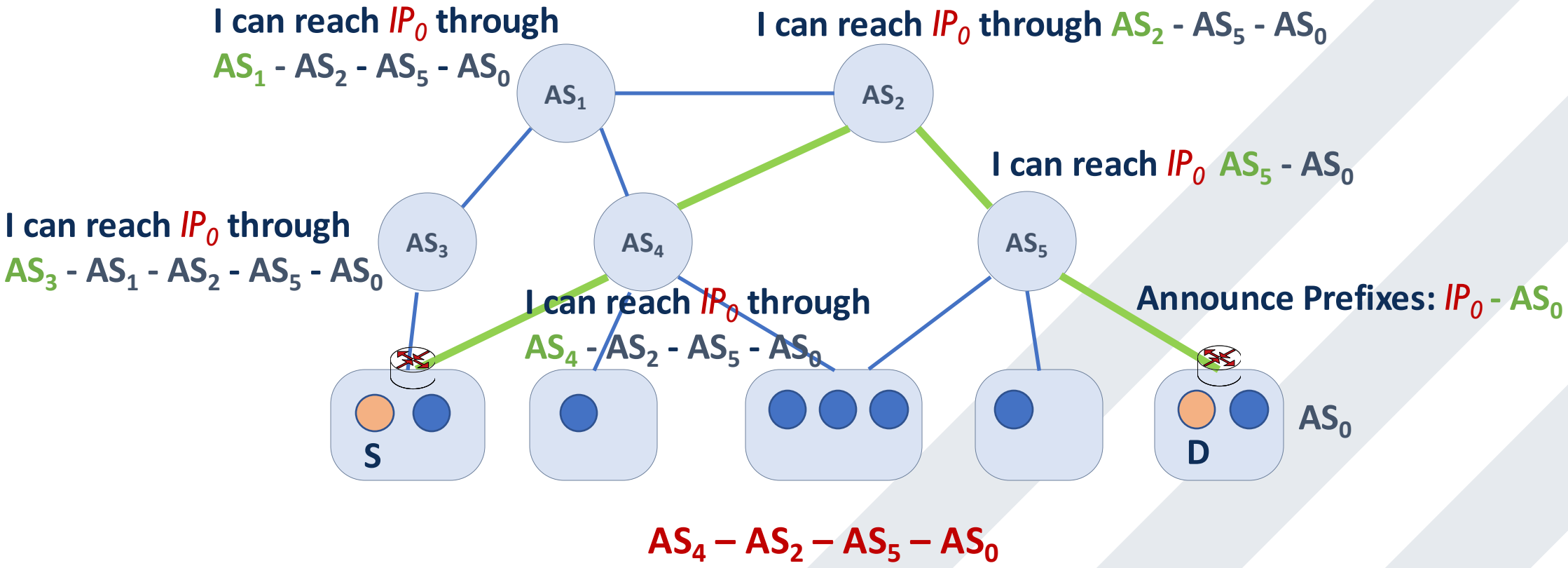

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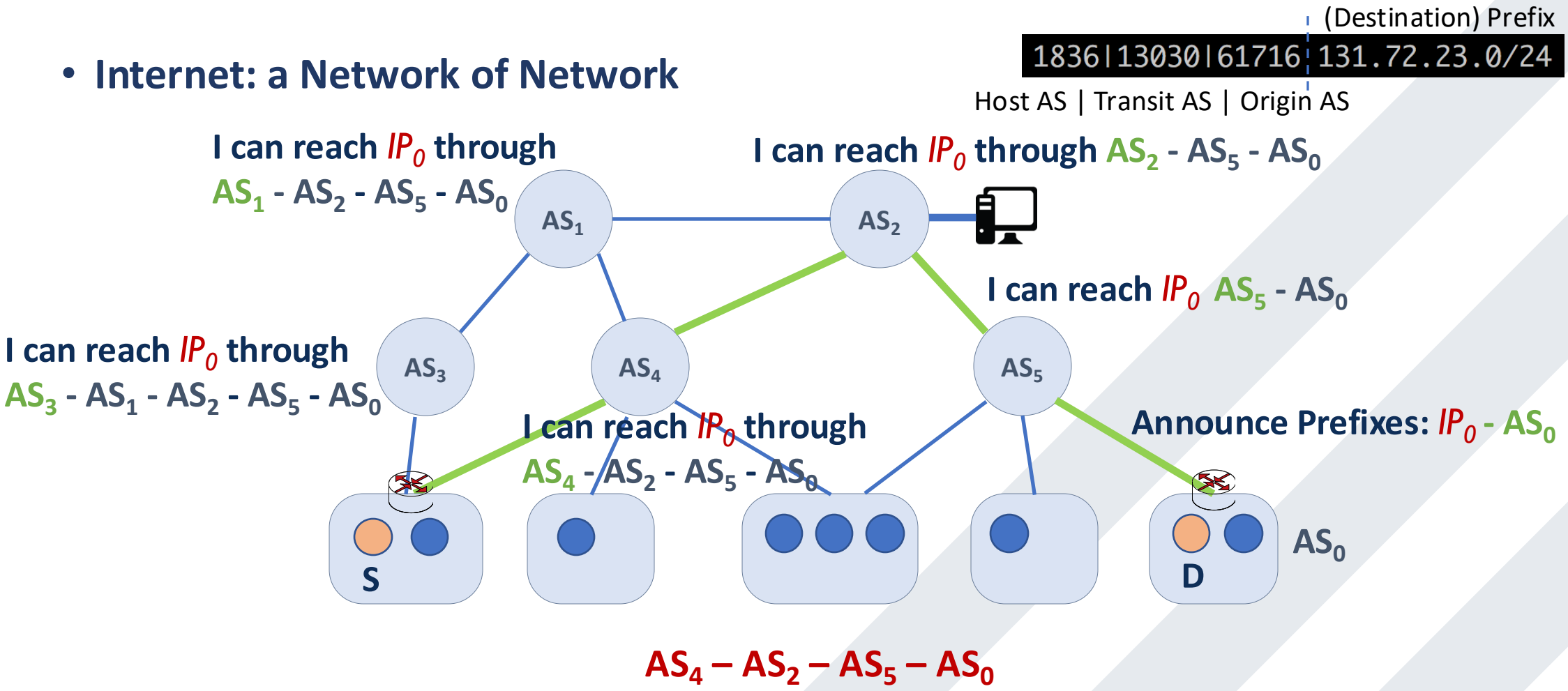

BGP (In)Security

- BGP update messages contain no authentication or integrity protection
- Attacker (malicious ASes or misconfiguration) may falsify the advertised routes (BGP Hijacking)

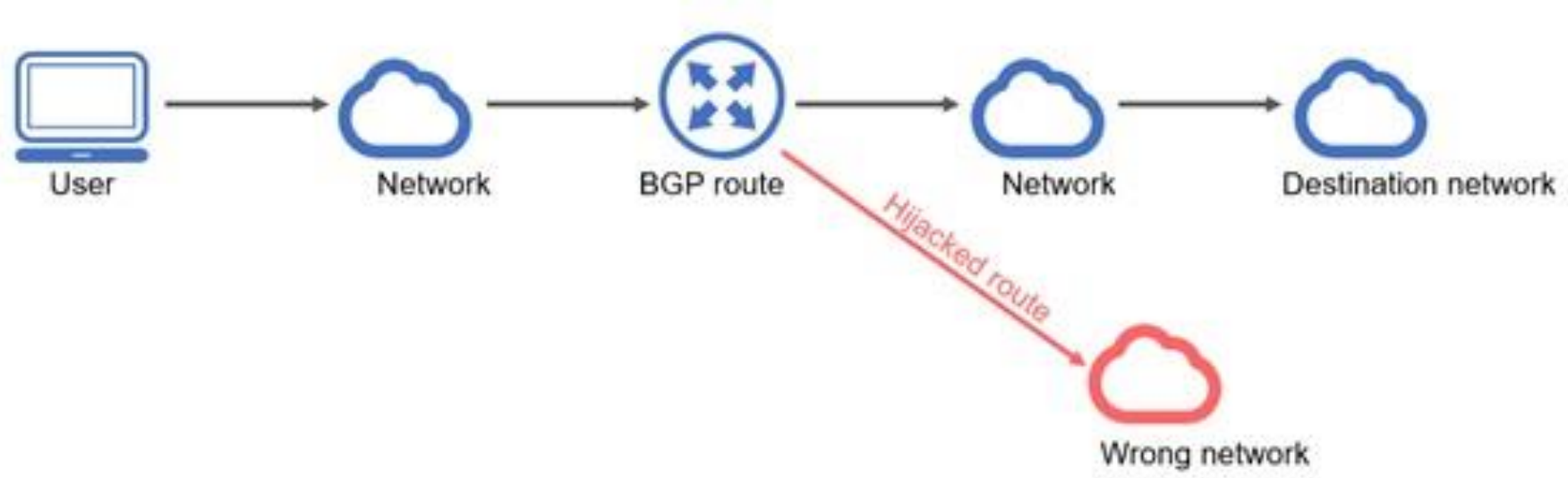

Image: https://nsfocusglobal.com/bgp-hijackings-come-back/

BGP (In)Security

- **BGP update messages contain no authentication or integrity protection**
- **Attacker (malicious ASes or misconfiguration) may falsify the advertised routes (BGP Hijacking)**
  - Modify the IP prefixes associated with a route
    - Can blackhole traffic to certain IP prefixes
  - Change the AS path
    - Either attract traffic to attacker's AS, or divert traffic away
    - Economic incentive: an ISP wants to dump its traffic on other ISPs without routing their traffic in exchange

BGP (In)Security

- **BGP Hijacking – (Sub-)Prefix Hijacking**
  - Routers perform routing by the manner of the most specific prefix matching (i.e., longest-matching)

BGP (In)Security

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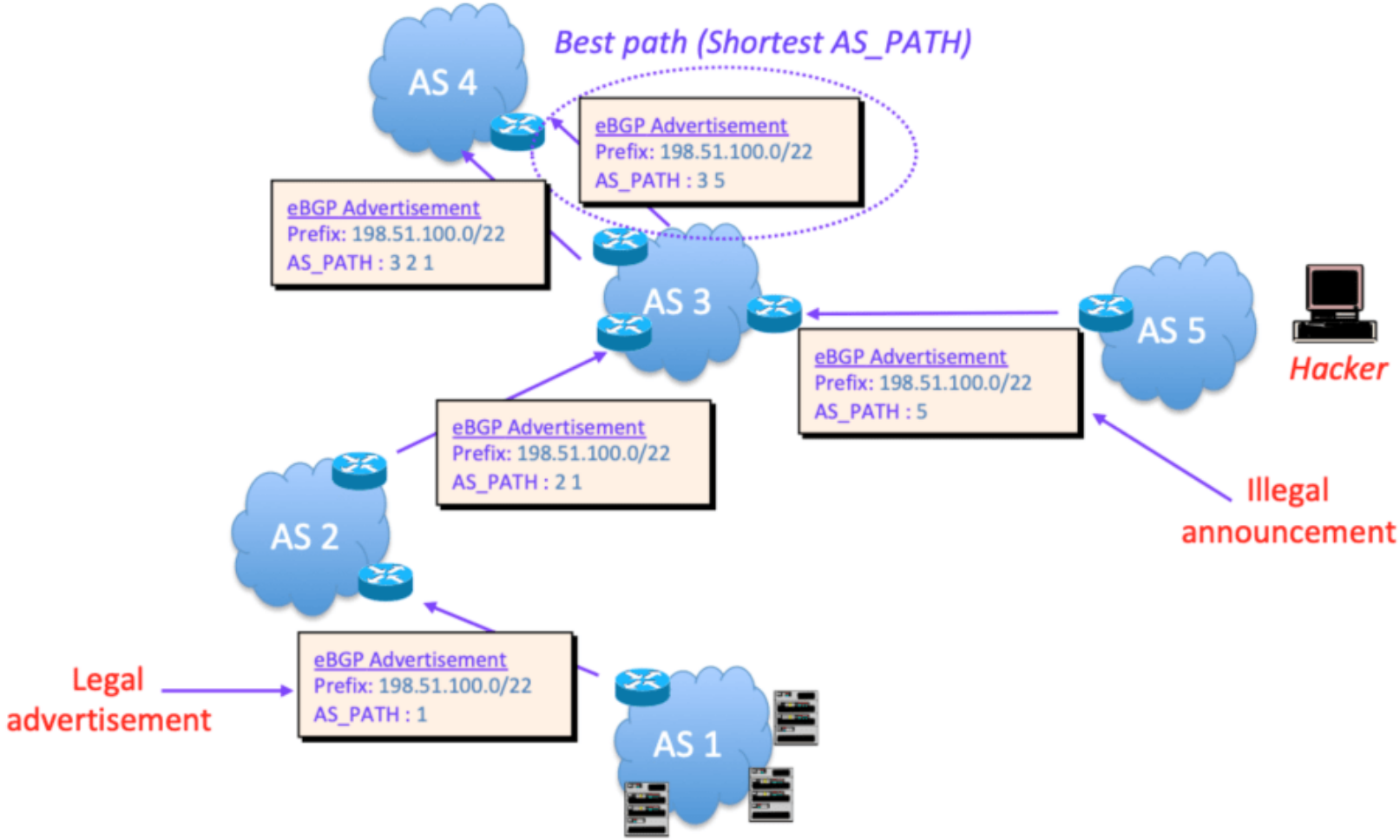

Image: MANRS

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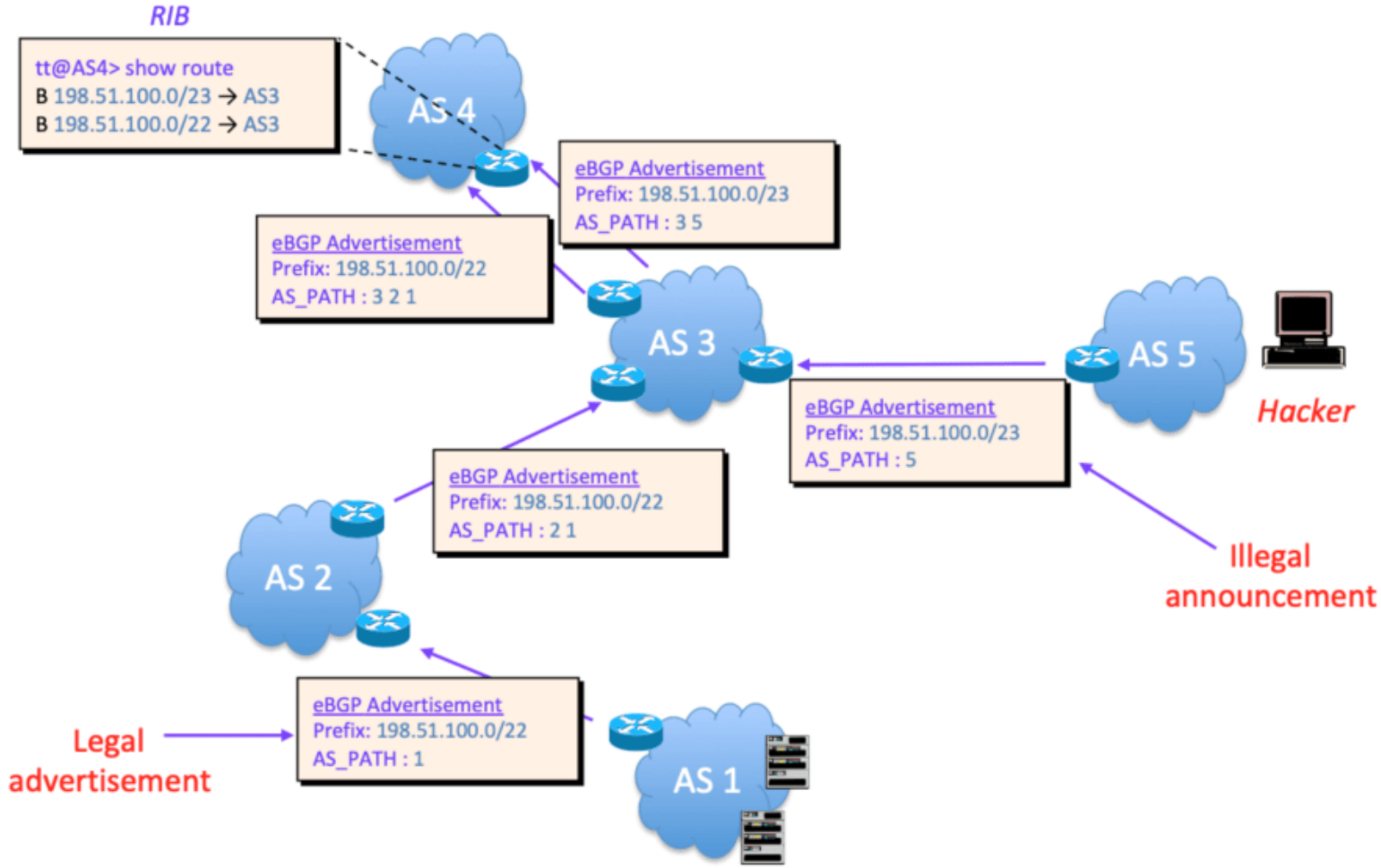

Image: MANRS

BGP (In)Security

- **BGP Hijacking – (Sub-)Prefix Hijacking**
  - Routers perform routing by the manner of the most specific prefix matching (i.e., longest-matching)
    - Adversaries may intentionally announce a prefix “smaller” than originally advertised one
    - A fraction of Internet traffic destined to the prefix to be captured by the adversary
    - Captured traffic is blackholed

BGP (In)Security

- **BGP Hijacking – Path Hijacking (Interception attack)**
  - ASes selectively/incidentally put themselves on the path
    - Adversaries may announce reachability of a prefix to attract traffic to be routed through the AS
    - The interception attack allows the malicious AS to become an intermediate AS in the path
    - Traffic can be routed back – keep the connection alive

BGP (In)Security

- **BGP Incident**
  - April 25, 1997: “The day the Interne
    - Network advertises good routes to
    - Result: packets go into a network “
      - AS7007 (Florida Internet Exchange advertised all prefixes as if it origir
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      - Huge network instability as incorrect routing data propagated and routers crashed under traffic

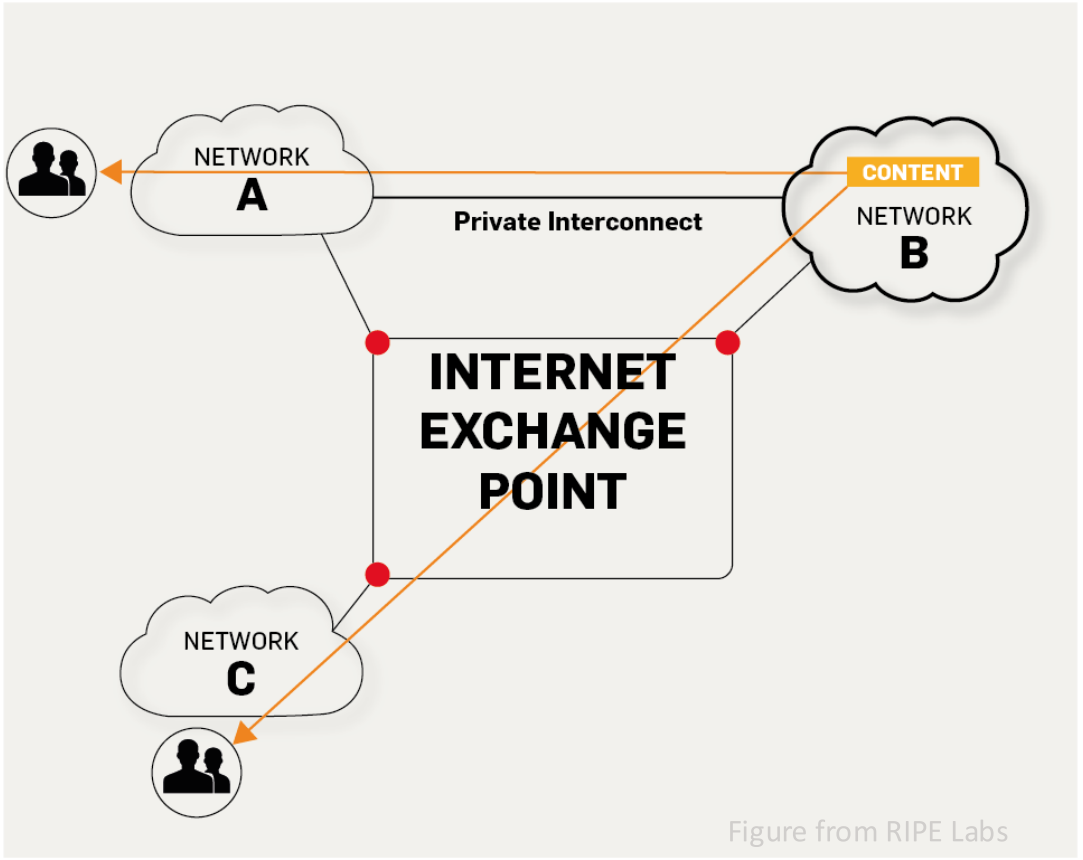

Figure from RIPE Labs

BGP (In)Security

- **BGP Incident**
  - April 25, 1997: “The day the Internet died”
    - Network advertises good routes to addresses it does not know how to reach
    - Result: packets go into a network “blackhole”
      - AS7007 (Florida Internet Exchange) de-aggregated the BGP route table and re-advertised all prefixes as if it originated paths to them
      - In effect, AS7007 was advertising that it has the best route to every host on the Internet
      - Huge network instability as incorrect routing data propagated and routers crashed under traffic

BGP (In)Security

- **BGP Incident:** Pakistan Telecom hijacks YouTube (February 2008)
  - Pakistan government wants to block YouTube
    - AS17557 (Pakistan Telecom) advertises 208.65.153.0/24
    - All YouTube traffic worldwide directed to AS17557

BGP (In)Security

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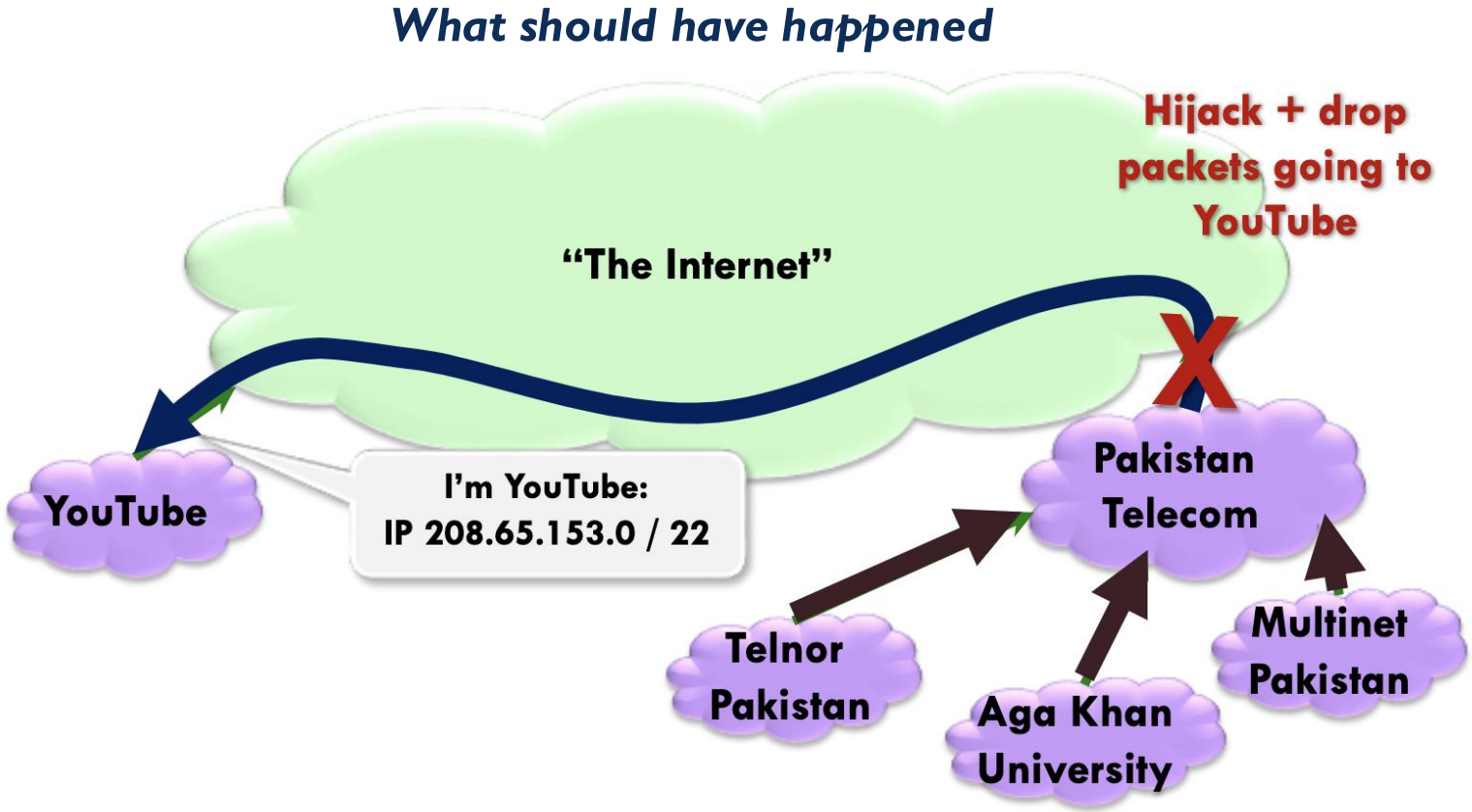

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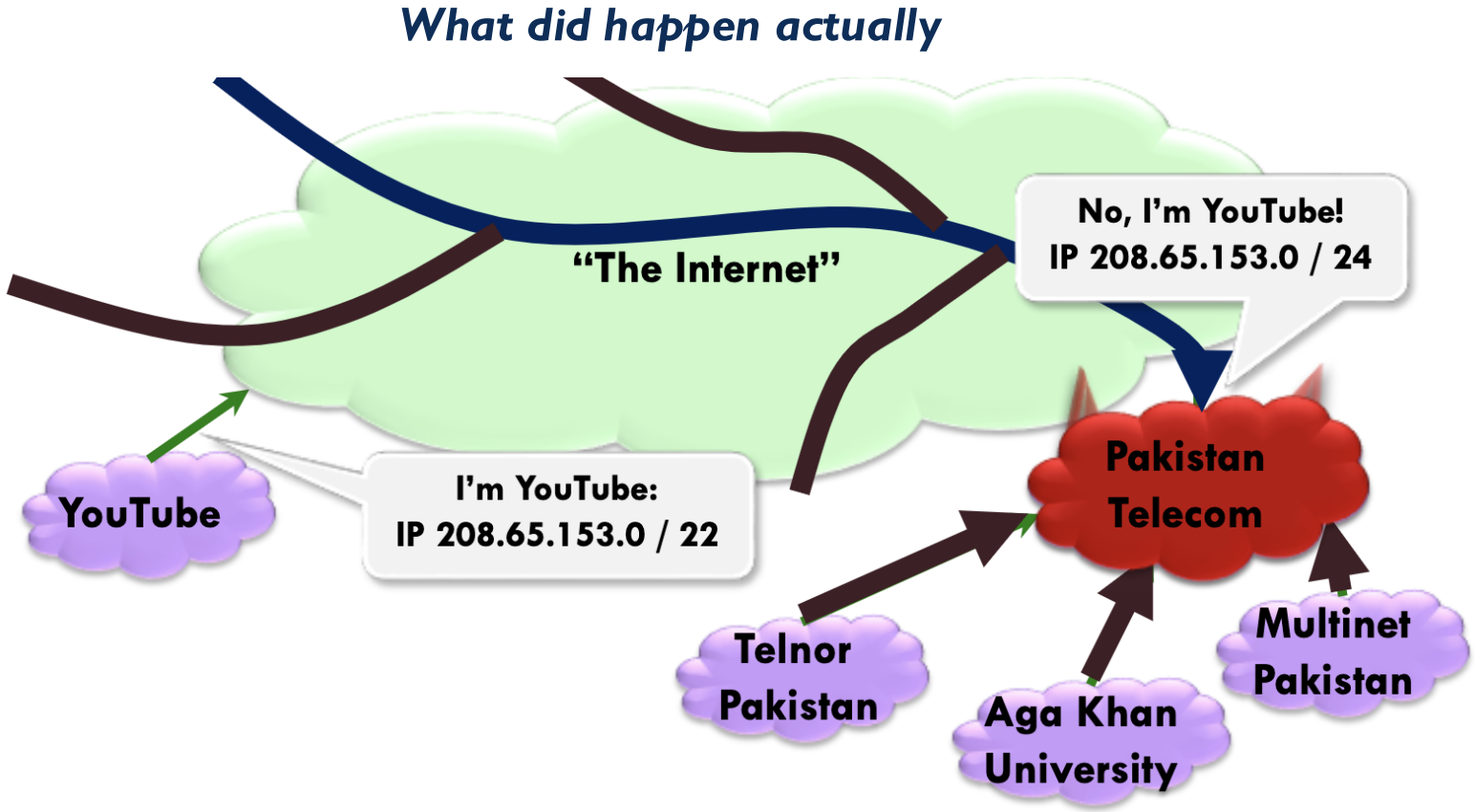

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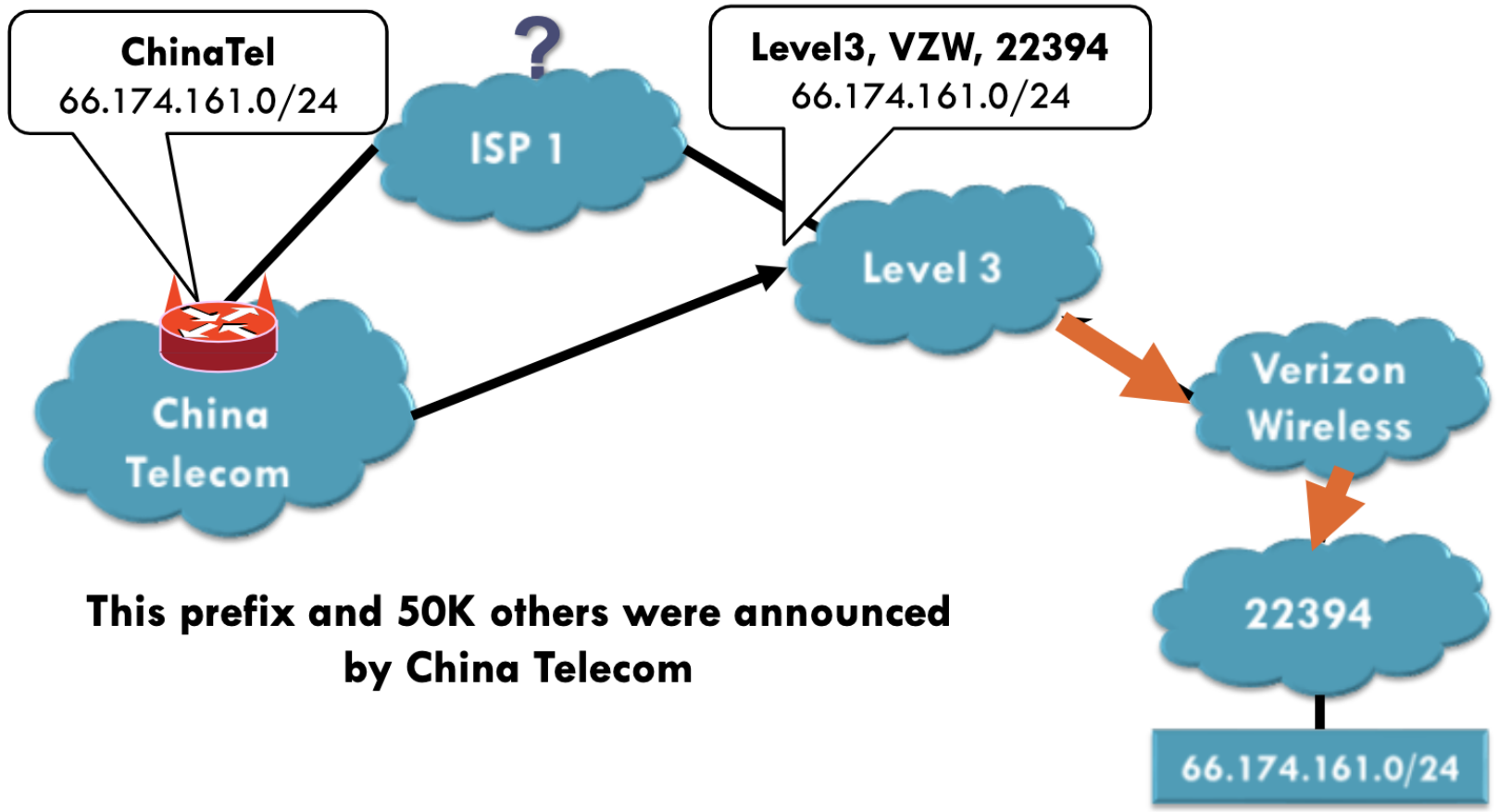

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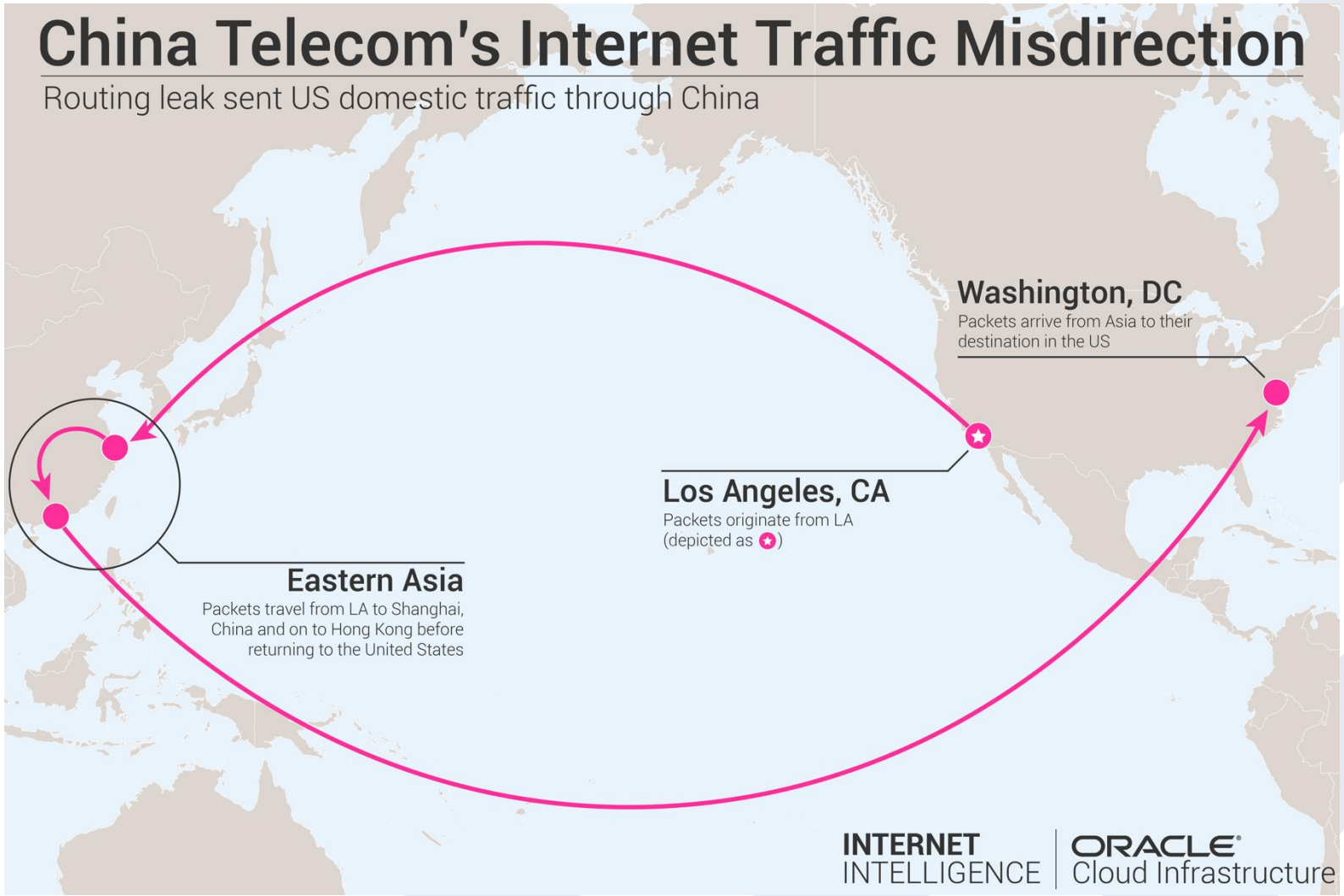
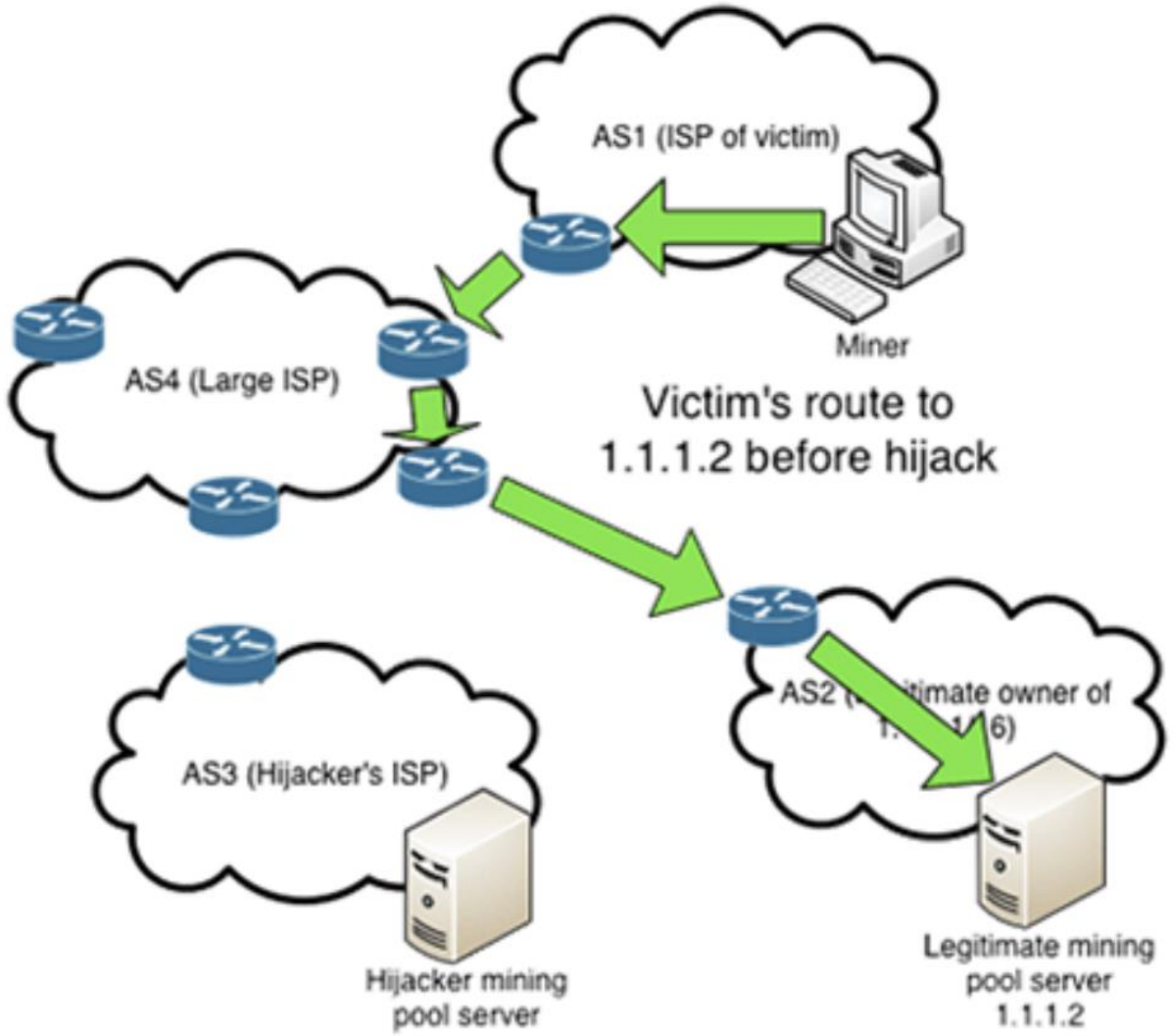


BGP (In)Security

- **BGP Incident**
  - Bitcoin Hijack (February 2014)
    - Hijacked users got directed to a mining server that was under the control of hijacker and redirects them to a malicious mining pool
    - Miners continues to receive mining tasks but don’t get compensated



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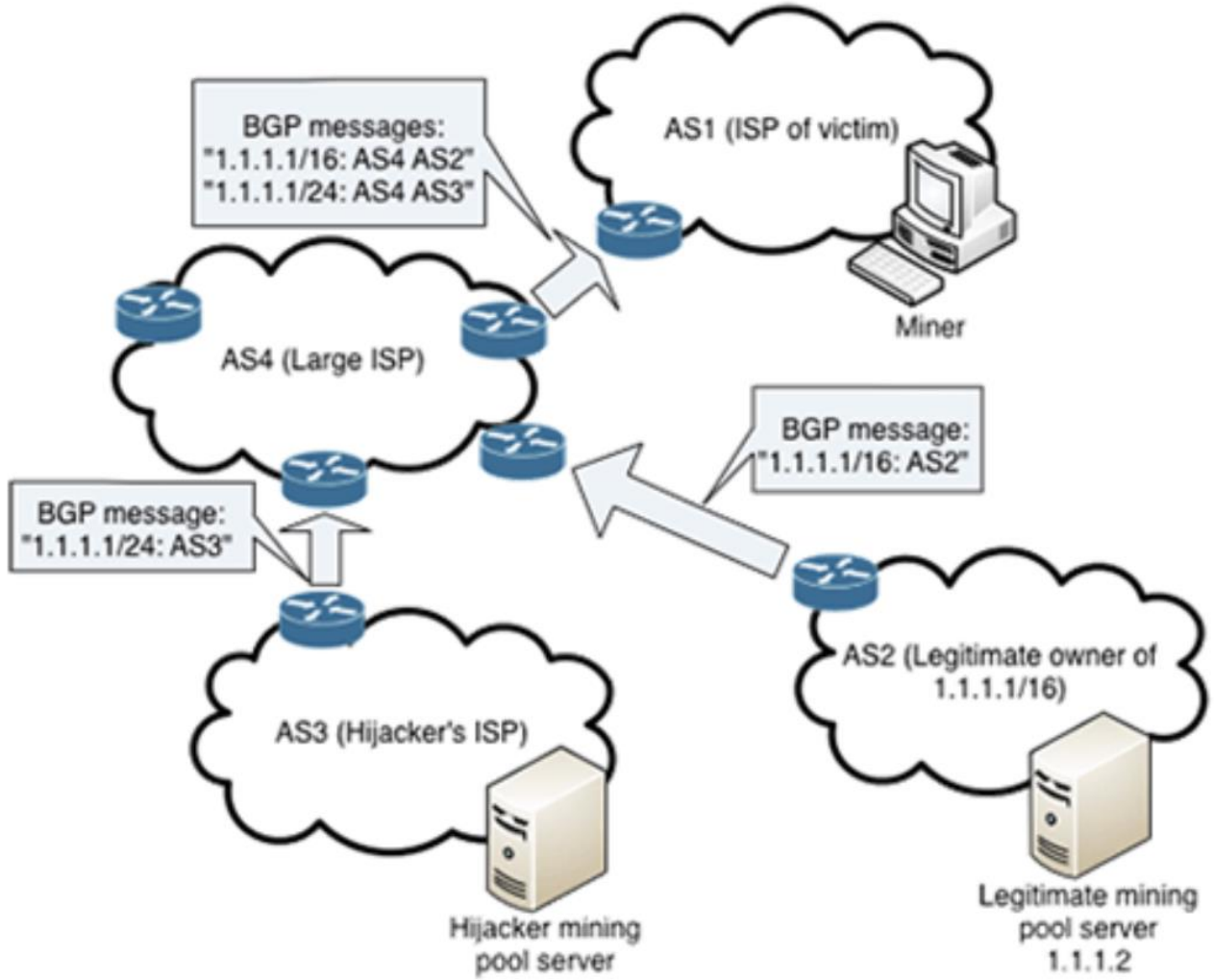

BGP (In)Security

- **BGP Incident**
  - Bitcoin Hijack (February 2014)
    - Hijacked users got directed to a mining server that was under the control of hijacker and redirects them to a malicious mining pool
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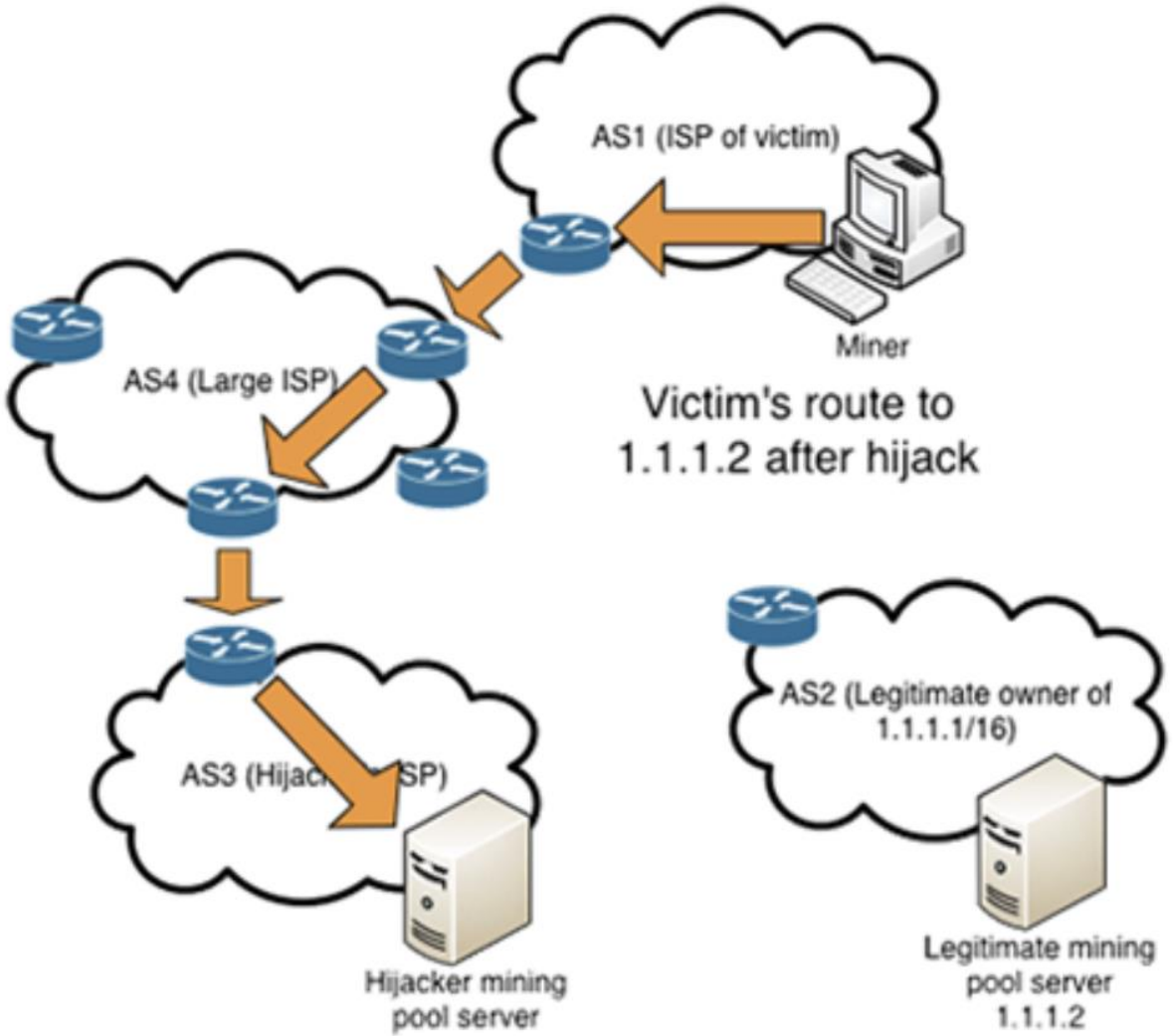

BGP (In)Security

- **Securing BGP is extremely hard**
  - The victim AS doesn’t see the problem
    - Picks its own route
  - May not cause entire loss of connectivity
    - Partial damage
    - Performance degradation
  - Diagnosing prefix hijacking
    - Analyzing updates from many vantage points

BGP (In)Security

- **Securing BGP is extremely hard**
  - Complex System
    - Around 100K Autonomous Systems
    - Decentralized Control among ASes
    - Hard to reach agreement on the solution
    - Hard to deploy the solution even standardized
      - Low incentive: many solutions benefit others rather than the deployer itself, e.g., ingress filter to defend IP spoofing

BGP (In)Security

- **Securing BGP is extremely hard**
  - RPKI – Resource Public Key Infrastructure
    - Against prefix hijacking
    - Adding a signature to authenticate AS-prefix mapping
    - Internet's core networks have widely deployed
  - Secure BGP/BGPSec
    - Cryptographically authenticate the entire BGP
    - Against both prefix and path hijacking
    - Rarely deployed in practice

Content Delivery Network (CDN)

- **Content Delivery Network**
  - An add-on component becomes part of underlying Internet infrastructure
    - Deploy a large number of edge servers proximal to clients
    - Emerging in late 90s

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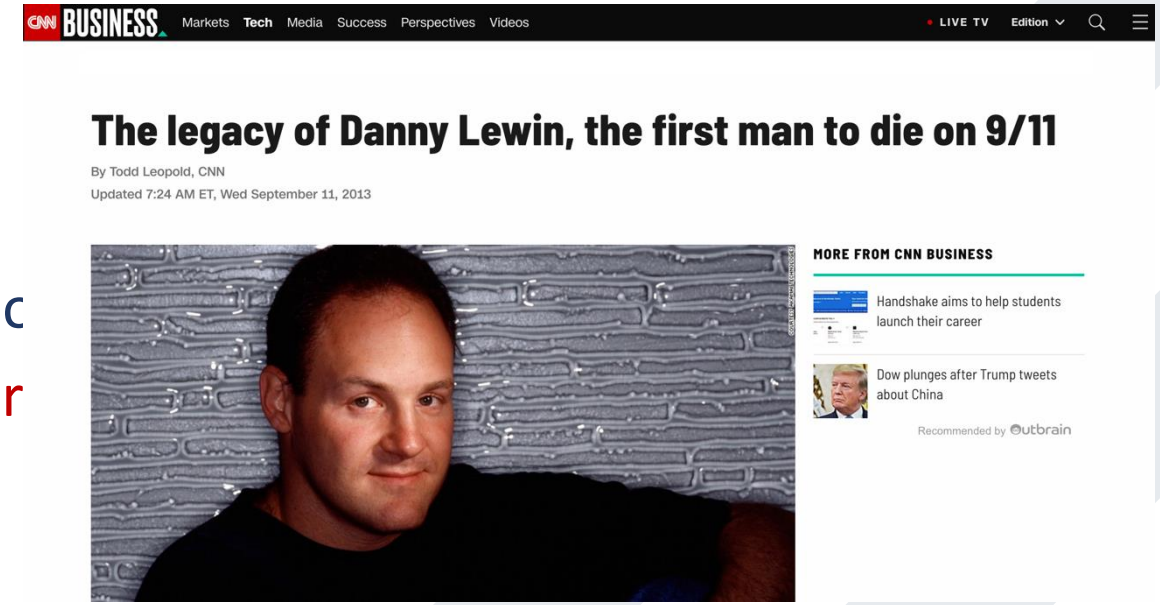

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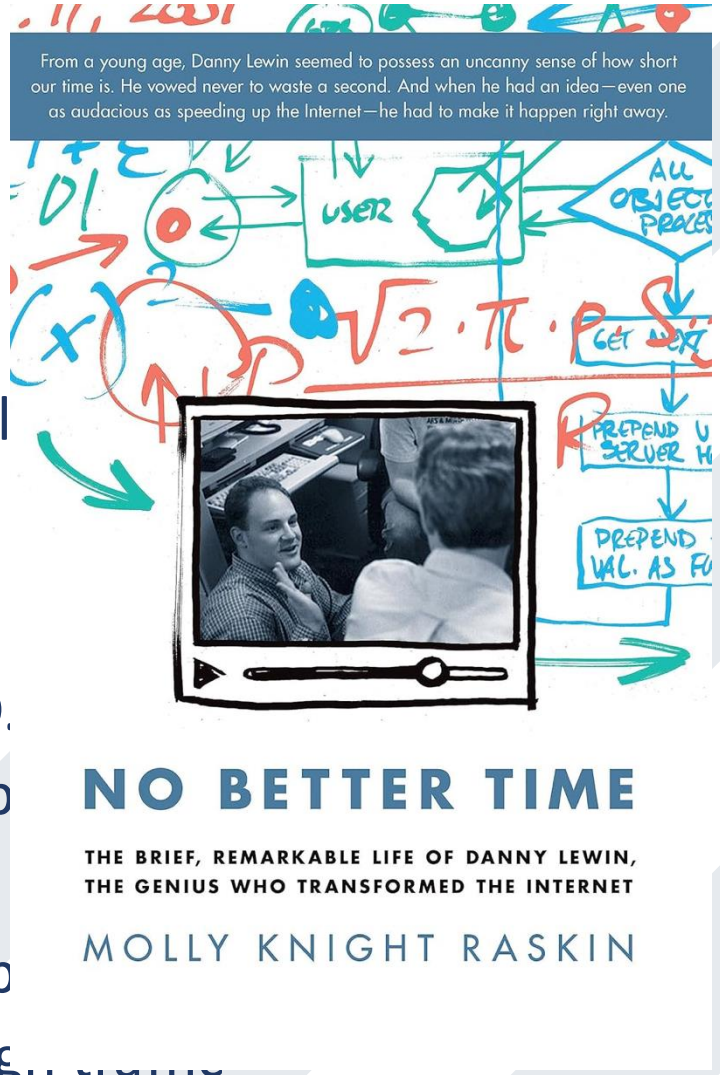


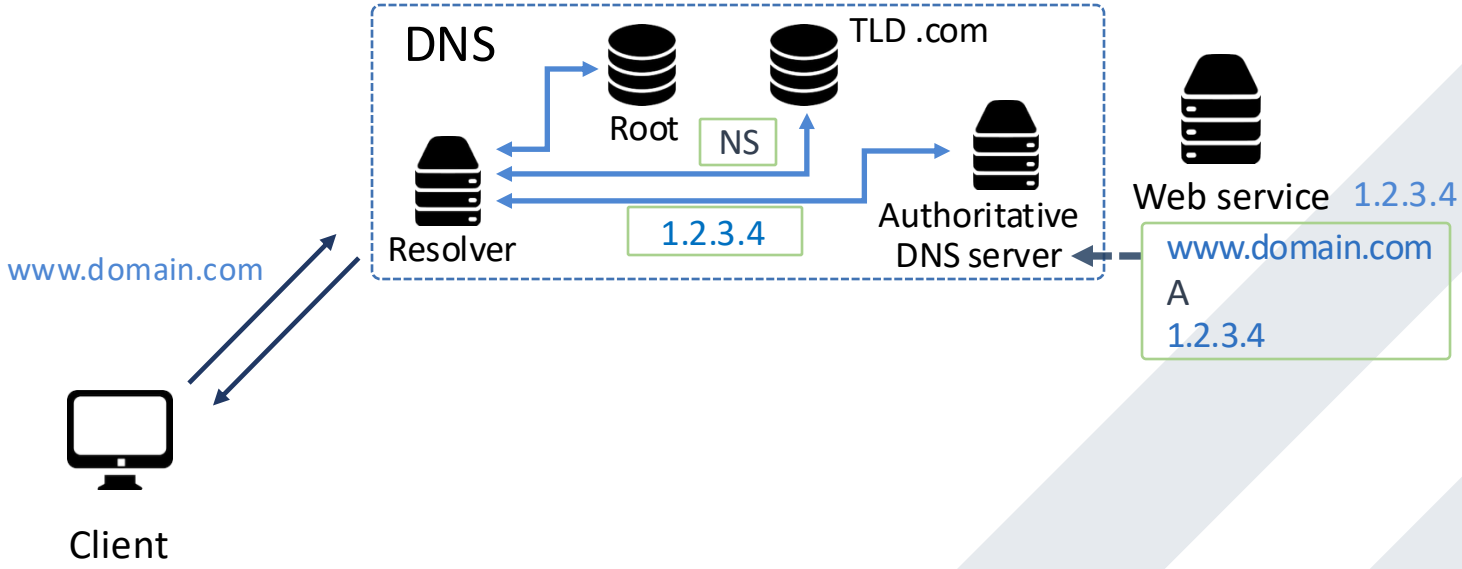
"Because of Akamai, almost every major news site remained up and running [on 9/11], a feat that proved everything Danny promised to be possible"

Content Delivery Network (CDN)

- **Content Delivery Network: Pushing Internet to the Edge**
  - An add-on component becomes part of underlying Internet infrastructure
    - Deploy a large number of edge servers proximal to clients
    - Emerging in late 90s
  - Delivery significant port of Internet traffic
    - All top Internet services leverage CDNs (private and/or third-party)
  - DNS-based CDNs vs. Anycast-based CDNs

Content Delivery Network (CDN)

- **Content Delivery Network: Pushing Internet to the Edge**



DNS-based CDNs

Content Delivery Network (CDN)

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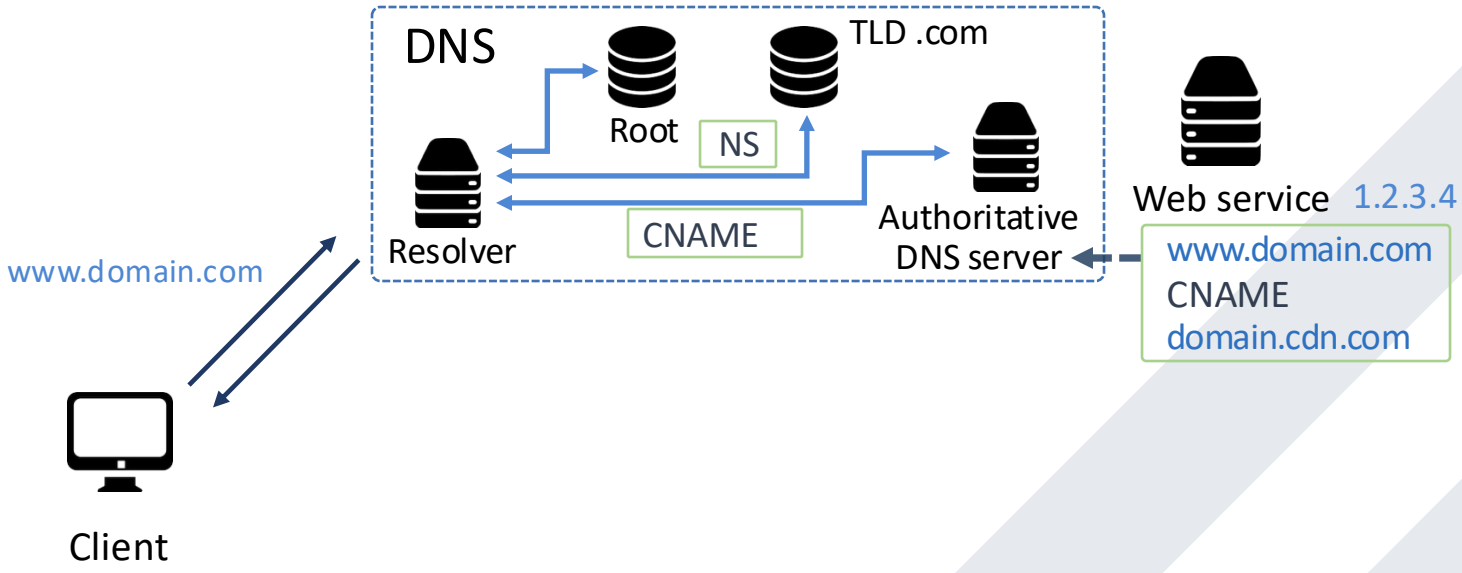

DNS-based CDNs

Content Delivery Network (CDN)

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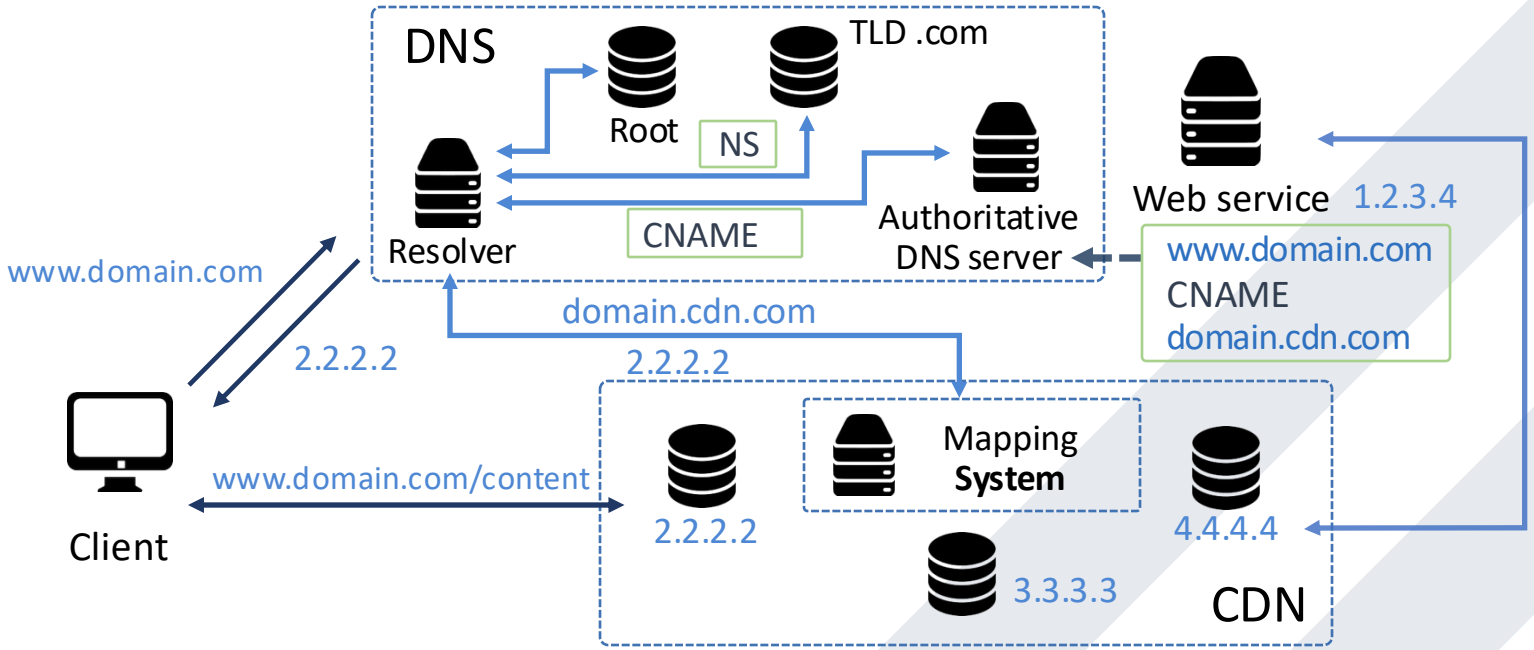
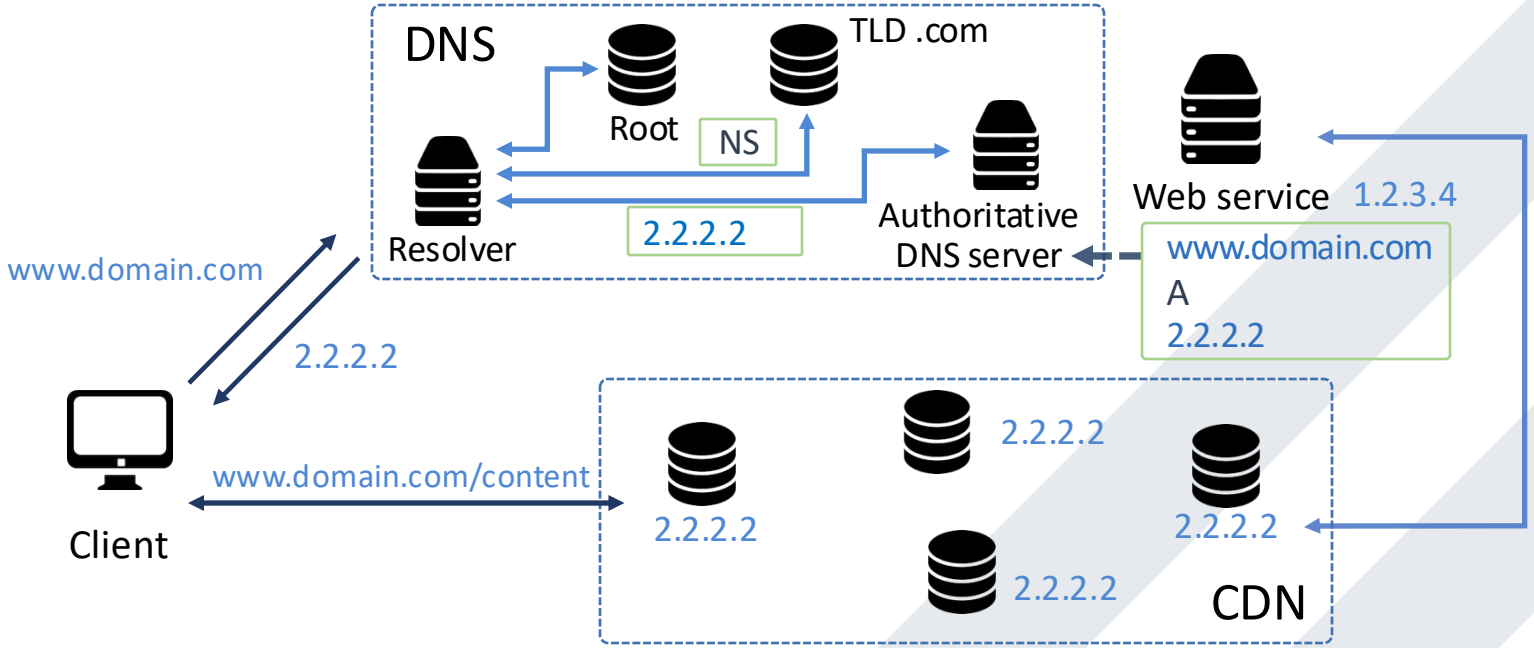


DNS-based CDNs

Content Delivery Network (CDN)

- **Content Delivery Network: Pushing Internet to the Edge**



Anycast-based CDNs

Content Delivery Network (CDN)

- **Instinct Security Provided by CDNs**
  - Additional layer of proxy
    - Hide the actual origin source of web services
  - Highly distributed, scalable platforms
    - Absorb malicious traffic (blackholing/scrubbing traffic)
    - Redundancy of service instance
  - Provision of integrity/authentication (TLS/SSL)

Network Security

- TCP/IP
- (D)DoS Attacks
- DNS
- BGP
- CDN
- Applied Cryptography
- PKI
- SSL/TLS and HTTPS
- DNSSEC
- RPKI

CS 772/872: **Advanced**
Computer and Network Security

Fall 2025

Course Link:
https://shhaos.github.io/courses/CS872/netsec-fall25.html