Security II: Network Security

Lecture 21

COS 461: Computer Networks

Kyle Jamieson

Today: Network Security

- Last lecture: Foundation Concepts
  - Application layer (Email, Web)
  - Transport layer (TLS/SSL)
  - Network layer (IP Sec)

- **This lecture:** Network Infrastructure Security
  - Naming: Secure DNS (DNS-Sec)
  - Routing: Secure BGP (BGP-Sec)

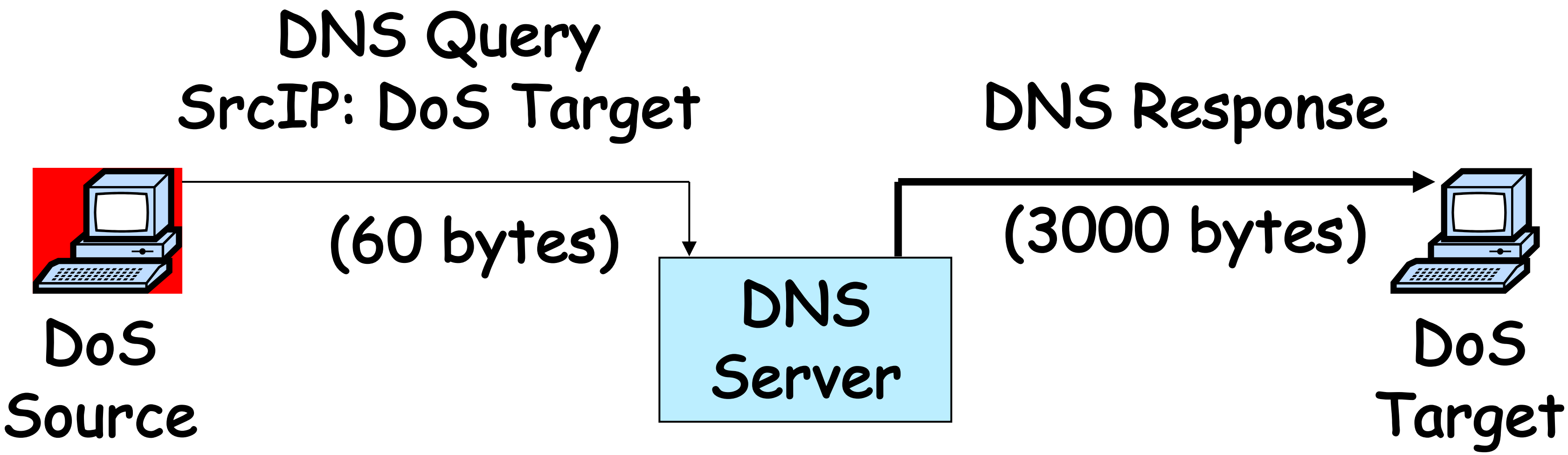
DNS Security

DoS attacks on DNS Availability

- February 6, 2007
  - Botnet attack on the 13 Internet DNS root servers
  - Lasted 2.5 hours
  - None crashed, but two performed badly:
    - g-root (DoD), l-root (ICANN)
    - Most other root servers use anycast

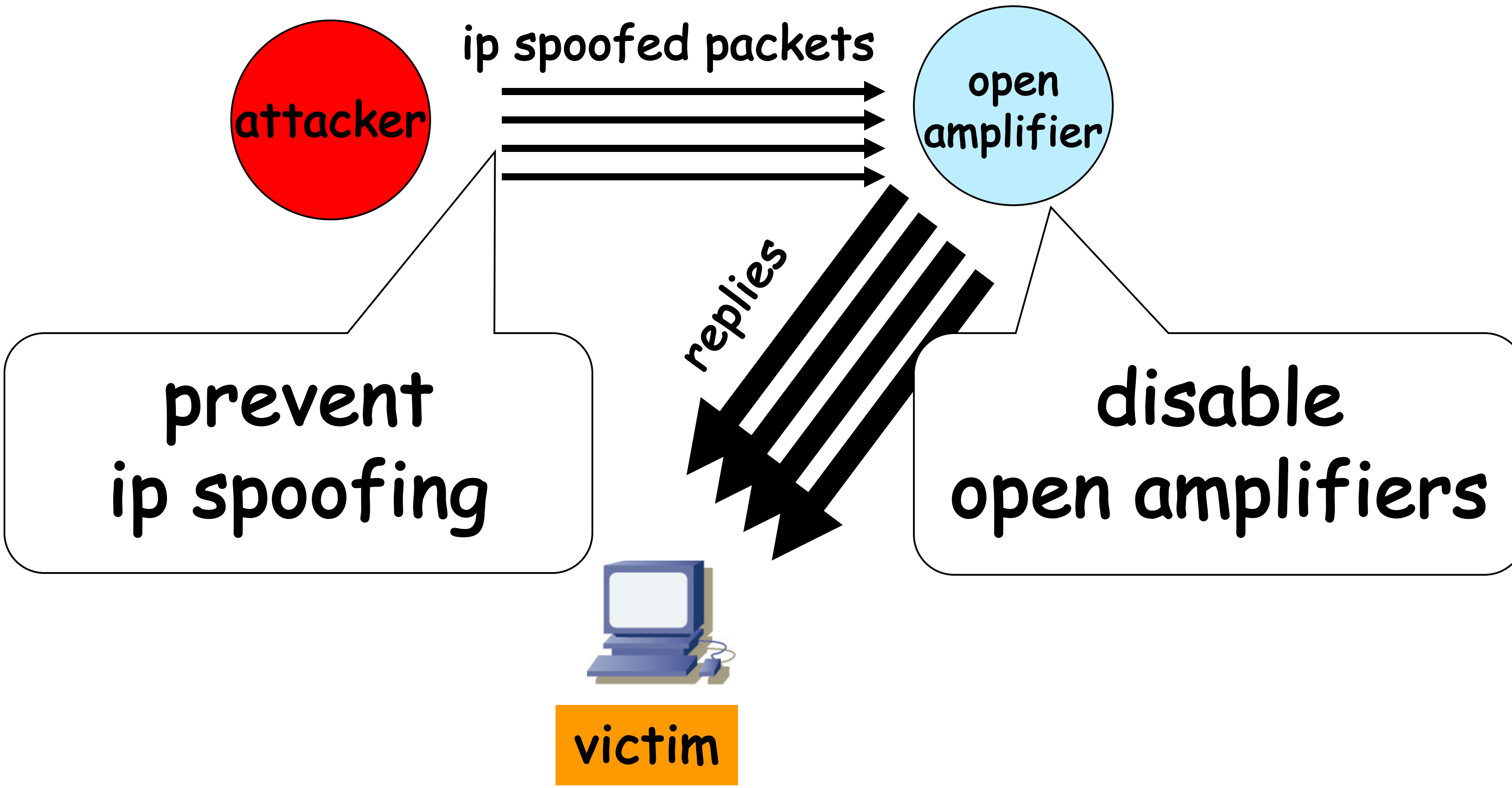
Denial-of-Service Attacks on Hosts

×40 amplification



580,000 open resolvers on Internet (Kaminsky-Shiffman'06)

Preventing Amplification Attacks



DNS Integrity: Cache Poisoning

- Was answer from an authoritative server?
  - Or from somebody else?
- DNS cache poisoning
  - Client (local nameserver) asks for www.evil.com
  - Nameserver authoritative for www.evil.com returns **additional section for (www.cnn.com, 1.2.3.4, A)**
  - Local name server: "Thanks! I won't bother to check what I asked for"

DNS Integrity: DNS Hijacking

- To prevent cache poisoning, client remembers:
  - The domain name in the request
  - A 16-bit request ID (used to demux UDP response)

- DNS hijacking
  - 16 bits: 65K possible IDs
  - What rate to enumerate all in 1 sec? 64B/packet
  - 64*65536*8 / 1024 / 1024 = 32 Mbps

- Prevention: also randomize DNS source port
  - Kaminsky attack: this source port… wasn't random

Instead: Let's strongly believe the answer! Enter DNSSEC

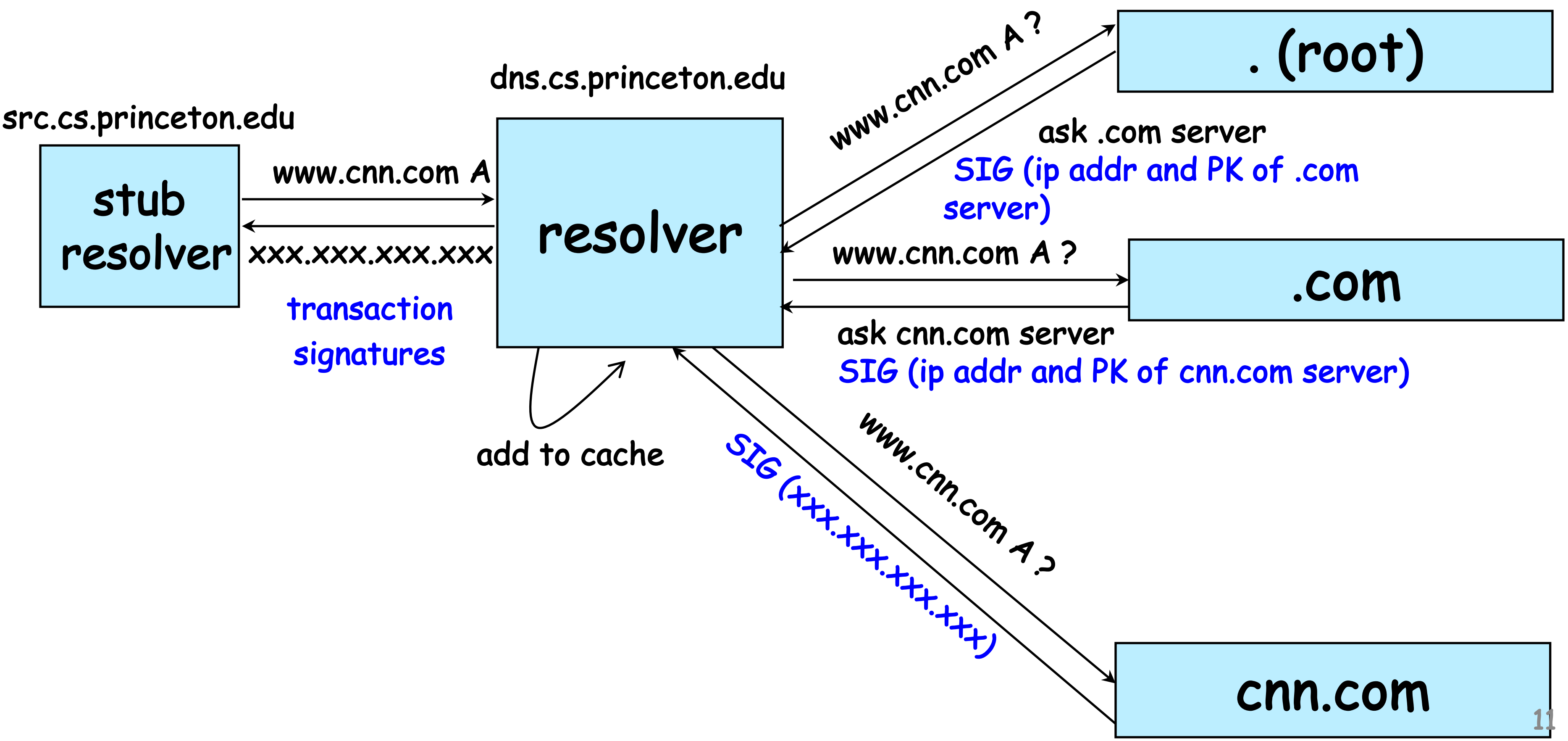
- DNSSEC protects against data spoofing and corruption
- DNSSEC also provides mechanisms to authenticate servers and requests
- DNSSEC provides mechanisms to establish authenticity and integrity

PK-DNSSEC (Public Key)

- The DNS servers sign the hash of resource record set with its private (signature) keys
  - Public keys can be used to verify the SIGs
- Leverages hierarchy:
  - Authenticity of name server's public keys is established by a signature over the keys by the parent's private key
  - In ideal case, only roots' public keys need to be distributed out-of-band

Verifying the Tree

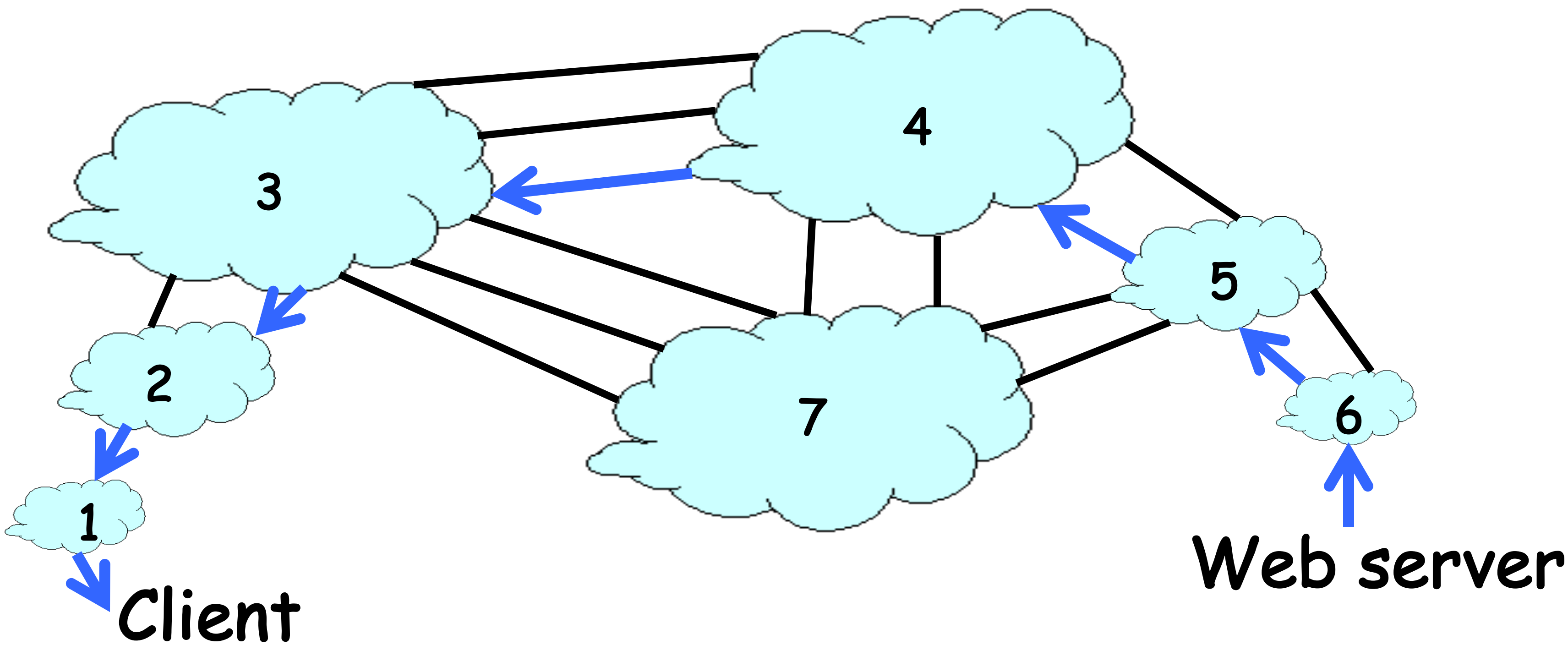
Question: www.cnn.com ?



Interdomain Routing Security

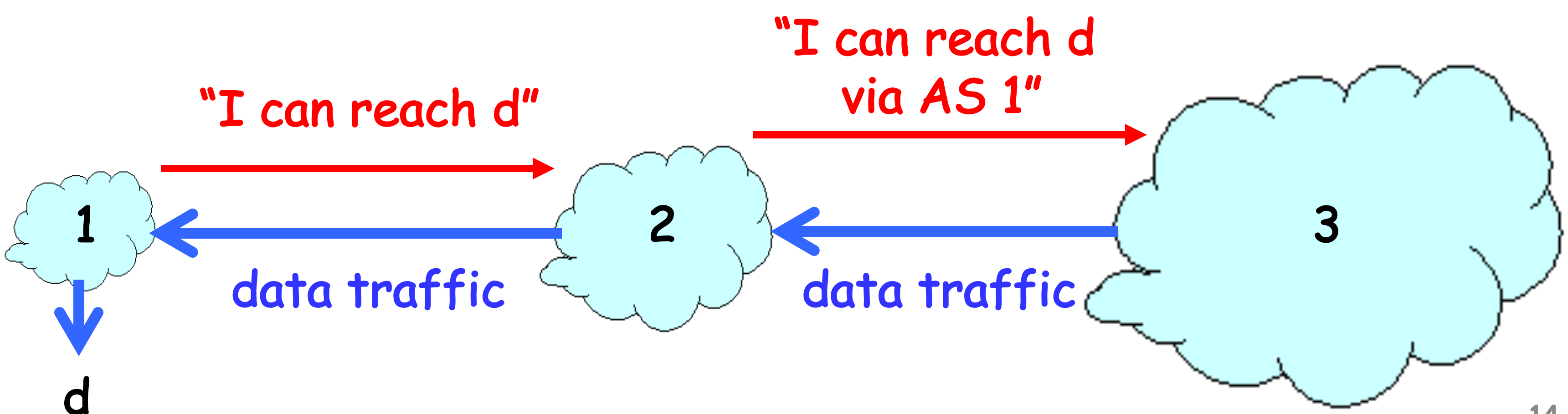
Interdomain Routing

- AS-level topology
  - Nodes are Autonomous Systems (ASes)
  - Edges are links and business relationships



Review: Border Gateway Protocol

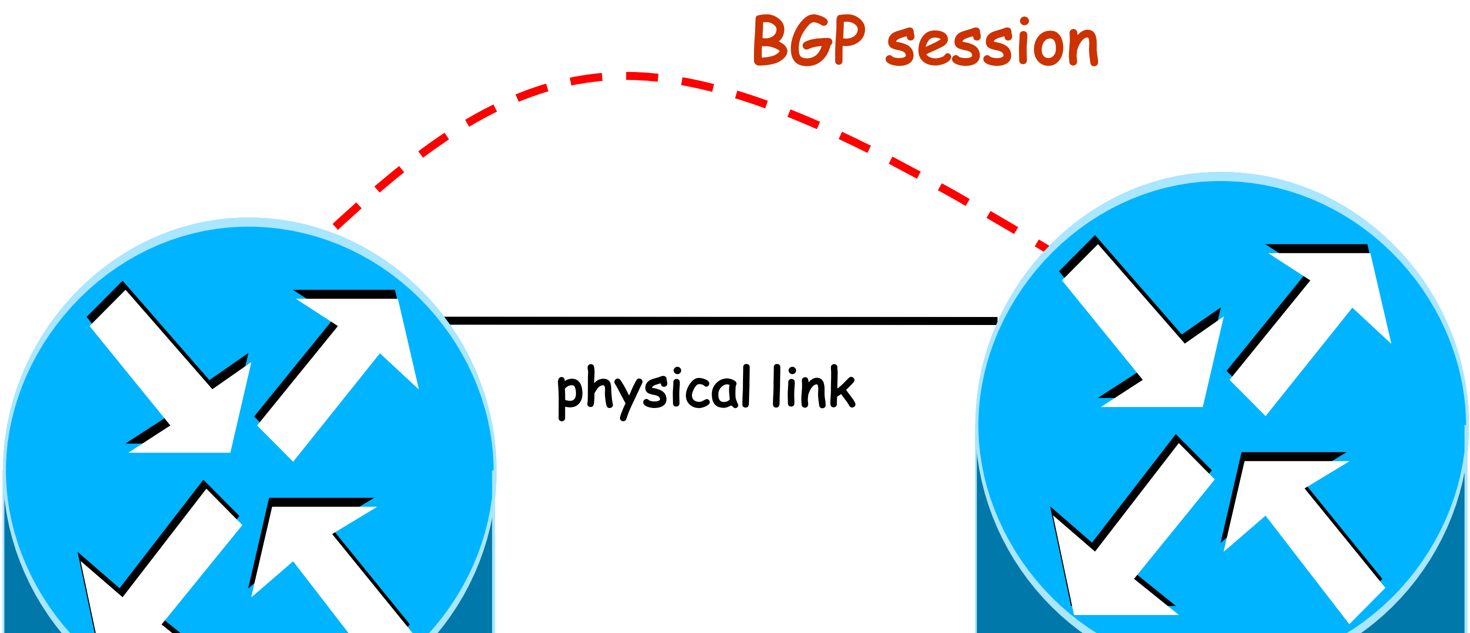
- ASes exchange reachability information
  - Destination: Block of addresses (an "IP prefix")
  - AS path: Sequence of ASes along the path
- Policies configured by network operators
  - Path selection: Which of the paths to use?
  - Path export: Which neighbors to tell?



BGP Session Security

TCP Connection Underlying BGP Session

- BGP session runs over TCP
  - TCP connection between neighboring routers
    - BGP messages sent over TCP connection
  - Makes BGP vulnerable to attacks on TCP



Attacks on Session Security

- Confidentiality
  - Eavesdropping by tapping the link
  - Inferring routing policies and stability
- Integrity
  - Tampering by dropping, modifying, adding packets
  - Changing, filtering, or replaying BGP routes
- Availability
  - Resetting the session or congesting the link
  - Disrupting communication and overloading routers

Defending Session Security is Easy

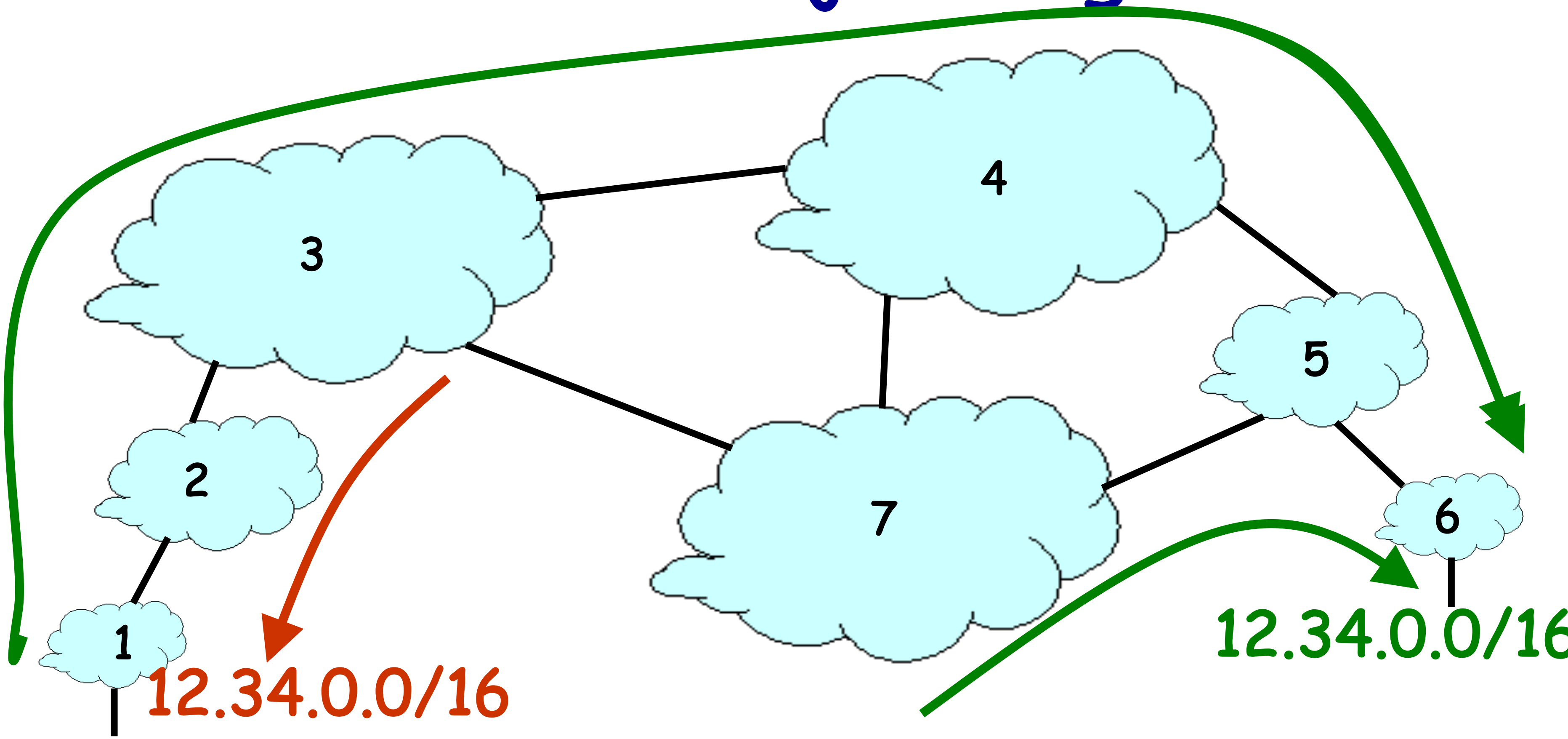
- BGP routing information is propagated widely
  - Confidentiality isn't all that important
- Two end-points have a business relationship
  - Use known IP addresses and ports to communicate
  - **Can agree to sign and encrypt messages**
- Limited physical access to the path
  - Direct physical link, often in same building
- Low volume of special traffic
  - Filter packets from unexpected senders
  - Can give BGP packets higher priority

Validity of routing information: Origin authentication

IP Address Ownership, Hijacking

- IP address block assignment
  - ICANN -> Regional Internet Registries -> ISPs
- Proper origination of a prefix into BGP
  - By the AS who owns the prefix
  - … or, by its upstream provider(s) in its behalf
- However, what's to stop someone else?
  - Prefix hijacking: another AS originates the prefix
  - BGP does not verify that the AS is authorized
  - Registries of prefix ownership are inaccurate

Prefix Hijacking

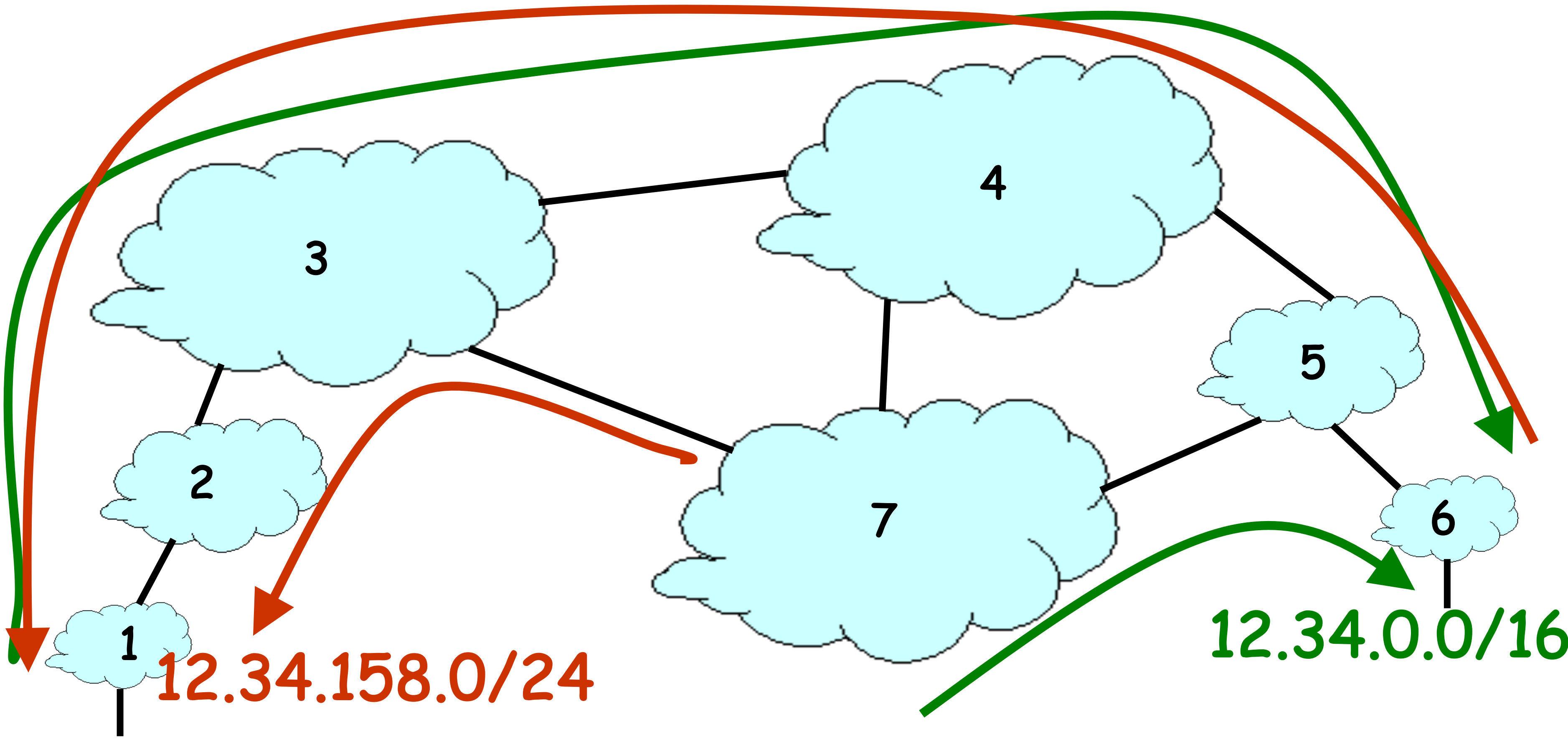


- Blackhole: data traffic is discarded
- Snooping: data traffic is inspected, then redirected
- Impersonation: traffic sent to bogus destinations

Hijacking is Hard to Debug

- The victim AS doesn't see the problem
  - Picks its own route, might not learn the bogus route
- May not cause loss of connectivity
  - Snooping, with minor performance degradation
- Or, loss of connectivity is isolated
  - E.g., only for sources in parts of the Internet
- Diagnosing prefix hijacking
  - Analyzing updates from many vantage points
  - Launching traceroute from many vantage points

Sub-Prefix Hijacking



- Originating a more-specific prefix
  - Every AS picks the bogus route for that prefix
  - Traffic follows the longest matching prefix

YouTube Outage on Feb 24, 2008

- YouTube (AS 36561): 208.65.152.0/22
- Pakistan Telecom (AS 17557)
  - Government order to block access to YouTube
  - Announces 208.65.153.0/24 to PCCW (AS 3491)
  - All packets to YouTube get dropped on the floor
- Mistakes were made
  - AS 17557: announce to everyone, not just customers
  - AS 3491: not filtering routes announced by AS 17557
- Lasted 100 minutes for some, 2 hours for others

Timeline (UTC Time)

- 18:47:45: First evidence of hijacked /24 route in Asia
- 18:48:00: Several big trans-Pacific providers carrying route
- 18:49:30: Bogus route fully propagated
- 20:07:25: YouTube advertising /24 to attract traffic back
- 20:08:30: Many (but not all) providers are using valid route
- 20:18:43: YouTube announces two more-specific /25 routes
- 20:19:37: Some more providers start using the /25 routes
- 20:50:59: AS 17557 starts prepending ("3491 17557 17557")
- 20:59:39: AS 3491 disconnects AS 17557
- 21:00:00: Internet back up

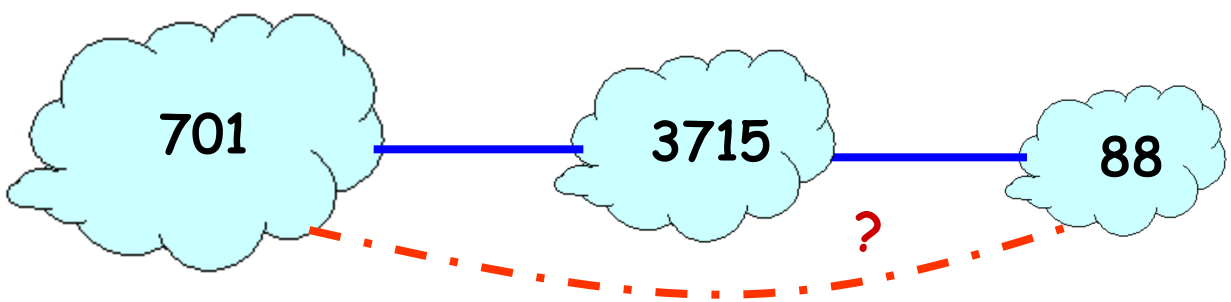
Another Example: Spammers

- Spammers sending spam
  - Form a (bidirectional) TCP connection to mail server
  - Send a bunch of spam e-mail, then disconnect
- But, best not to use your real IP address
  - Relatively easy to trace back to you
- Could hijack someone's address space
  - But you might not receive all the (TCP) return traffic
- How to evade detection
  - Hijack unused (i.e., unallocated) address block
  - Temporarily use the IP addresses to send your spam

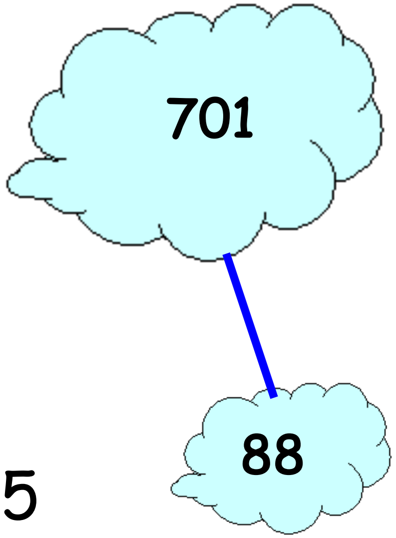
BGP AS Path

Bogus AS Paths

- Remove ASes from the AS path
  - E.g., turn "701 3715 88" into "701 88"
- Motivations
  - Attract sources that normally try to avoid AS 3715
  - Help AS 88 appear closer to the Internet's core
- Who can tell that this AS path is a lie?
  - Maybe AS 88 *does* connect to AS 701 directly



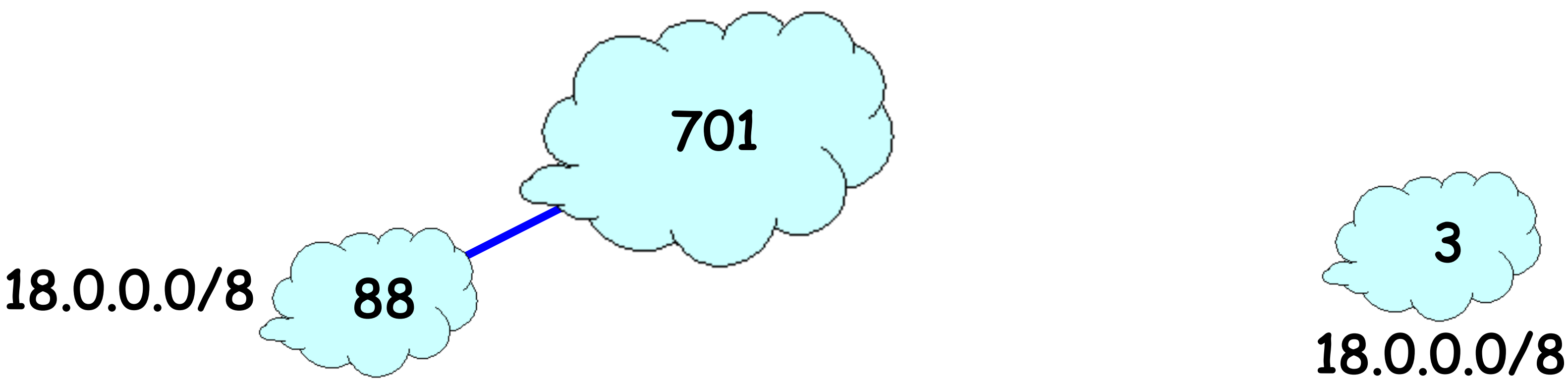
Bogus AS Paths



- Add ASes to the path
  - E.g., turn “701 88” into “701 3715 88”
- Motivations
  - Trigger loop detection in AS 3715
    - Denial-of-service attack on AS 3715
    - Or, blocking unwanted traffic from AS 3715!
  - Make your AS look like is has richer connectivity
- Who can tell the AS path is a lie?
  - AS 3715 could, if it could see the route
  - AS 88 could, but would it really care?

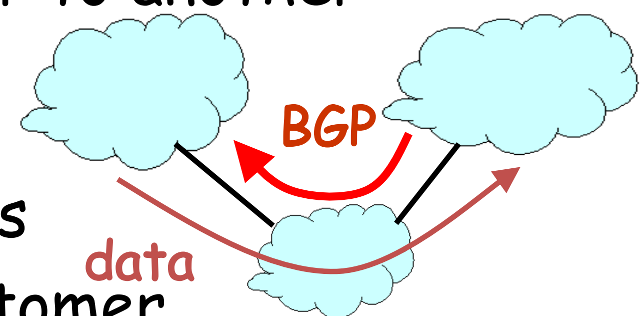
Bogus AS Paths

- Adds AS hop(s) at the end of the path
  - E.g., turns "701 88" into "701 88 3"
- Motivations
  - Evade detection for a bogus route
  - E.g., by adding the legitimate AS to the end
- Hard to tell that the AS path is bogus…
  - Even if other ASes filter based on prefix ownership



Invalid Paths

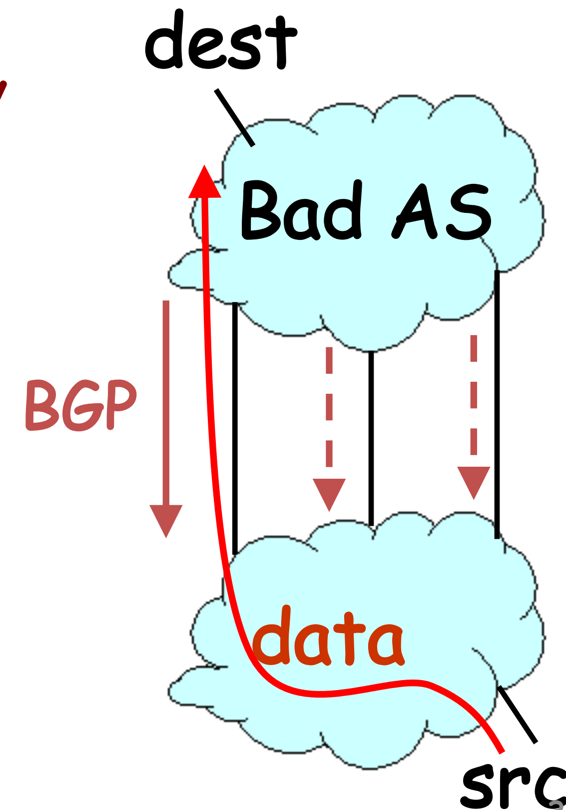
- AS exports a route it shouldn't
  - AS path is a valid sequence, but violated policy
- Example: customer misconfiguration
  - Exports routes from one provider to another
- Interacts with provider policy
  - Provider prefers customer routes
  - Directing all traffic through customer



- Main defense
  - Filtering routes based on prefixes and AS path

Missing/Inconsistent Routes

- Peers require consistent export
  - Prefix advertised at all peering points
  - Prefix advertised with same AS path length
- Reasons for violating the policy
  - Trick neighbor into "cold potato"
  - Configuration mistake
- Main defense
  - Analyzing BGP updates or traffic for signs of inconsistency



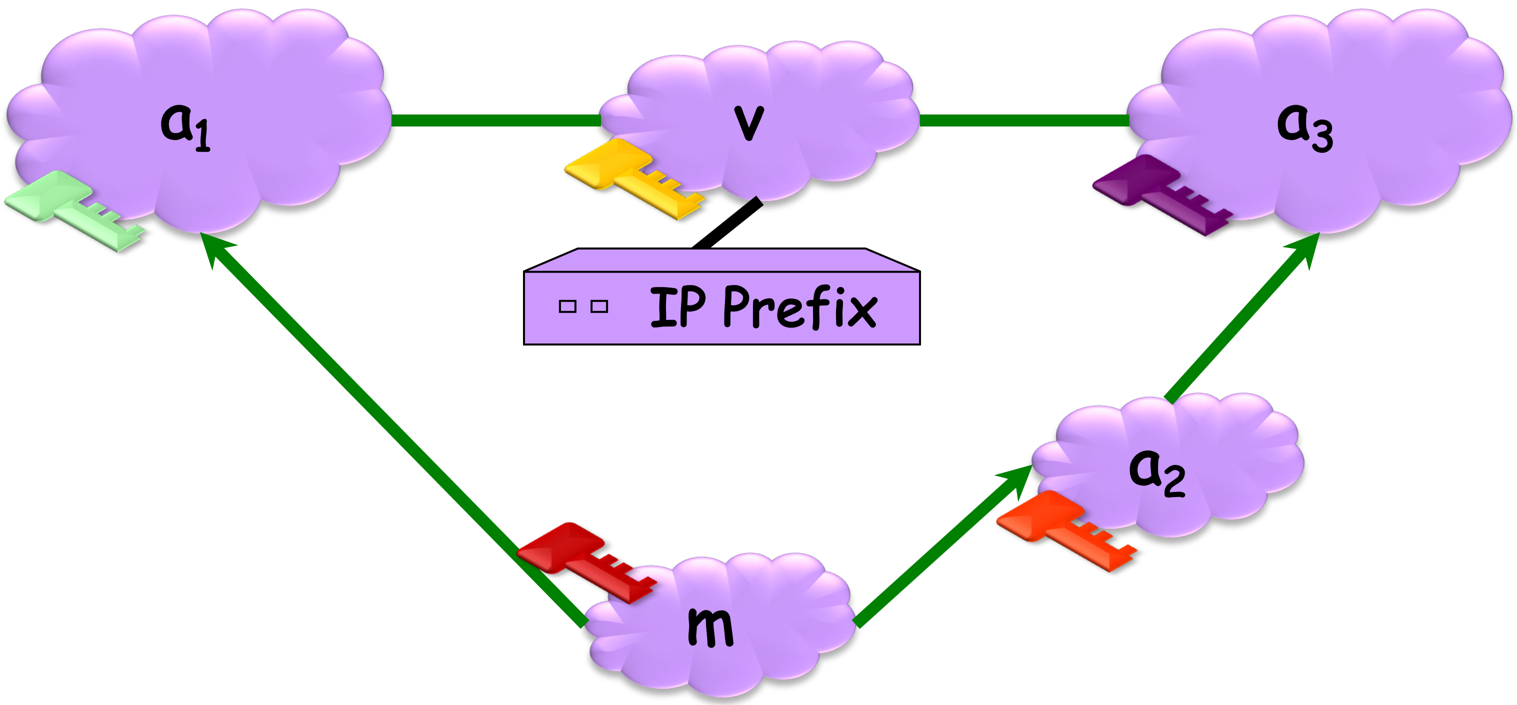
BGP Security Today

- Applying "best common practices"
  - Securing the session (authentication, encryption)
  - Filtering routes by prefix and AS path
  - Packet filters to block unexpected control traffic
- This is not good enough
  - Depends on vigilant application of practices
  - Doesn't address fundamental problems
    - Can't tell who owns the IP address block
    - Can't tell if the AS path is bogus or invalid
    - Can't be sure data packets follow the chosen route

Proposed Enhancements to BGP

Secure BGP

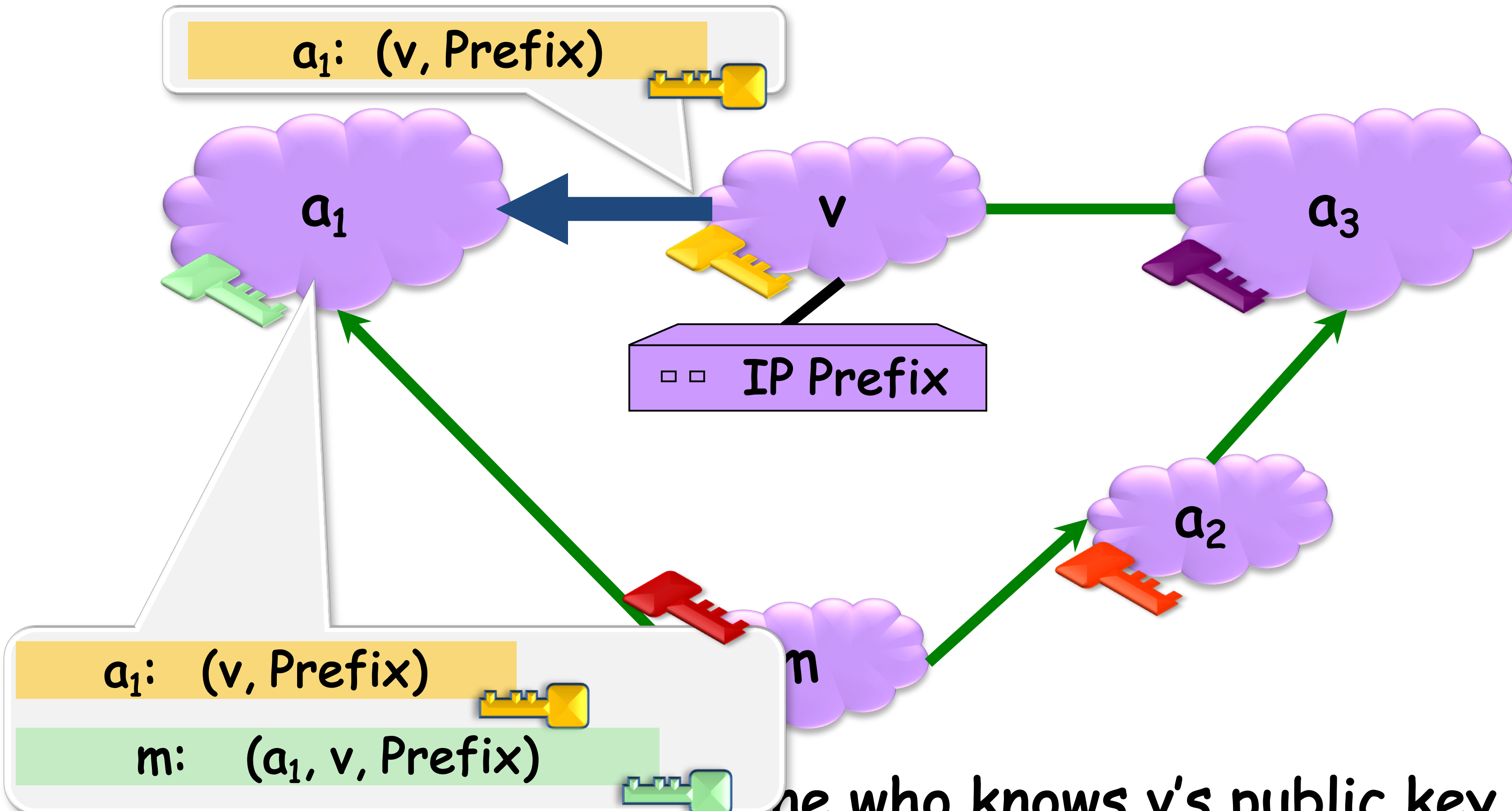
Origin Authentication + cryptographic signatures



Public Key Signature: Anyone who knows v's public key can verify that the message was sent by v.

Secure BGP

Origin Authentication + cryptographic signatures



…ne who knows v's public key can verify that the message was sent by v.

"Secure BGP"

- Route attestations
  - Distributed as an attribute in BGP update message
  - Signed by each AS as route traverses the network
- Address attestations
  - Claim the right to originate a prefix
  - Signed and distributed out-of-band
  - Checked through delegation chain from ICANN
- S-BGP can validate
  - AS path indicates the order ASes were traversed
  - No intermediate ASes were added or removed
  - Proper ASes originate prefixes

S-BGP Deployment Challenges

- Complete, accurate registries of prefix "owner"
- Public Key Infrastructure
  - To know the public key for any given AS
- Cryptographic operations
  - E.g., digital signatures on BGP messages
- Need to perform operations quickly
  - To avoid delaying response to routing changes
- Difficulty of incremental deployment
  - Hard to have a "flag day" to deploy S-BGP

Incrementally-Deployable Solutions?

- Backwards compatible
  - No changes to router hardware or software
  - No cooperation from other ASes
- Incentives for early adopters
  - Security benefits for ASes that deploy the solution
  - … and further incentives for others to deploy
- What kind of solutions are possible?
  - Detecting suspicious routes
  - … and then filtering or depreferencing them

Detecting Suspicious Routes

- Monitoring BGP update messages
  - Use past history as an implicit registry
- E.g., AS that announces each address block
  - Prefix 18.0.0.0/8 usually originated by AS 3
- E.g., AS-level edges and paths
  - Never seen the subpath "7018 88 1785"
- Out-of-band detection mechanism
  - Generate reports and alerts
  - Internet Alert Registry: http://iar.cs.unm.edu/
  - Prefix Hijack Alert System: http://phas.netsec.colostate.edu/

Avoiding Suspicious Routes

- Soft response to suspicious routes
  - Prefer routes that agree with the past
  - Delay adoption of unfamiliar routes when possible
- Why is this good enough?
  - Some attacks will go away on their own
  - Let someone else be the victim instead of you
  - Give network operators time to investigate
- How well would it work?
  - If top ~40 largest ASes applied the technique
  - … most other ASes are protected, too

What's the Internet to Do?

BGP is So Vulnerable

- Several high-profile outages
  - http://merit.edu/mail.archives/nanog/1997-04/msg00380.html
  - http://www.renesys.com/blog/2005/12/internetwide_nearcatastrophela.shtml
  - http://www.renesys.com/blog/2006/01/coned_steals_the_net.shtml
  - http://www.renesys.com/blog/2008/02/pakistan_hijacks_youtube_1.shtml
  - http://www.theregister.co.uk/2010/04/09/china_bgp_interweb_snafu/
- Many smaller examples
  - Blackholing a single destination prefix
  - Hijacking unallocated addresses to send spam
- Why isn't it an even bigger deal?
  - Really, most big outages are configuration errors
  - Most bad actors want the Internet to stay up

BGP is So Hard to Fix

- Complex system
  - Large, with around 40,000 ASes
  - Decentralized control among competitive Ases
- Hard to reach agreement on the right solution
  - S-BGP with PKI, registries, and crypto?
  - Who should be in charge of running PKI & registries?
  - Worry about data-plane attacks or just control plane?
- Hard to deploy the solution once you pick it
  - Hard enough to get ASes to apply route filters
  - Now you want them to upgrade to a new protocol

Conclusions

- Internet protocols designed based on trust
  - Insiders are good actors, bad actors on the outside
- Border Gateway Protocol is very vulnerable
  - Glue that holds the Internet together
  - Hard for an AS to locally identify bogus routes
  - Attacks can have serious global consequences
- Proposed solutions/approaches
  - Secure variants of the Border Gateway Protocol
  - Anomaly detection, with automated response
  - Broader focus on data-plane availability