Computer Networks

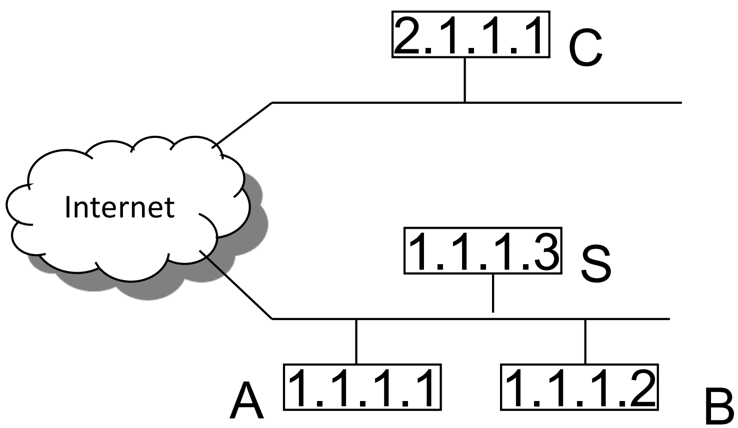
Security

Security Vulnerabilities

- At every layer in the protocol stack!
- Network-layer attacks
  - IP-level vulnerabilities
  - Routing attacks
- Transport-layer attacks
  - TCP vulnerabilities
- Application-layer attacks

Security Flaws in IP

- The IP addresses are filled in by the originating host
  - Address spoofing
- Using source address for authentication
  - r-utilities (rlogin, rsh, rhosts etc..)



- Can A claim it is B to the server S?
  - ARP Spoofing
- Can C claim it is B to the server S?
  - Source Routing

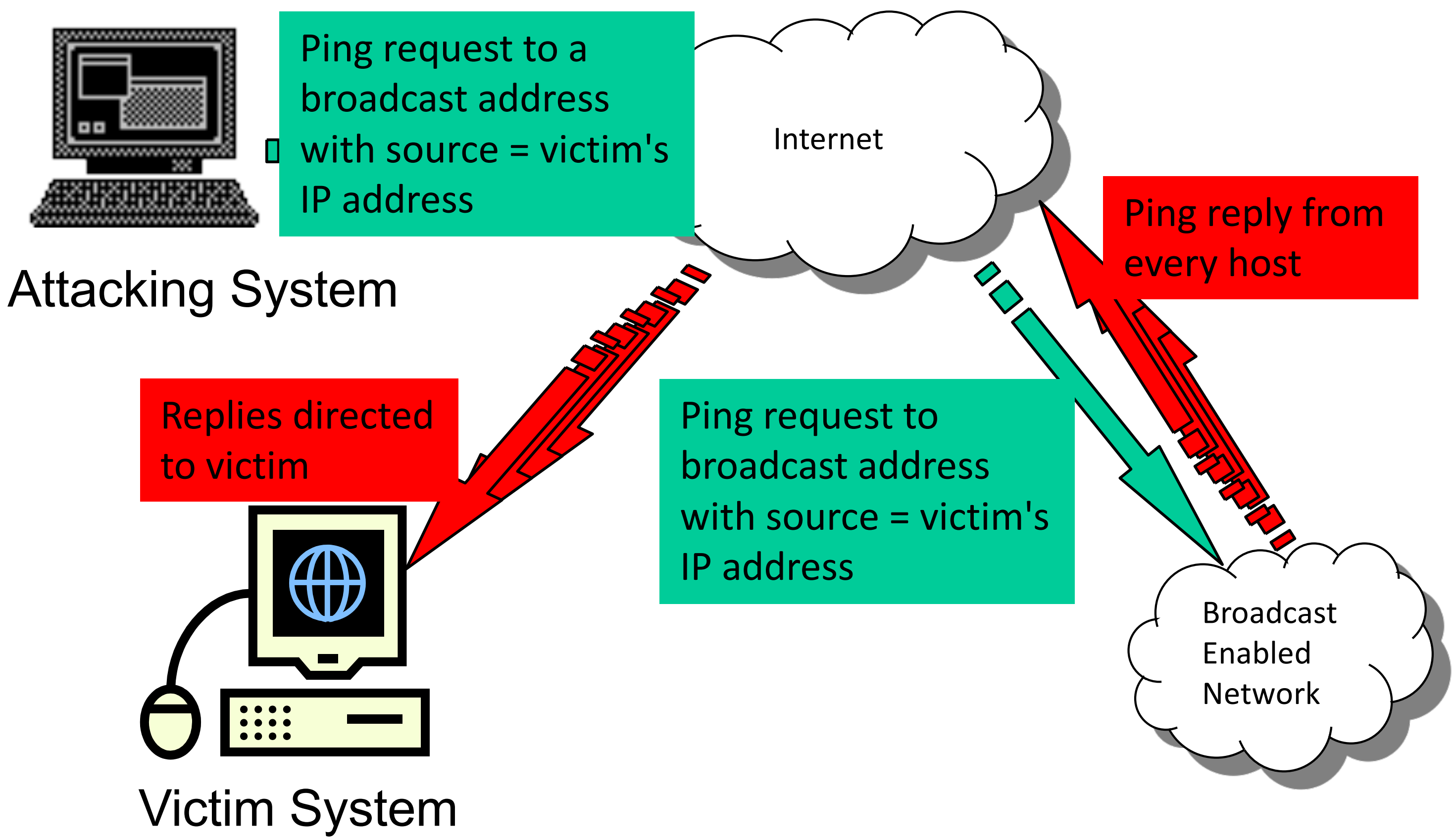
ARP Spoofing

- Attacker uses ARP protocol to associate MAC address of attacker with another host's IP address
- E.g. become the default gateway:
  - Forward packets to real gateway (interception)
  - Alter packets and forward (man-in-the-middle attack)
  - Use non-existent MAC address or just drop packets (denial of service attack)

Source Routing

- ARP spoofing cannot redirect packets to another network
  - if you spoof an IP source address, replies go to the spoofed host
- An *option* in IP is to provide a route in the packet: *source routing.*
  - Equivalent to tunneling.
- Attack: spoof the host IP address and specify a source route back to the attacker.

Smurf Attack

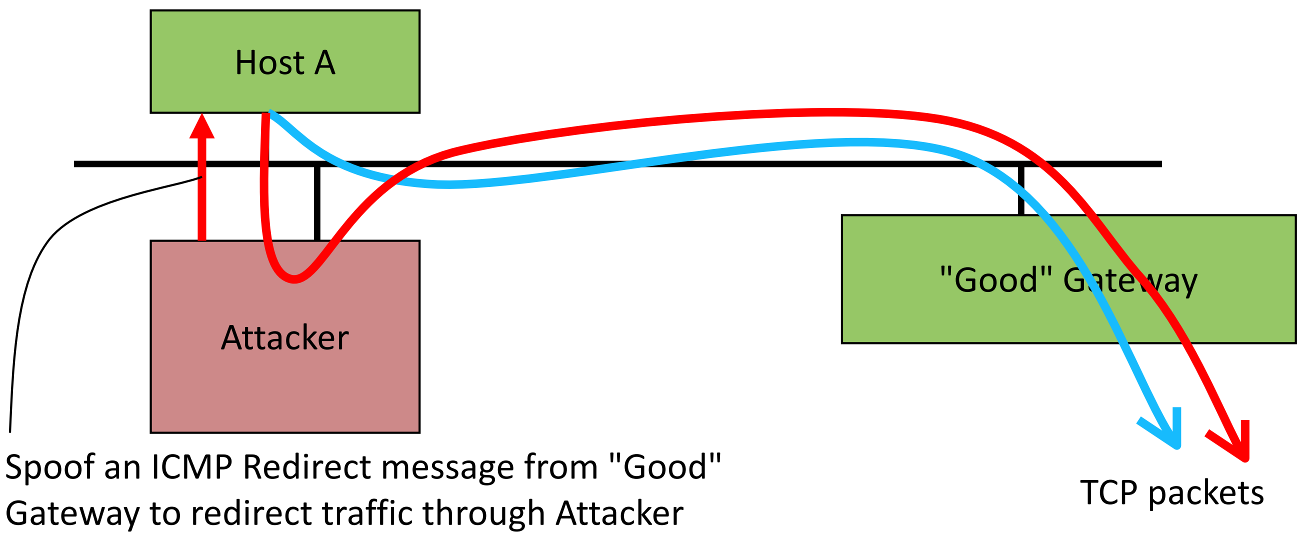


ICMP Attacks

- No authentication
- ICMP redirect message
- Oversized ICMP messages can crash hosts
- Destination unreachable
  - Can cause the host to drop connection
- Many more…
  - http://www.sans.org/rr/whitepapers/threats/477.php

ICMP Redirect

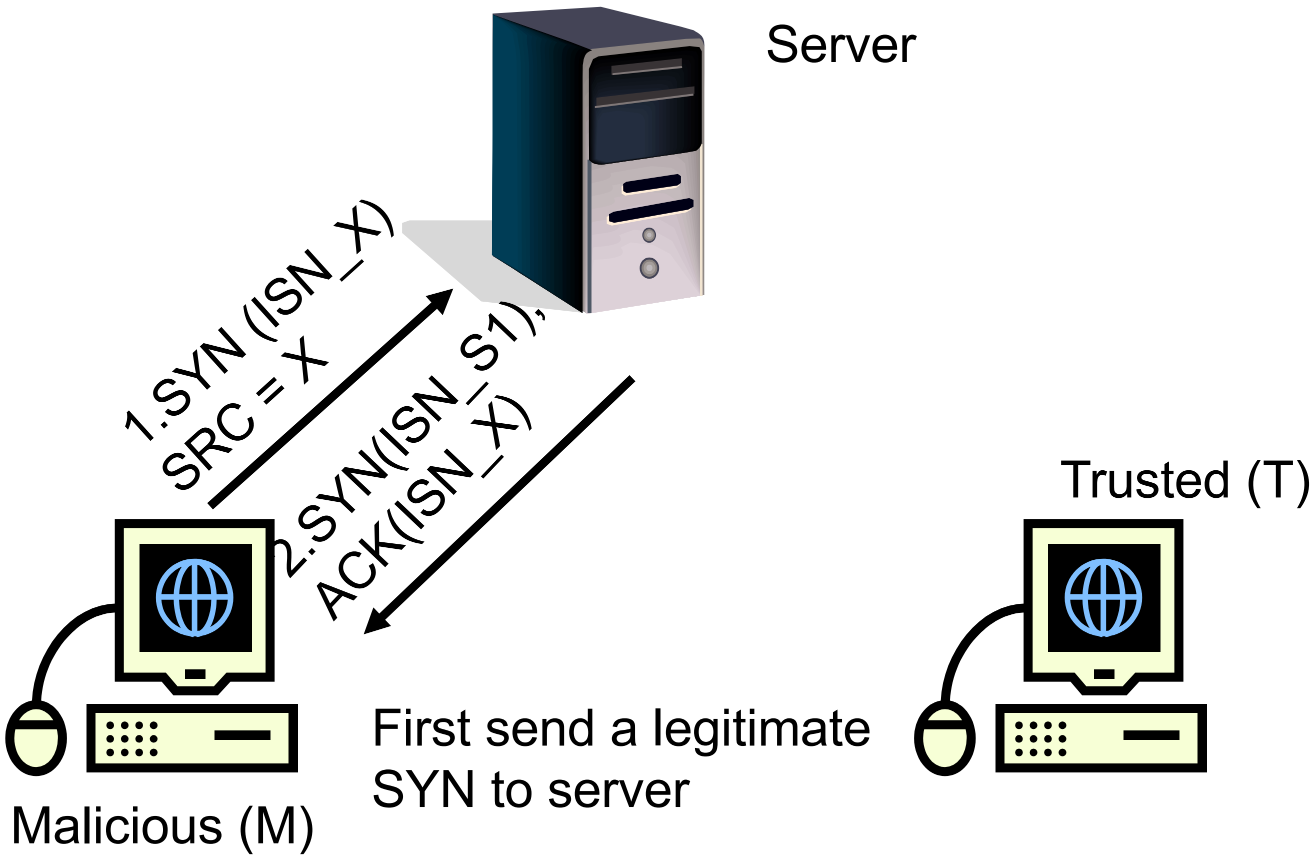
- ICMP Redirect message: tell a host to use a different gateway on the same network (saves a hop for future packets)



TCP-level attacks

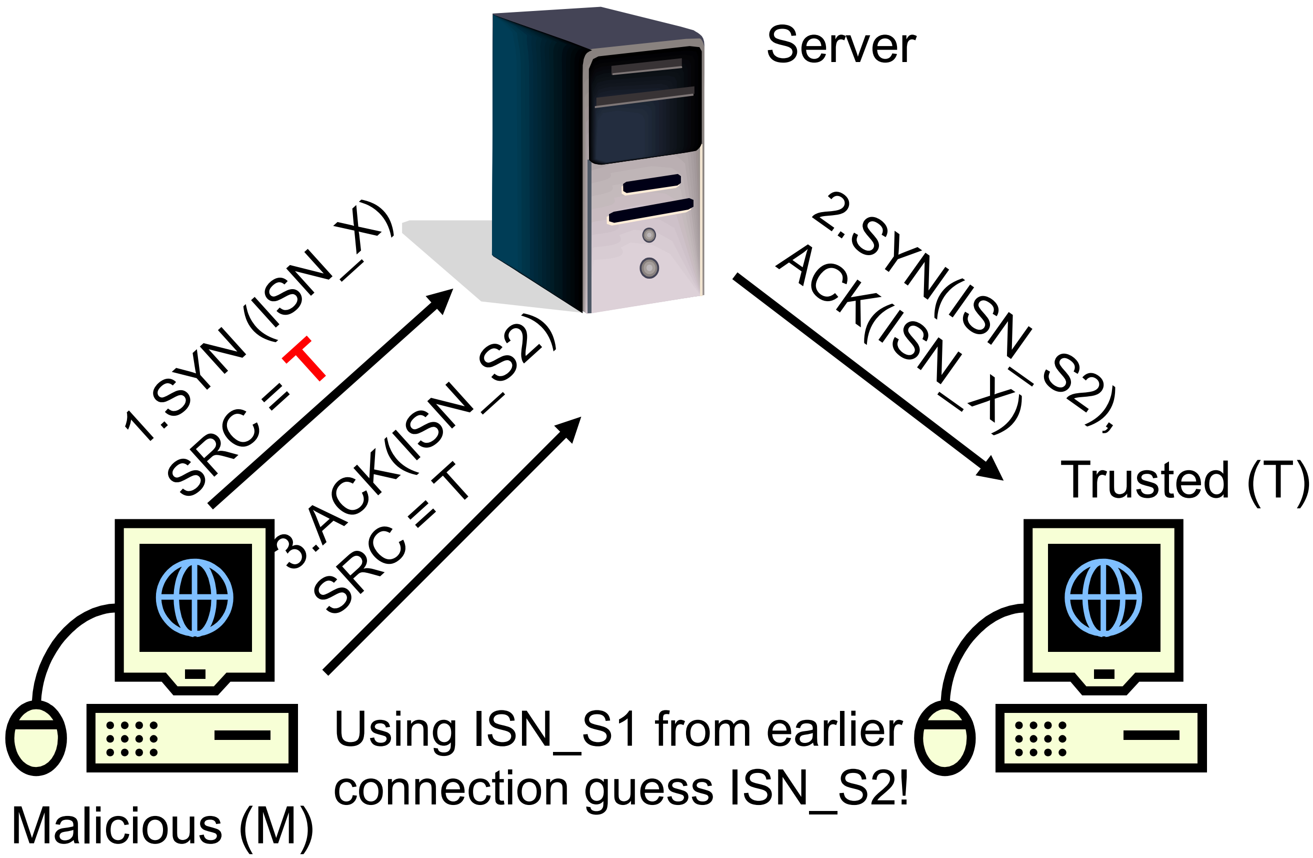
- SYN-Floods
  - Implementations create state at servers before connection is fully established
- Session hijack
  - Pretend to be a trusted host
  - Sequence number guessing
- Session resets
  - Close a legitimate connection

Session Hijack



First send a legitimate SYN to server

Session Hijack



TCP Layer Attacks

- TCP SYN Flooding
  - Exploit state allocated at server after initial SYN packet
  - Send a SYN and don’t reply with ACK
  - Server will wait for 511 seconds for ACK
  - Finite queue size for incomplete connections (1024)
  - Once the queue is full it doesn’t accept requests

TCP Layer Attacks

- TCP Session Poisoning
  - Send RST packet
    - Will tear down connection
  - Do you have to guess the exact sequence number?
    - Anywhere in window is fine
    - For 64k window it takes 64k packets to reset
    - About 15 seconds for a T1

Where do the problems come from?

- Protocol-level vulnerabilities
  - Implicit trust assumptions in design
- Implementation vulnerabilities
  - Both on routers and end-hosts
- Incomplete specifications
  - Often left to the imagination of programmers

Denial of Service Attacks

Questions

- What are the DoS attacks at different levels of the network architecture?

- How can we mitigate them?

DoS can happen at any layer

- Sample Dos at different layers (by order):
  - Link
  - TCP/UDP
  - Application
- There are some generic DoS solutions

- However, current Internet not designed to handle DDoS attacks

Internet Reality

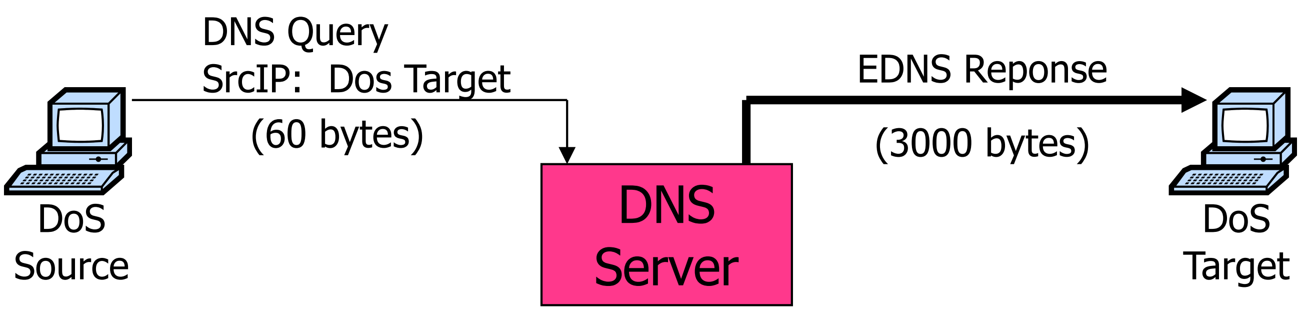
- Distributed Denial-of-Service is a huge problem today!
  - Akamai reports DDOS against US banks peaking at 65 Gbps …
- There are no great solutions
  - CDNs, network traffic filtering, and best practices all help

Examples

- Already discussed:
  - Smurf ICMP amplification attack
  - TCP SYN resource exhaustion attack

DNS Attack (May '06)

DNS Amplification attack: ($\times$50 amplification)



Millions of open resolvers on Internet

A classic SYN flood example

- MS Blaster worm (2003)
  - Infected machines at noon on Aug 16th:
    - SYN flood on port 80 to **windowsupdate.com**
    - 50 SYN packets every second.
      - each packet is 40 bytes.
    - Spoofed source IP: a.b.X.Y where X,Y random.
- MS solution:
  - new name: windowsupdate.microsoft.com
  - Win update file delivered by Akamai

Low rate SYN flood defenses

- Non-solution:
  - Increase backlog queue size or decrease timeout

- Correct solution (when under attack) :
  - **Syncookies**: remove state from server
  - Small performance overhead

Syncookies [Bernstein, Schenk]

- Idea: use secret key and data in packet to gen. server SN

- Server responds to Client with SYN-ACK cookie:
  - T = 5-bit counter incremented every 64 secs.
  - L = MAC_{key} (SAddr, SPort, DAddr, DPort, SN_C, T) [24 bits]
    - key: picked at random during boot
  - SN_S = (T . mss . L) (|L| = 24 bits)
  - **Server does not save state** (other TCP options are lost)

- Honest client responds with ACK ($AN=SN_S$, $SN=SN_C+1$)
  - Server allocates space for socket only if valid SN_S.

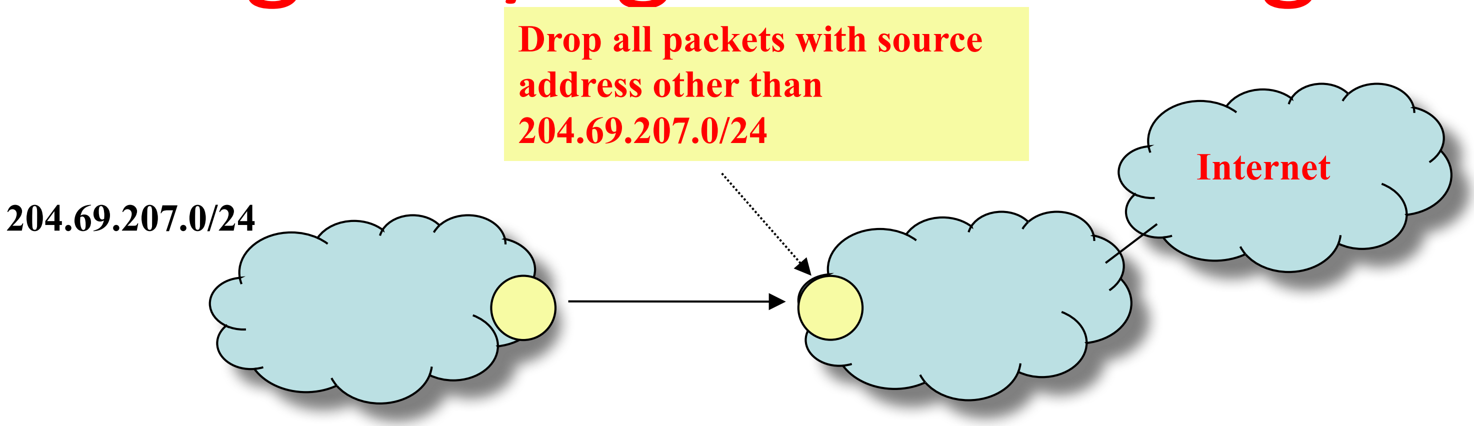
DoS Mitigation

Possible defenses I: Filtering

- Filtering at the victim's firewall
  - Likely to be useless, firewall itself can be targeted

- Filtering at the attacker's firewall
  - Routers drop packets with an "invalid" source IP address field
  - Would need near universal deployment to be effective
    - Besides, does not prevent subnet-level spoofing
  - Economic incentives?

Ingress/Egress Filtering



- RFC 2827: Routers install filters to drop packets from networks that are not downstream
- Feasible at edges; harder at “core”

Possible defenses II: Pushback

- Pushback: rate limit flows that compose large traffic aggregates to mitigate impact of DDoS
- Assumption: can identify anomalous traffic
- Distributed solution: the whole network benefits

- Requires router modifications
  - Deployment may take very long
  - Need authentication of filters

Possible Defenses III: Traceback [Savage et al. '00]

- Goal:
  - Given set of attack packets
  - Determine path to source

- How: change routers to record info in packets

- Assumptions:
  - Most routers remain uncompromised
  - Attacker sends many packets
  - Route from attacker to victim remains relatively stable

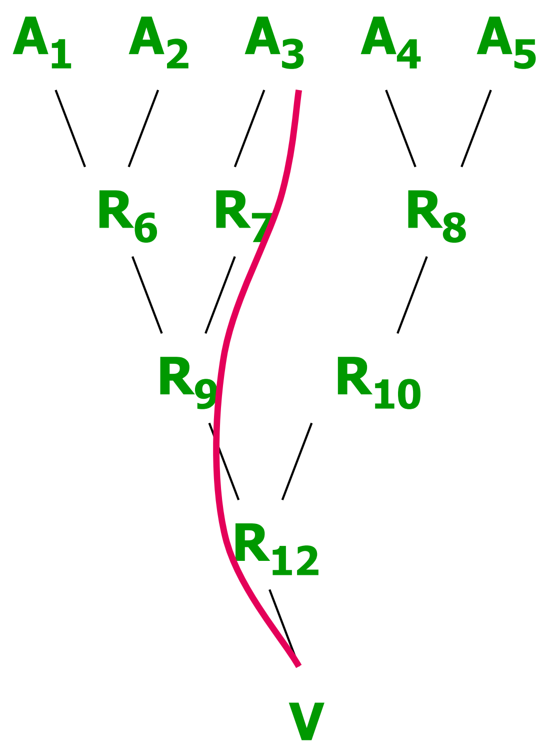
Simple method

- Write path into network packet
  - Each router adds its own IP address to packet
  - Victim reads path from packet

- Problem:
  - Requires space in packet
    - Path can be long
    - No extra fields in current IP format
      - Changes to packet format too much to expect

Better idea

- DDoS involves many packets on same path
- Store one link in each packet
  - Each router probabilistically stores own address
  - Fixed space regardless of path length



Edge Sampling

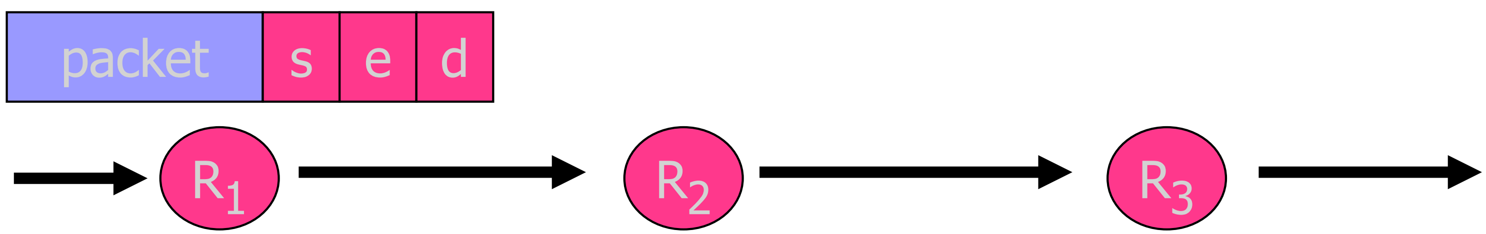
- Data fields written to packet:
  - Edge: *start* and *end* IP addresses
  - Distance: number of hops since edge stored

- Marking procedure for router R

```
if coin turns up heads (with probability p) then
        write R into start address
        write 0 into distance field
else
        if distance == 0 write R into end field
        increment distance field
```

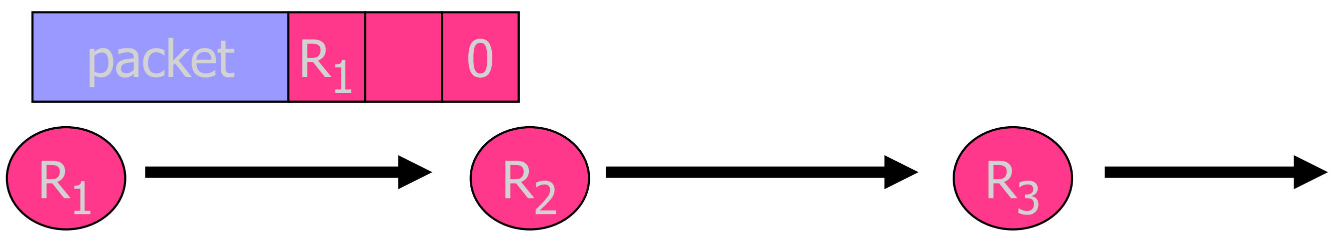
Edge Sampling: picture

- Packet received
  - R_1 receives packet from source or another router
  - Packet contains space for start, end, distance



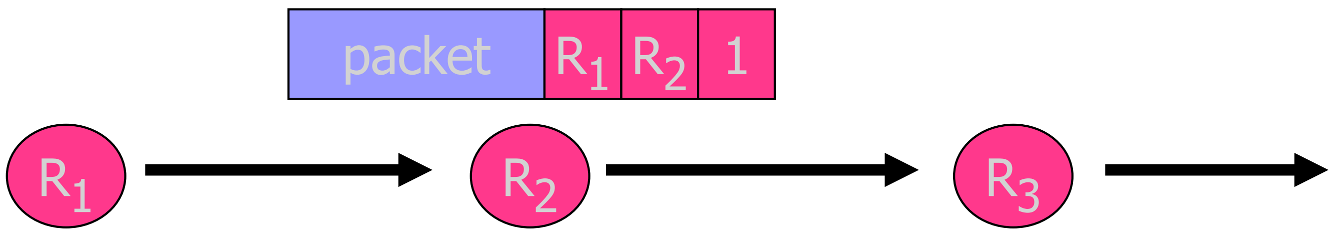
Edge Sampling: picture

- Begin writing edge
  - R_1 chooses to write start of edge
  - Sets distance to 0



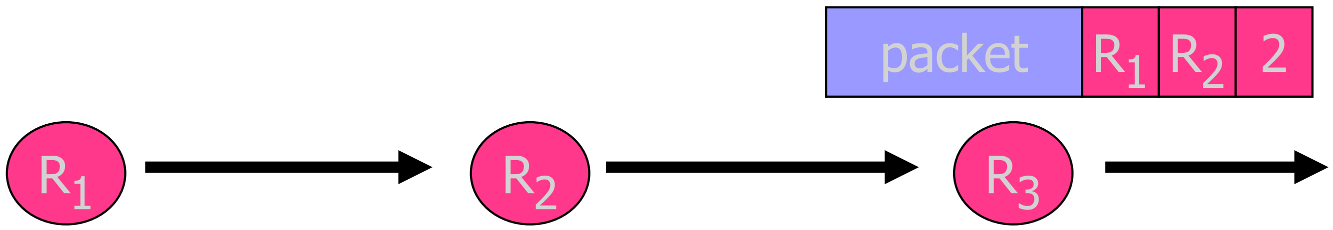
Edge Sampling

- Finish writing edge
  - R_2 chooses not to overwrite edge
  - Distance is 0
    - Write end of edge, increment distance to 1



Edge Sampling

- Increment distance
  - R_3 chooses not to overwrite edge
  - Distance >0
    - Increment distance to 2



Path reconstruction

- Extract information from attack packets
- Build graph rooted at victim
  - Each (start,end,distance) tuple provides an edge
- # packets needed to reconstruct path

$$E(X) < \frac{\ln(d)}{p(1-p)^{d-1}}$$

where p is marking probability, d is length of path

Capability based defense

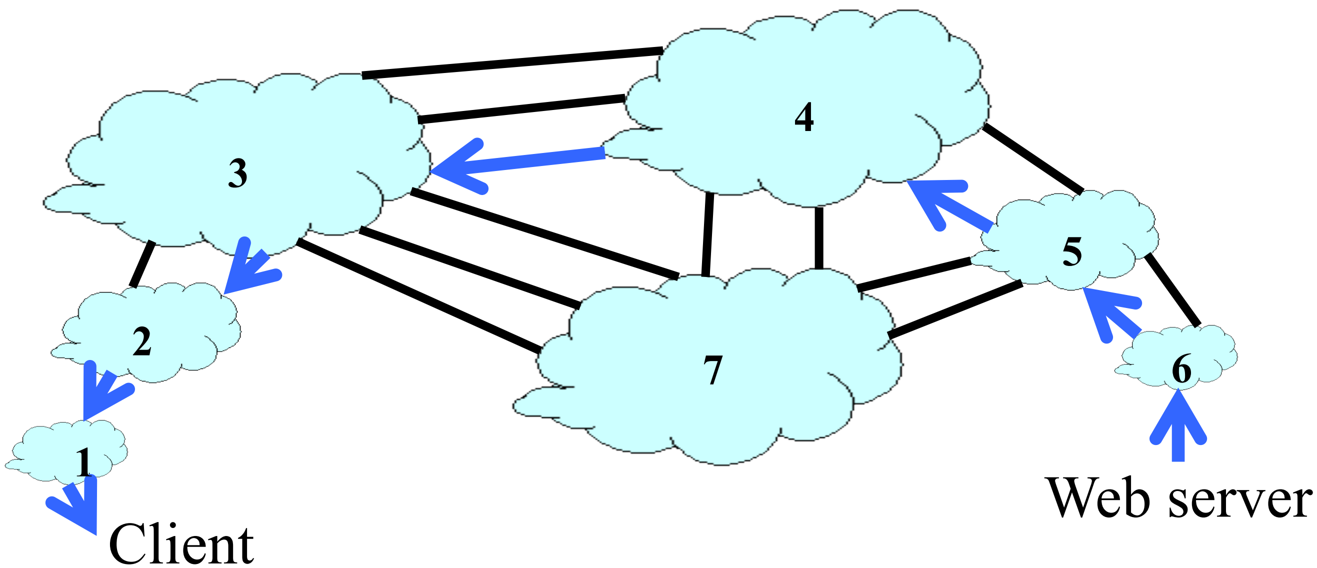
- Basic idea:
  - Receivers can specify what packets they want

- How:
  - Sender requests capability in SYN packet
    - Path identifier used to limit # reqs from one source
  - Receiver responds with capability
  - Sender includes capability in all future packets
  - **Main point**: Routers only forward:
    - Request packets, and
    - Packets with valid capability

Interdomain Routing Security

Interdomain Routing

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



TCP Connection Underlying BGP Session

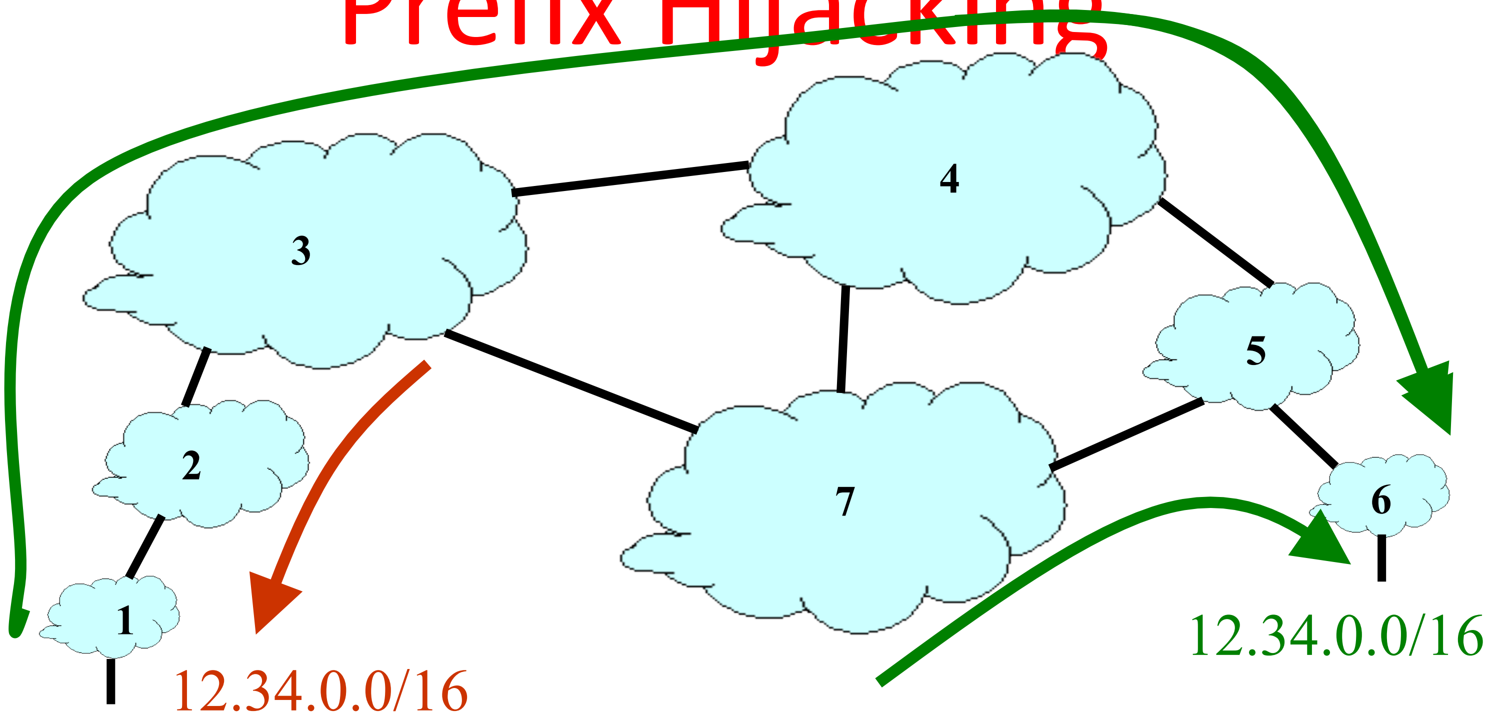
- BGP session runs over TCP
  - TCP connection between neighboring routers
  - BGP messages sent over TCP connection
  - Makes BGP vulnerable to attacks on TCP

Validity of the routing information: Origin authentication

IP Address Ownership and Hijacking

- IP address block assignment
  - Regional Internet Registries
  - Internet Service Providers
- 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

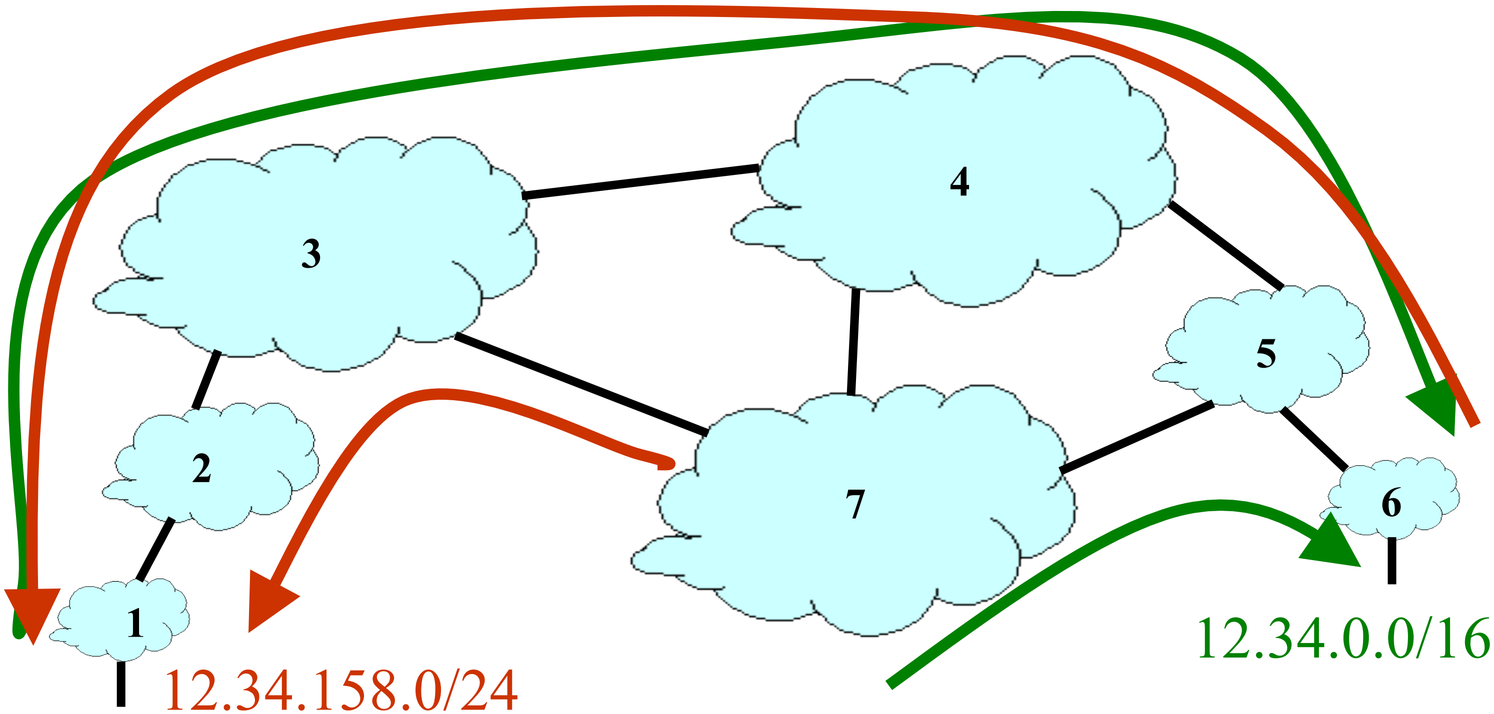


- Consequences for the affected ASes
  - Blackhole: data traffic is discarded
  - Snooping: data traffic is inspected, and then redirected
  - Impersonation: data traffic is sent to bogus destinations

Hijacking is Hard to Debug

- The victim AS doesn't see the problem
  - Picks its own route
  - Might not even learn the bogus route
- May not cause loss of connectivity
  - E.g., if the bogus AS snoops and redirects
  - … may only cause 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

How to Hijack a Prefix

- The hijacking AS has
  - Router with BGP session(s)
  - Configured to originate the prefix
- Getting access to the router
  - Network operator makes configuration mistake
  - Disgruntled operator launches an attack
  - Outsider breaks in to the router and reconfigures
- Getting other ASes to believe bogus route
  - Neighbor ASes do not discard the bogus route
  - E.g., not doing protective filtering

YouTube Outage on Feb 24, 2008

- YouTube (AS 36561)
  - Web site www.youtube.com
  - Address block 208.65.152.0/22
- Pakistan Telecom (AS 17557)
  - Receives government order to block access to YouTube
  - Starts announcing 208.65.153.0/24 to PCCW (AS 3491)
  - All packets directed to YouTube get dropped on the floor
- Mistakes were made
  - AS 17557: announcing 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 propagating in Asia
- 18:48:00
  - Several big trans-Pacific providers carrying the route
- 18:49:30
  - Bogus route fully propagated
- 20:07:25
  - YouTube starts advertising the /24 to attract traffic back
- 20:08:30
  - Many (but not all) providers are using the valid route

http://www.renesys.com/blog/2008/02/pakistan_hijacks_youtube_1.shtml

Timeline (UTC Time)

- 20:18:43
  - YouTube starts announcing 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
  - All is well, videos of cats flushing toilets are available

http://www.renesys.com/blog/2008/02/pakistan_hijacks_youtube_1.shtml

Another Example: Spammers

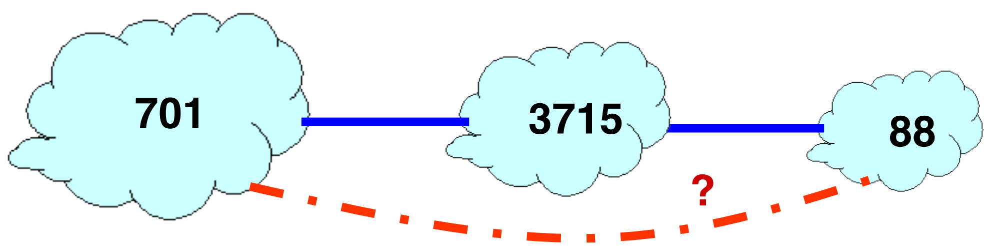
- Spammers sending spam
  - Form a (bidrectional) TCP connection to a mail server
  - Send a bunch of spam e-mail
- But, best not to use your real IP address
  - Relatively easy to trace back to you
- Could hijack someone's address space
  - But you might not receive all the (TCP) return traffic
  -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

Question

- What other attacks are possible with BGP?

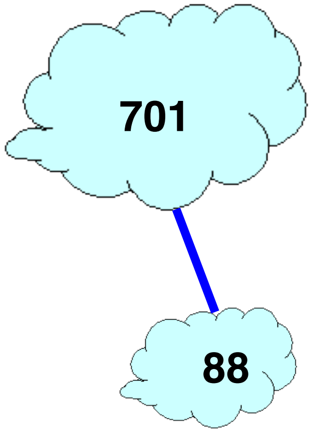
Bogus AS Paths

- Remove ASes from the AS path
  - E.g., turn “701 3715 88” into “701 88”
- Motivations
  - Make the AS path look shorter than it is
  - Attract sources that normally try to avoid AS 3715
  - Help AS 88 look like it is 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 coming 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 as long as it received data traffic meant for it?



Bogus AS Paths

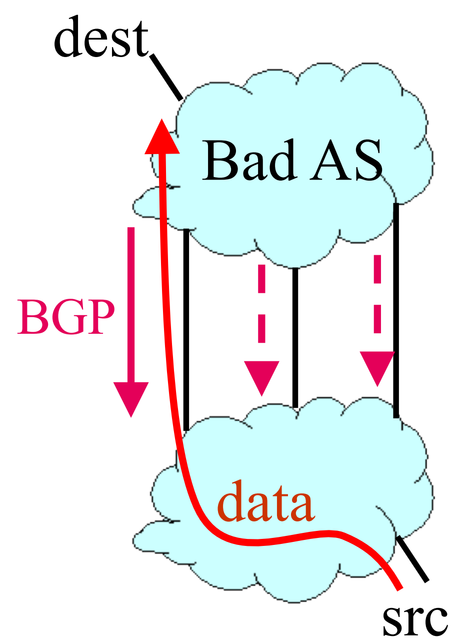
- Adds AS hop(s) at the end of the path
  - E.g., turns “701 88” into “701 88 3”
- Motivations
  - Evade detection for a bogus route
  - E.g., by adding the legitimate AS to the end
- Hard to tell that the AS path is bogus…
  - Even if other ASes filter based on prefix ownership

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 Internet 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 data traffic



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
  - 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 the data packets follow the chosen route

Proposed Enhancements to BGP

S-BGP Secure Version of BGP

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

S-BGP Deployment Challenges

- Complete, accurate registries
  - E.g., of prefix ownership
- 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
  - 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
  - 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
  - … since they mostly learn routes from the big ASes

Conclusions

- Border Gateway Protocol is very vulnerable
  - Glue that holds the Internet together
  - Hard for an AS to locally identify bogus routes
  - Attacks can have very serious global consequences
- Proposed solutions/approaches
  - Secure variants of the Border Gateway Protocol
  - Anomaly detection schemes, with automated response