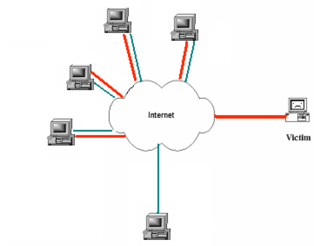
Filtering Based Techniques for DDOS Mitigation

Comp290: Network Intrusion Detection
Manoj Ampalam

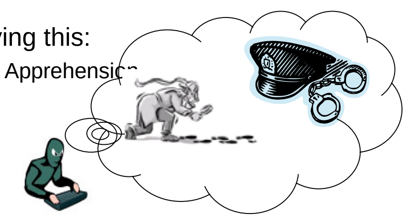
Introduction:

- DDOS Attacks:
  - Target CPU / Bandwidth
  - Attacker signals slaves to launch an attack on a specific target address (victim).
  - Slaves then respond by initiating TCP, UDP, ICMP or Smurf attack on victim
  - Spoofing – root cause



Introduction:

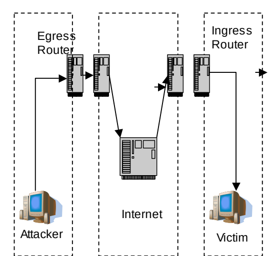
- Approaches to solving this:
  - Prevention through Apprehension



  - Super Protection

Introduction:

- Prevent or Mitigate DDOS by
  - Authorizing source IP
  - Making spoofing difficult
  - Deploying Filters: Ingress/Egress
  - Managing Network Bandwidth



Introduction:

- Brief overview of DDOS Detection/Mitigation Schemes:
  - Source Identification:
    - Link Testing:
      - Tracing back hop-by-hop manually
      - Multiple branch points, slow trace back, communication overhead
    - Audit Trail:
      - Via traffic logs at routers & gateways
      - High storage, processing overhead
    - Behavioral monitoring:
      - Likely behavior of attacker monitored
      - Requires logging of such events and activities

Introduction:

- Brief overview of DDOS Detection/Mitigation Schemes:
  - Packet-based traceback:
    - Packets marked with addresses of intermediate routers, later used to trace back
    - Variable length marking fields growing with path length leading to traffic overhead
    - Probabilistic Packet Marking:
      - Tries to achieve best of – space and processing efficiency
        - Constant marking-field
        - Minimal router support
      - Introduces uncertainty due to probabilistic sampling of flow's path

Introduction:

- Based on the location of deployment:
  - Router Based
    - Improve routing infrastructure
      - Off-line analysis of flooding traffic traces
        - Doesn't help sustain service availability during attack
      - On-line filtering of spoofed packets
        - Rely on IP-Router enhancements to detect abnormal patterns
    - No incentive for ISPs to implement these services
      - Administrative overhead
      - Lack of immediate benefit to their customers
  - End-System Based
    - Provide sophisticated resource management to internet servers
      - Doesn't required router support.
      - Not so effective

Topics for this presentation:

- Different Filtering Techniques
  - Hop-Count Filtering
    - End-System Based
    - Uses Packet Header Information
  - Distributed Packet Filtering
    - Route-based
    - Uses Routing Information
  - D-WARD
    - Source-end network based
    - Uses Abnormal Traffic Flow information
  - Ingress Filtering
    - Specifies Internet Best Current Practices

Hop-Count Filtering

Cheng Jin, Haining Wang, Kang G. Shin, Proceedings of the 10th ACM International Conference on Computer and Communications Security (CCS), October 2003

Hop-Count Filtering:

- Motivation:
  - Most spoofed IP packets when arriving at victims do not carry hop-count values that are consistent with those of legitimate ones.
  - Hop-Count distribution of client IP addresses at a server take a range of values

Hop-Count Filtering:

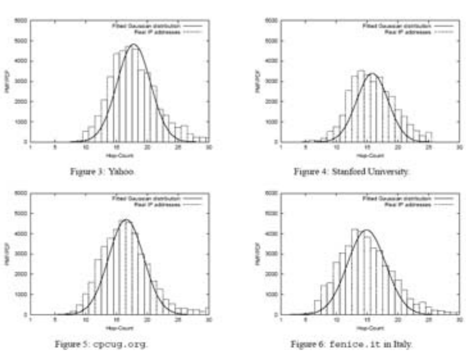


Figure 3: Yahoo
Figure 4: Stanford University
Figure 5: cpcug.org
Figure 6: fenice.it in Italy

Hop-Count Filtering:

- So, how's hop-count calculated?
  - Computed based on the 8-bit TTL filed of IP header
    - Introduced originally to specify maximum lifetime of IP packet
  - During transit, each intermediate router decrements the TTL value of an IP packet before forwarding
    - The difference between the final value and the initial value is thus the number of hops taken.
  - What's the initial value of TTL field? Is it a constant?
    - NO

Hop-Count Filtering:

- TTL field:
  - Varies with operating Systems.
    - So do we have to know the type of Operating System before computing hop-count?
      - Not Really required
  - Most modern OSs use only few selected initial TTL values: 30,32,60,64,128 and 256
  - Its generally believed that few internet hosts are apart by more than 30 hops
  - Hence, initial value of TTL is the smallest number in the standard list greater than the final TTL value

Hop-Count Filtering:

- The basic algorithm follows:

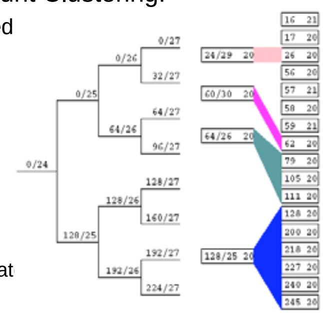
for each packet:
  extract the final TTL T and IP address S;
  infer the initial TTL T_0;
  compute the hop-count $H_c = T - T_0$;
  index S to get the stored hop-count H_s;
  if $(H_c \neq H_s)$
    packet is spoofed;
  else
    packet is legitimate;

Hop-Count Filtering:

- The 'making' of the HCF Tables:
  - Objectives:
    - Accurate IP2HC mapping
    - Up-to-date IP2HC mapping
      - Continuously monitory for legitimate hop-count changes
        - Legitimate – established TCP connections
    - Moderate storage
      - Concept of Aggregation with Hop-Count Clustering

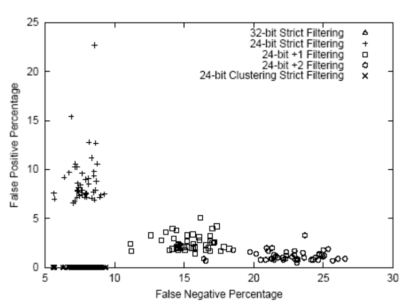
Hop-Count Filtering:

- Aggregation with Hop-Count Clustering:
  - IPs primarily mapped based on 24-bit prefix
  - IP address further divided based on hop-count
  - Nodes aggregated if hop-count value is same
    - No two IPs with different hop-counts aggregated
    - Not all IPs can be aggregat



Hop-Count Filtering:

- Aggregation with Hop-Count Clustering: Effectiveness



Hop-Count Filtering:

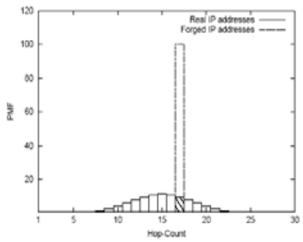
- Effectiveness:
  - HCF removes nearly 90% of spoofed traffic
  - Assessed from a mathematical standpoint
  - Assumptions:
    - Victim knows complete IP2HP mapping
    - Attacker randomly selects source IP addresses
    - Static Hop-Count Values
    - Attackers evenly divide flooding traffic

Hop-Count Filtering:

- Effectiveness: For single source simple attack
  - Hop-count from flooding source to victim – *h*
  - Fraction of IP having *h* hop counts to victim – α_h

Fraction of spoofed IP Addresses that cannot be detected -- α_h

Even when a attacker w Mean HC is considered α_h is around 10%

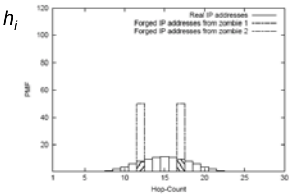


Hop-Count Filtering:

- Effectiveness: For multiple (*n*) source simple attack
  - Total Flood Packets – *F*
  - Each attacker generates *F/n* packets
  - h_i - hop count from attacker *i* to victim
  - α_{hi} – fraction of IPs with hopcount h_i

Fraction of spoofed IP Addresses that cannot be detected from i-- α_{hi}

Fraction of non-identifiable spoofed packets = $(1/n)\sum\alpha_{hi}$



Hop-Count Filtering:

- Can this filter be outplayed?
  - What if the attacker manufactures an appropriate initial TTL value for each spoofed packet?
    - Should know hop-count between randomized IP and victim.
    - Has to build a priori an IP2HC mapping table at victim.
  - What if the hop-count mapping is found through an accurate router-level topology of internet?
    - No such contemporary tools giving accurate topology information.
  - Why choose random-IP? Choose to spoof an IP address from a set of compromised machines.
    - Weakens the attacking capability.
    - Will be defeated by currently existing practices.
  - Sabotage router to alter TTL value?
    - Don't know how far that's feasible.

Distributed Packet Filtering

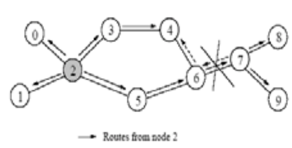
Kihong Park, Heejo Lee, Proceedings of ACM SIGCOMM 2001, San Diego, California, August 2001

DPF: Distributed Packet Filtering

- Route based distributed packet filtering
  - Uses routing information to determine 'goodness' of a arriving packet
  - Similar to the limitation of firewalls whose filtering rules reflect access constraints local to the network system being guarded.
- Salient features:
  - Proactively filters out a significant fraction of spoofed packet flows
  - Reactively identifies source of spoofed IP flows
  - Takes advantage of the 'power-law' structure of the Internet AS topology.

DPF: Distributed Packet Filtering

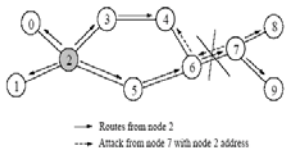
- Filtering: Main Idea:
  - Works on a graph of Internet Autonomous Systems (AS)



  - Node 7 uses IP address belonging to node 2 when attacking node 4
  - What if a border router belonging AS 6 would recognize if its cognizant of route topology?

DPF: Distributed Packet Filtering

- Filtering: Issues:



  - Filtering done at granularity of AS node
    - No filtering on attacks originating within a node
  - An edge in AS graph between pair of nodes – a set of peering point connections
    - All border routers mush carry filtering tasks
  - Two IPs belonging to the same node may lead to different paths on AS topology
    - Incorporate multi-path routing

DPF: Distributed Packet Filtering

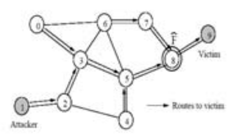
- Filtering:
  - Terminology:
    - Given *G=(V,E)* representing Internet AS topology
      - *μ(u,v) – set of all loop-free paths from u to v*
      - *R(u,v) – set of computed routes using a routing algorithm*
      - *R(u,v) is subset of μ(u,v)*
    - A Filter F_e is a *route based packet filter with respect to R* if
      - $F_e(s,t) = 0$ for *e belonging to R(s,t)*
      - F_e *is a maximal filter* if it satisfies $F_e(s,t) = 0$ iff there exists a path in *R(s,t)* with *e* as one of the links
      - F_e *is a semi-maximal filter with respect to R* if

$$F_e(s,t) = \begin{cases} 0, & \text{if } e\in R(s,v) \text{ for some } v\in V_i \\ 1, & \text{otherwise} \end{cases}$$

DPF: Distributed Packet Filtering

- Filtering:
  - Terminology:
    - $S_{a,t}$ – set of nodes that an attacker at AS *a* can use as a spoofed address to reach *t*.

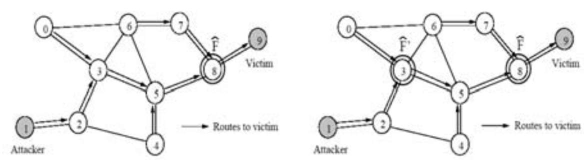
With route based filtering at node 8
$S_{1,9}$ = {0,1,2,3,4,5}

- 

have sent an IP packet *M(s,t)* with id not get filtered on its way

DPF: Distributed Packet Filtering

- DPF Effectiveness:



  - With no filtering $S_{1,9}$ = {0,1,2,3,4,5,6,7,8}
  - With route-based filtering at node 8 $S_{1,9}$ = {0,1,2,3,4,5}
  - With route-based filtering at node 8 & 3 $S_{1,9}$ = {1,2}

DPF: Distributed Packet Filtering

- Performance Metrics:
  - Proactive: Fraction of AS's from which no spoofed IP packet can reach its target.

$$\phi = \frac{\left|\{a : \forall t\in V, |S_{a,t}| \le 1\}\right|}{n}$$

  - Reactive: Parameterized by α ≥ 1, denotes Fraction of AS's which upon receiving a spoofed IP packet can localize its true source within α sites.

$$\psi(\alpha) = \frac{\left|\{: \forall s\in V, |C_{s,t}| \le \alpha\}\right|}{n}$$

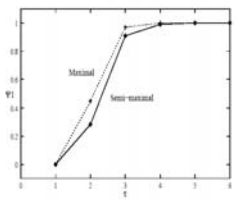
DPF: Distributed Packet Filtering

- Evaluation:
  - Study effectiveness of the Filtering process given:
    - Topology Graph: *G*
      - *1997-99* Internet AS topologies
      - Artificially generated topologies
    - Subset of nodes where filtering is performed: *T*
      - Node Selection:
        - Randomly
        - Vertex cover
    - Routing Algorithm: *R*
      - Multipath Routing
        - Loose *R* – any of loop free paths taken
        - Tight *R* – only shortest one considered

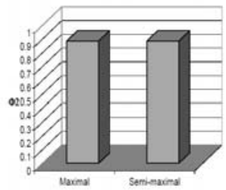
DPF: Distributed Packet Filtering

- Evaluation: Maximal Vs Semi-Maximal Filters
  - I997 Internet Topology:

Reactive Metric



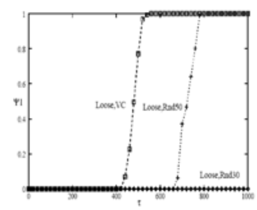
Proactive Metric



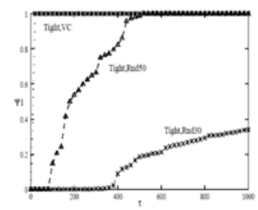
DPF: Distributed Packet Filtering

- Evaluation: Loose Vs Tight Routing
  - I997 Internet Topology:

Loose

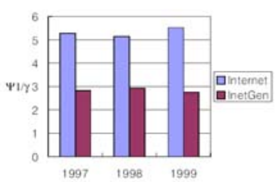


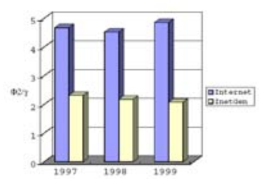
Tight



DPF: Distributed Packet Filtering

- Evaluation: Impact of Network Topology
  - Performance difference between Inet and Internet AS graphs:

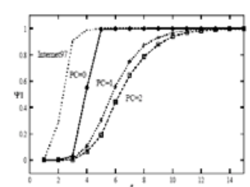




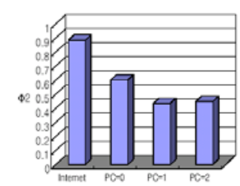
DPF: Distributed Packet Filtering

- Evaluation: Results on a generated Topology
  - Using Brite Topology Generator with Preferential Connectivity (PC) parameter: Different PC's – Different probability density functions

Reactive Metric



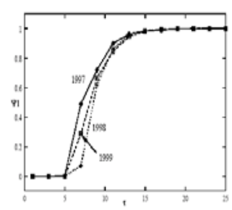
Proactive Metric



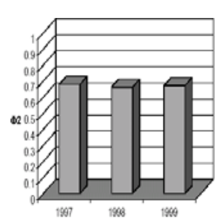
DPF: Distributed Packet Filtering

- Evaluation: Results without Ingress Filtering
  - Using 1997-1999 topologies with trusted set *T* allowing local DoS attacks including those targeted to other domains

Reactive Metric



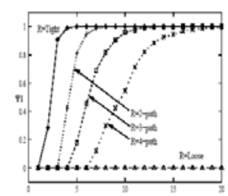
Proactive Metric



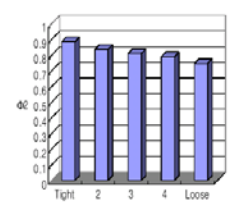
DPF: Distributed Packet Filtering

- Evaluation: Effect of Multi Path Routing
  - Based on a routing options.
    - "*R=loose*" - any loop-free path can be used
    - "*R=tight*" - shortest path to be used

Reactive Metric



Proactive Metric



D-WARD

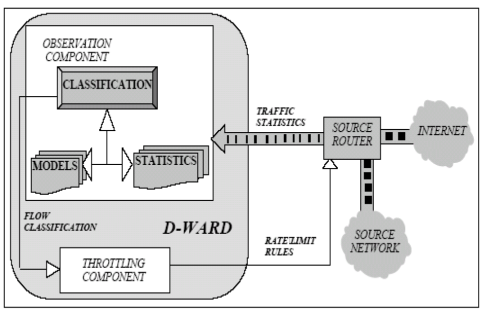
Jelena Mirkovic, Gregory Prier, Peter Reiher, 10th IEEE International Conference on Network Protocols, Paris, France, November 2002

D-WARD:

- Attacking DDOS at source.
  - Attack flows can be stopped before they enter Internet core
  - Facilitate easier trace back and investigation of attack
- Basic Idea
  - Monitor incoming and outgoing traffic
  - Detect attack by observing abnormalities
  - Respond to attack by rate limiting

D-WARD:

- Architecture:



D-WARD:

- Monitoring and attack detection:
  - Configured with a set of ‘police addresses’ (PA)
  - Monitors two-way traffic at flow granularity
    - Flow – aggregate traffic between PA set foreign host
  - Monitors traffic at connection level
    - Connection – aggregate traffic between 2 IPs (PA and foreign host) and port numbers
    - Identify legitimate connections

D-WARD:

- Monitoring and attack detection:
  - Flow Classification
    - Flow statistics kept in a limited-size hash table as flow records
    - Stored at granularity of IP address of host
    - Statistics on three types of traffic: TCP, UDP & ICMP
      - Number of packets sent
      - Bytes sent / received
      - Active Connections

D-WARD:

- Monitoring and attack detection:
  - Normal Traffic Modes
    - TCP: defines TCP_{rto} – maximum allowed ratio of number of packets sent and received in the aggregate TCP flow to the peer.
    - ICMP: defines $ICMP_{rto}$ – maximum allowed ratio of number of echo, time stamp and information request and reply packets sent and received in the aggregate flow to the peer.
    - UCP: defines
      - n_{conn} – an upper bound on number of allowed connections per destination
      - p_{conn} – a lower bound on number of allowed connections per destination
      - UDP_{rate} – maximum allowed sending rate per connection
  - Connection Classification
    - Good if compliant: receive guaranteed good service
    - Bad

D-WARD:

- Attack Response:
  - Throttling component defines the allowed sending rate for a particular flow based on the current flow characterization and its aggressiveness.
  - Borrows ideas from TCP congestion control - Multiplicative Decrease
  - Uses following equations:

$$rl = \min(rl, rate) * f_{dec} * \frac{B_{sent}}{B_{sent} + B_{dropped}}$$

$$rl = rl + rate_{inc} * \frac{B_{sent}}{B_{sent} + B_{dropped}}$$

$$rl = rl * (1 + f_{inc} * \frac{B_{sent}}{B_{sent} + B_{dropped}})$$

f_{dec}- fraction of offending sending rate for this flow in previous observation

rate – realized sending rate

rl – current rate limit

$rate_{inc}$- speed of slow-recovery

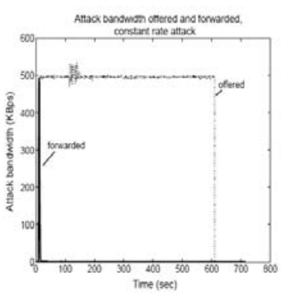
f_{inc}- speed of fast-recovery

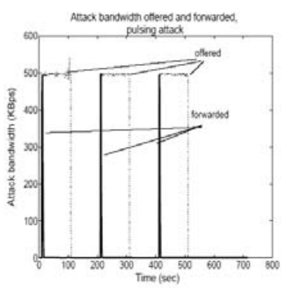
D-WARD:

- Evaluation:
  - Implemented on a linux software router
  - Simulated different types of attacks
    - Customized traffic mixture
    - Constant rate attack
    - Pulsing attack
    - Increasing rate attack
    - Gradual pulse attack
  - Test Network:
    - Attacker and legitimate client belong to source network and are part of police address set
    - Foreign host playing role of victim

D-WARD:

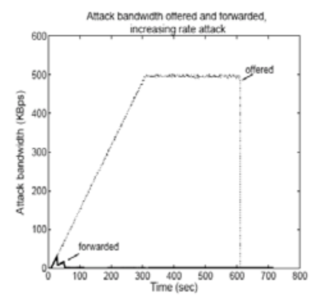
- Evaluation: Attack Bandwidth passed to Victim

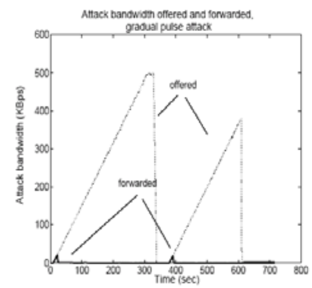




D-WARD:

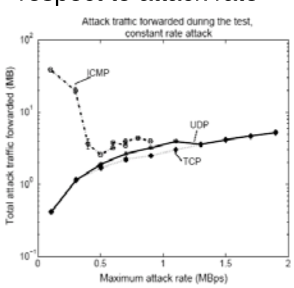
- Evaluation: Attack Bandwidth passed to Victim

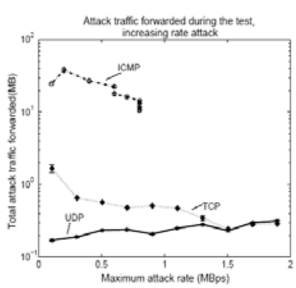




D-WARD:

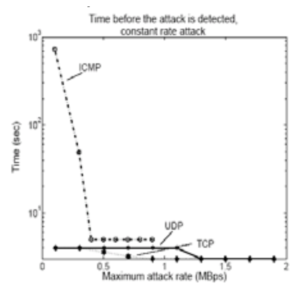
- Evaluation: Total attack traffic forwarded with respect to attack rate

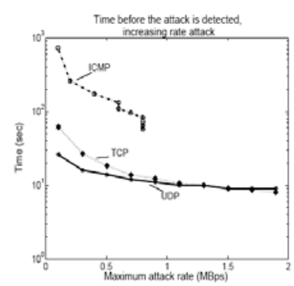




D-WARD:

- Evaluation: Attack Detection Time to Maximum





Network Ingress Filtering

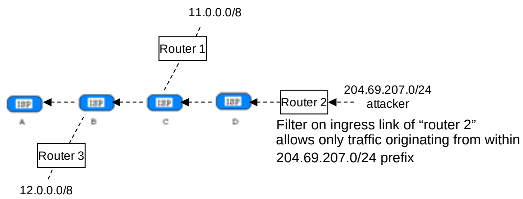
P. Ferguson, D. Senie, RFC 2827, May 2000

Ingress Filtering

- An RFC document intending to increase security practices and awareness for internet community
- Discusses a simple, effective and straightforward ingress traffic filter

Ingress Filtering

- Restricting forged Traffic:
  - Idea is to eliminate spoofing
    - by restricting downstream network traffic to known, and intentionally advertised prefixes through an ingress filter
    - Example:



Ingress Filtering

- Further possible capabilities for networking equipment:
  - Automatic filtering on remote access servers
    - Check every packet on ingress to ensure user not spoofing
- Liabilities
  - Filtering can break some types of “special services”
    - Example: Mobile IP
      - Traffic from a mobile node not tunneled – source address do not match with attached network.
  - This RFC suggests considering alternate methods for implementing these services
    - Mobile IP Working Group developed “reverse tunnels” to accommodate ingress filtering

Thank You !!!