0x1A Great Papers in Computer Security

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http://www.cs.utexas.edu/~shmat/courses/cs380s/

D. Moore, G. Voelker, S. Savage

Inferring
Internet Denial-of-Service Activity

(USENIX Security 2001)

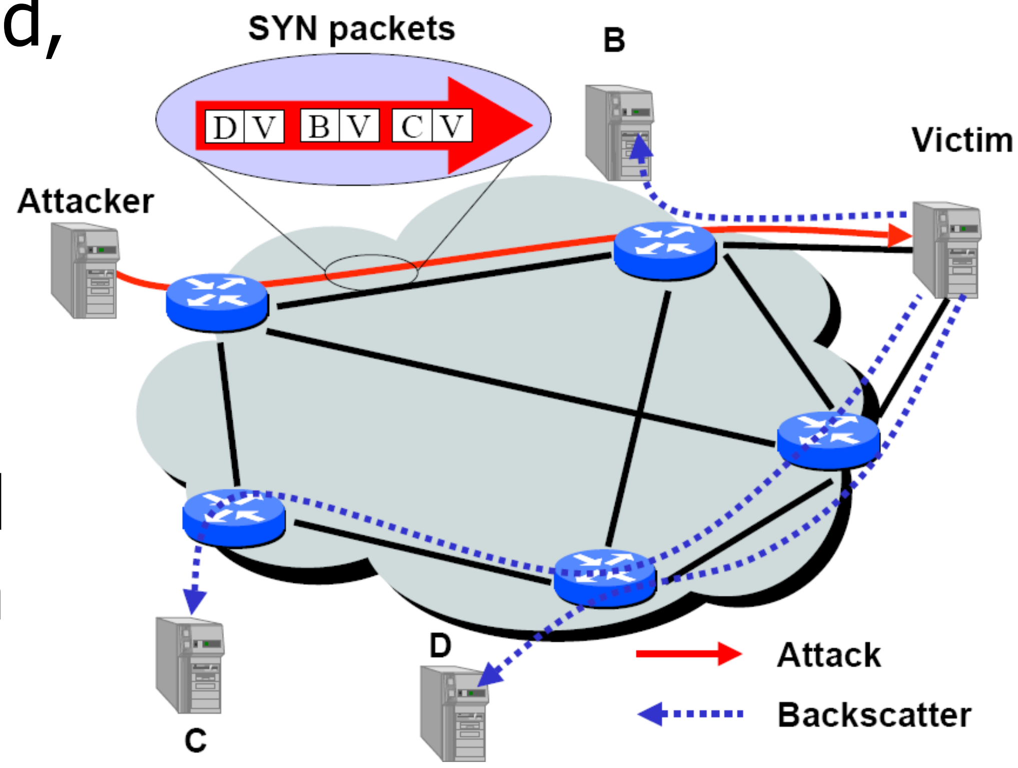
Network Telescopes and Honeypots

- Monitor a cross-section of Internet address space
  - Especially useful if includes unused "dark space"
- Attacks in far corners of the Internet may produce traffic directed at your addresses
  - "Backscatter": responses of attack victims to randomly spoofed IP addresses
  - Random scanning by worms
- Can combine with "honeypots"
  - Any outbound connection from a "honeypot" behind an otherwise unused IP address means infection (why?)
  - Can use this to extract worm signatures (how?)

Backscatter

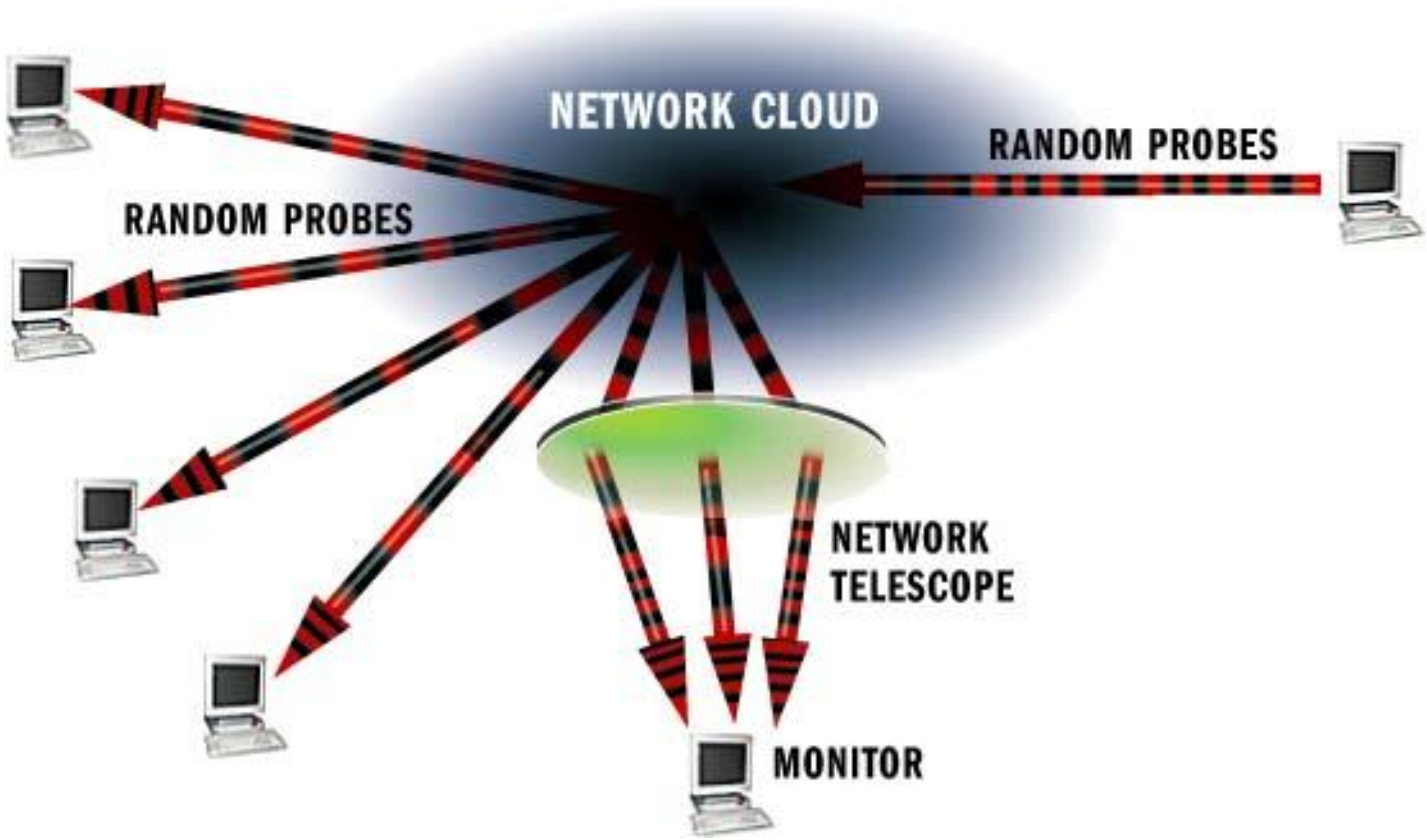
[Moore, Voelker, Savage]

- Attacker uses spoofed, randomly selected source IP addresses
- Victim replies to spoofed source IP
- Results in unsolicited response from victim to third-party IP addresses



How a Network Telescope Works

[Moore, Voelker, Savage]



Backscatter Analysis

[Moore, Voelker, Savage]

- m attack packets sent
- n distinct IP addresses monitored by telescope
- Expectation of observing an attack:

$$E(X) = \frac{nm}{2^{32}}$$

- R' = actual rate of attack,

  R = extrapolated attack rate

$$R \geq R' \frac{2^{32}}{n}$$

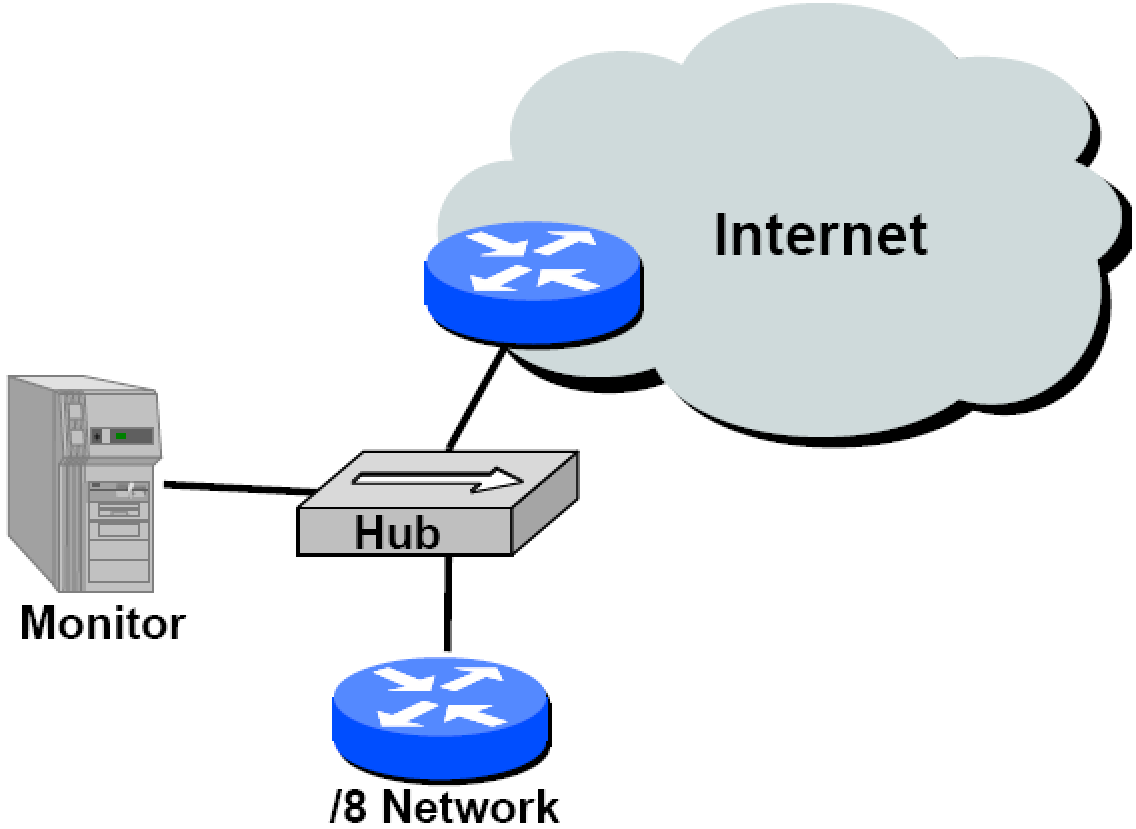
Analysis Assumptions

[Moore, Voelker, Savage]

- Address uniformity
  - Spoofed addresses are random, uniformly distributed
- Reliable delivery
  - Attack and backscatter traffic delivered reliably
- Backscatter hypothesis
  - Unsolicited packets observed represent backscatter

Data Collection

[Moore, Voelker, Savage]



/8 network 2^24 addresses 1/256 of Internet address space

Observed Protocols

[Moore, Voelker, Savage]

Kind	Trace-1		Trace-2		Trace-3	
	Attacks	Packets (k)	Attacks	Packets (k)	Attacks	Packets (k)
TCP (RST ACK)	2,027 (49)	12,656 (25)	1,837 (47)	15,265 (20)	2,118 (45)	11,244 (18)
ICMP (Host Unreachable)	699 (17)	2,892 (5.7)	560 (14)	27,776 (36)	776 (16)	19,719 (32)
ICMP (TTL Exceeded)	453 (11)	31,468 (62)	495 (13)	32,001 (41)	626 (13)	22,150 (36)
ICMP (Other)	486 (12)	580 (1.1)	441 (11)	640 (0.82)	520 (11)	472 (0.76)
TCP (SYN ACK)	378 (9.1)	919 (1.8)	276 (7.1)	1,580 (2.0)	346 (7.3)	937 (1.5)
TCP (RST)	128 (3.1)	2,309 (4.5)	269 (6.9)	974 (1.2)	367 (7.7)	7,712 (12)
TCP (Other)	2 (0.05)	3 (0.01)	0 (0.00)	0 (0.00)	1 (0.02)	0 (0.00)

Kind	Trace-1		Trace-2		Trace-3	
	Attacks	Packets (k)	Attacks	Packets (k)	Attacks	Packets (k)
TCP	3,902 (94)	28,705 (56)	3,472 (90)	53,999 (69)	4,378 (92)	43,555 (70)
UDP	99 (2.4)	66 (0.13)	194 (5.0)	316 (0.40)	131 (2.8)	91 (0.15)
ICMP	88 (2.1)	22,020 (43)	102 (2.6)	23,875 (31)	107 (2.3)	18,487 (30)
Proto 0	65 (1.6)	25 (0.05)	108 (2.8)	43 (0.06)	104 (2.2)	49 (0.08)
Other	19 (0.46)	12 (0.02)	2 (0.05)	1 (0.00)	34 (0.72)	52 (0.08)

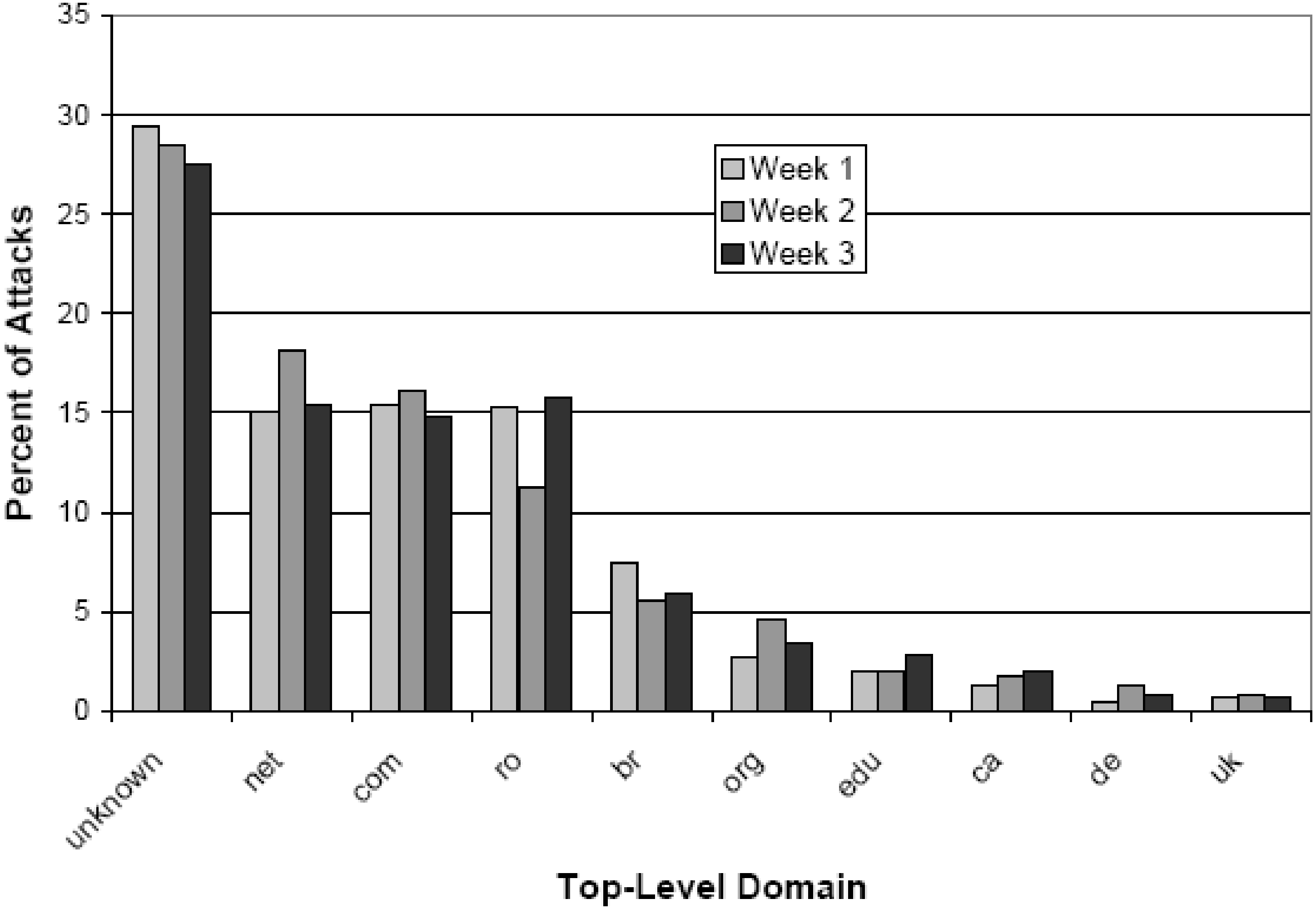
Victims by Port

[Moore, Voelker, Savage]

Kind	Trace-1				Trace-2				Trace-3			
	Attacks		Packets (k)		Attacks		Packets (k)		Attacks		Packets (k)	
Multiple Ports	2,740	(66)	24,996	(49)	2,546	(66)	45,660	(58)	2,803	(59)	26,202	(42)
Uniformly Random	655	(16)	1,584	(3.1)	721	(19)	5,586	(7.1)	1,076	(23)	15,004	(24)
Other	267	(6.4)	994	(2.0)	204	(5.3)	1,080	(1.4)	266	(5.6)	410	(0.66)
Port Unknown	91	(2.2)	44	(0.09)	114	(2.9)	47	(0.06)	155	(3.3)	150	(0.24)
HTTP (80)	94	(2.3)	334	(0.66)	79	(2.0)	857	(1.1)	175	(3.7)	478	(0.77)
0	78	(1.9)	22,007	(43)	90	(2.3)	23,765	(30)	99	(2.1)	18,227	(29)
IRC (6667)	114	(2.7)	526	(1.0)	39	(1.0)	211	(0.27)	57	(1.2)	1,016	(1.6)
Authd (113)	34	(0.81)	49	(0.10)	52	(1.3)	161	(0.21)	53	(1.1)	533	(0.86)
Telnet (23)	67	(1.6)	252	(0.50)	18	(0.46)	467	(0.60)	27	(0.57)	160	(0.26)
DNS (53)	30	(0.72)	39	(0.08)	3	(0.08)	3	(0.00)	25	(0.53)	38	(0.06)
SSH (22)	3	(0.07)	2	(0.00)	12	(0.31)	397	(0.51)	18	(0.38)	15	(0.02)

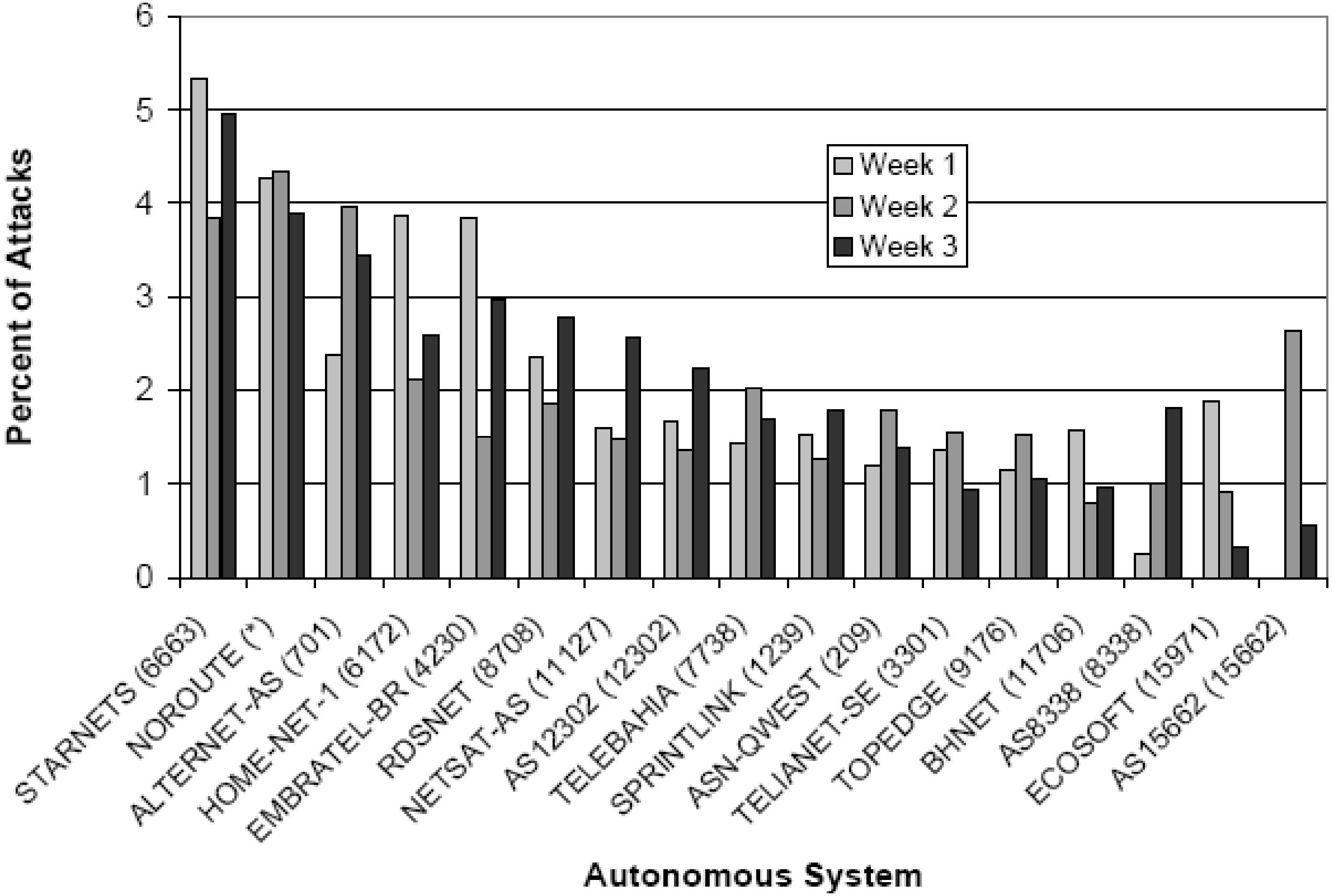
Victims by Top-Level Domain

[Moore, Voelker, Savage]



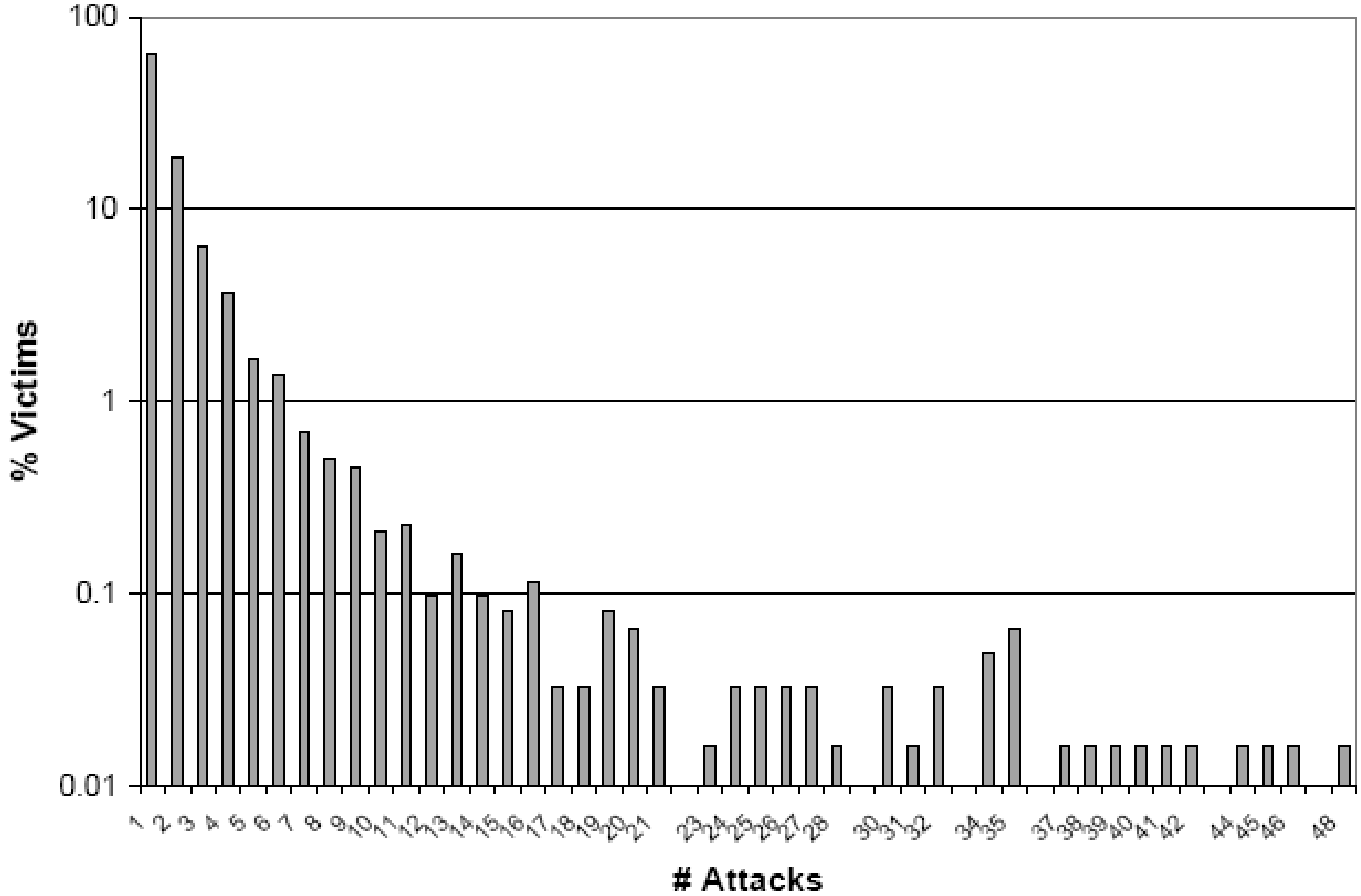
Victims by Autonomous System

[Moore, Voelker, Savage]



Repeated Attacks

[Moore, Voelker, Savage]



Conclusions of the [MSV01] Study

[Moore, Voelker, Savage]

- Observed 12,000 attacks against more than 5,000 distinct targets.
- Distributed over many different domains and ISPs
- Small number of long attacks with large % of attack volume
- Unexpected number of attacks targetting home machines, a few foreign countries, specific ISPs

A. Kumar, V. Paxson, N. Weaver

Outwitting the Witty Worm:
Exploiting Underlying Structure for Detailed Reconstruction of an Internet-scale Event

(IMC 2005)

Witty Worm

- Exploits buffer overflow in the ICQ filtering module of ISS BlackICE/RealSecure intrusion detectors
  - Single UDP packet to port 4000, standard stack smash
  - Deletes randomly chosen sectors of hard drive
  - Payload contains "(^.^ insert witty message here ^.^)"
- Chronology of Witty
  - Mar 8, 2004: vulnerability discovered by EEye
  - Mar 18, 2004: high-level description published
  - 36 hours later: worm released
  - 75 mins later: all 12,000 vulnerable machines infected!

CAIDA/UCSD Network Telescope

- Monitors /8 of IP address space
  - All addresses with a particular first byte
- Recorded all Witty packets it saw
- In the best case, saw approximately 4 out of every 1000 packets sent by each Witty infectee (why?)

Pseudocode of Witty (1)

[Kumar, Paxson, Weaver]

1. srand(get_tick_count()) ← Seed pseudo-random generator
2. for(i=0; i<20,000; i++)
3. destIP ← $\text{rand()}_{[0..15]}$ | $\text{rand()}_{[0..15]}$
4. destPort ← $\text{rand()}_{[0..15]}$
5. packetSize ← 768 + $\text{rand()}_{[0..8]}$
6. packetContents ← top of stack
7. send packet to destIP/destPort
8. if(open(physicaldisk,$\text{rand()}_{[13..15]}$))
   write($\text{rand()}_{[0..14]}$ || 0x4E20); goto 1;
9. else goto 2

Each Witty packet contains bits from 4 consecutive pseudo-random numbers

Witty's PRNG

[Kumar, Paxson, Weaver]

- Witty uses linear congruential generator to generate pseudo-random addresses

$$X_{i+1} = A * X_i + B \quad \text{mod } M$$

  - First proposed by Lehmer in 1948
  - With A = 214013, B = 2531011, M = 2^{32}, orbit is a complete permutation (every 32-bit integer is generated exactly once)

- Can reconstruct the entire state of generator from a single packet (equivalent to a sequence number)

destIP ← $(X_i)_{[0..15]}$ | $(X_{i+1})_{[0..15]}$

destPort ← $(X_{i+2})_{[0..15]}$

… try all possible lower 16 bits and check if they yield X_{i+1} and X_{i+2} consistent with the observations

Given top 16 bits of X_i …

Estimating Infectee's Bandwidth

[Kumar, Paxson, Weaver]

- Suppose two consecutively received packets from a particular infectee have states X_i and X_j
- Compute j-i
  - Count the number of PRNG "turns" between X_i and X_j
- Compute the number of packets sent by infectee between two observations
  - Equal to (j-i)/4 (why?)
- sendto() in Windows is blocking (means what?)
- Bandwidth of infectee = $(j-i)/4 * \text{packet size} / \Delta T$
  - Does this work in the presence of packet loss?

Pseudocode of Witty (2)

[Kumar, Paxson, Weaver]

1. srand(get_tick_count()) ← Seed pseudo-random generator
2. for(i=0; i<20,000; i++)
3. destIP ← $\text{rand()}_{[0..15]}$ | $\text{rand()}_{[0..15]}$
4. destPort ← $\text{rand()}_{[0..15]}$
5. packetSize ← 768 + $\text{rand()}_{[0..8]}$
6. packetContents ← top of stack
7. send packet to destIP/destPort
8. if(open(physicaldisk,$\text{rand()}_{[13..15]}$))
   write($\text{rand()}_{[0..14]}$ || 0x4E20); goto 1;
9. else goto 2

Each Witty packet contains bits from 4 consecutive pseudo-random numbers

What does it mean if telescope observes consecutive packets that are "far apart" in the pseudo-random sequence?

Answer:
<u>re-seeding</u> of infectee's PRNG caused by successful disk access

More Analysis

[Kumar, Paxson, Weaver]

- Compute seeds used for reseeding
  - srand(get_tick_count()) – seeded with uptime
  - Seeds in sequential calls grow linearly with time
- Compute exact random number used for each subsequent disk-wipe test
  - Can determine whether it succeeded or failed, and thus the number of drives attached to each infectee
- Compute every packet sent by every infectee
- Compute who infected whom
  - Compare when packets were sent to a given address and when this address started sending packets

Bug in Witty's PRNG

[Kumar, Paxson, Weaver]

- Witty uses a permutation PRNG, but only uses 16 highest bits of each number
  - Misinterprets Knuth's advice that the higher-order bits of linear congruential PRNGs are more "random"
- Result: orbit is not a compete permutation, misses approximately 10% of IP address space and visits 10% twice
- … but telescope data indicates that some hosts in the "missed" space still got infected
  - Maybe multi-homed or NAT'ed hosts scanned and infected via a different IP address?

Witty's Hitlist

[Kumar, Paxson, Weaver]

- Some hosts in the unscanned space got infected very early in the outbreak
  - Many of the infected hosts are in adjacent /24's
  - Witty's PRNG would have generated too few packets into that space to account for the speed of infection
  - They were not infected by random scanning!
    - Attacker had the hitlist of initial infectees
- Prevalent /16 = U.S. military base
  - Likely explanation: attacker (ISS insider?) knew of ISS software installation at the base
  - Worm released 36 hours after vulnerability disclosure

Patient Zero

[Kumar, Paxson, Weaver]

- A peculiar "infectee" shows up in the telescope observation data early in the Witty oubreak
  - Sending packets with destination IP addresses that could not have been generated by Witty's PRNG
    - It was not infected by Witty, but running different code to generate target addresses!
  - Each packet contains Witty infection, but payload size not randomized; also, this scan did not infect anyone
    - Initial infectees came from the hitlist, not from this scan
- Probably the source of the Witty outbreak
  - IP address belongs to a European retail ISP; information passed to law enforcement