BotSniffer: Detecting Botnet Command and Control Channels in Network Traffic

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Roadmap

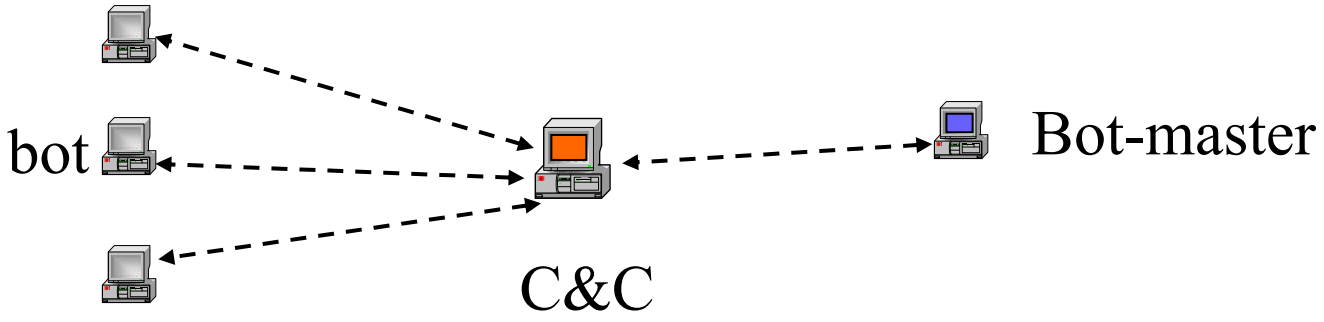
- Introduction
- BotSniffer
  - Motivation
  - Architecture
  - Algorithm
  - Experimental Evaluation
- Summary

Botnets: Big Problem

- "Attack of zombie computers is growing threat" (New York Times)
- "Why we are losing the botnet battle" (Network World)
- "Botnet could eat the internet" (Silicon.com)
- "25% of Internet PCs are part of a botnet" (Vint Cerf)

What are Bots/Botnets?

- Bot (Zombie)
  - Compromised computer controlled by botcodes (malware) without owner consent/knowledge
  - Professionally written; self-propagating
- Botnets (Bot Armies)
  - Networks of bots controlled by criminals
  - Key platform for fraud and other for-profit exploits



Botnet Epidemic

- More than 95% of all spam
- All distributed denial of service (DDoS) attacks
- Click fraud
- Phishing & pharming attacks
- Key logging & data/identity theft
- Distributing other malware, e.g., spyware/adware

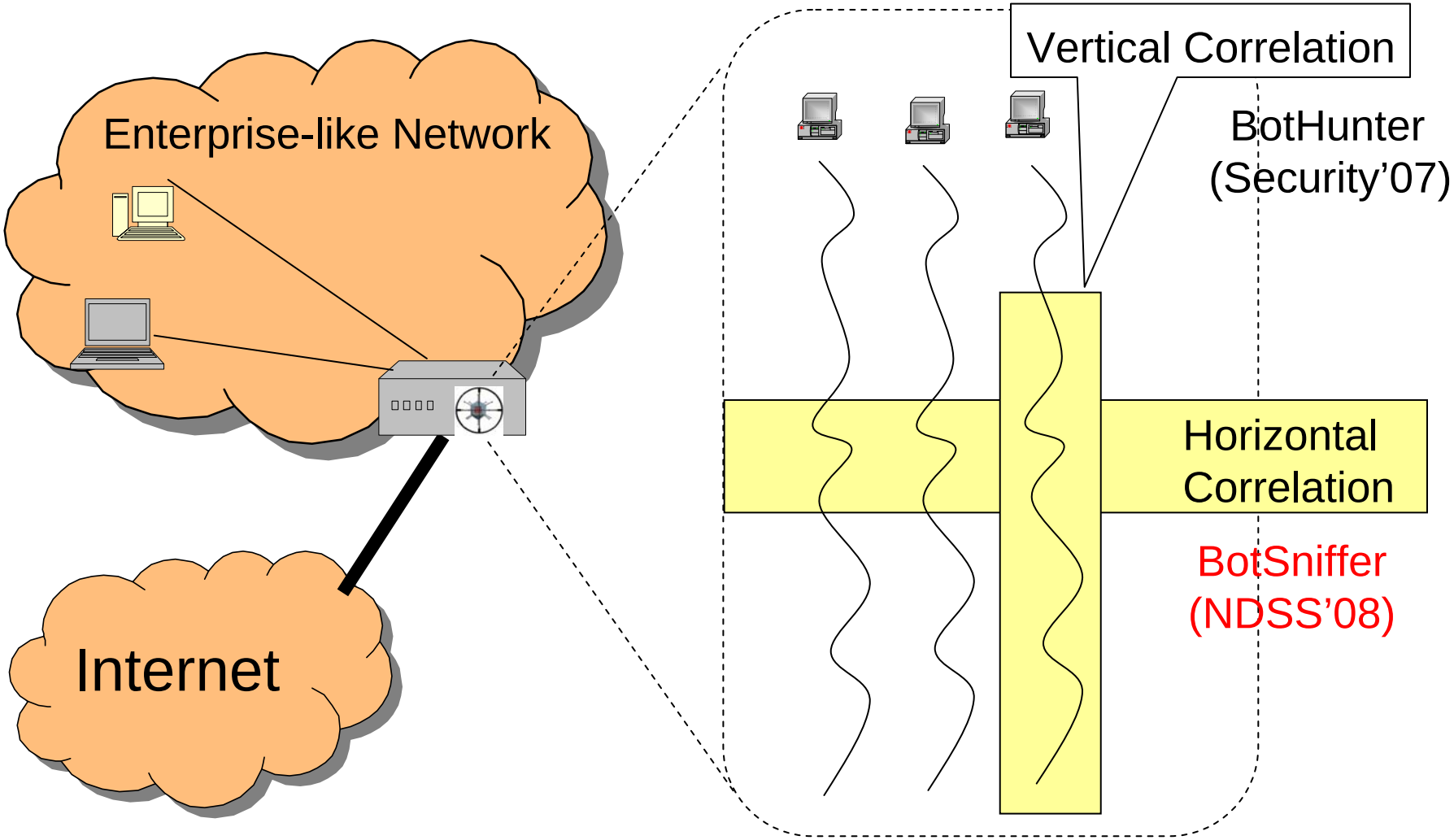
Botnet C&C Detection

- C&C is essential to a botnet
  - Without C&C, bots are just discrete, unorganized infections
- C&C detection is important
  - Relatively stable and unlikely to change within botnets
  - Reveal C&C server and local victims
  - The weakest link
- C&C detection is hard
  - Use existing common protocol instead of new one
  - Low traffic rate
  - Obscure/obfuscated communication

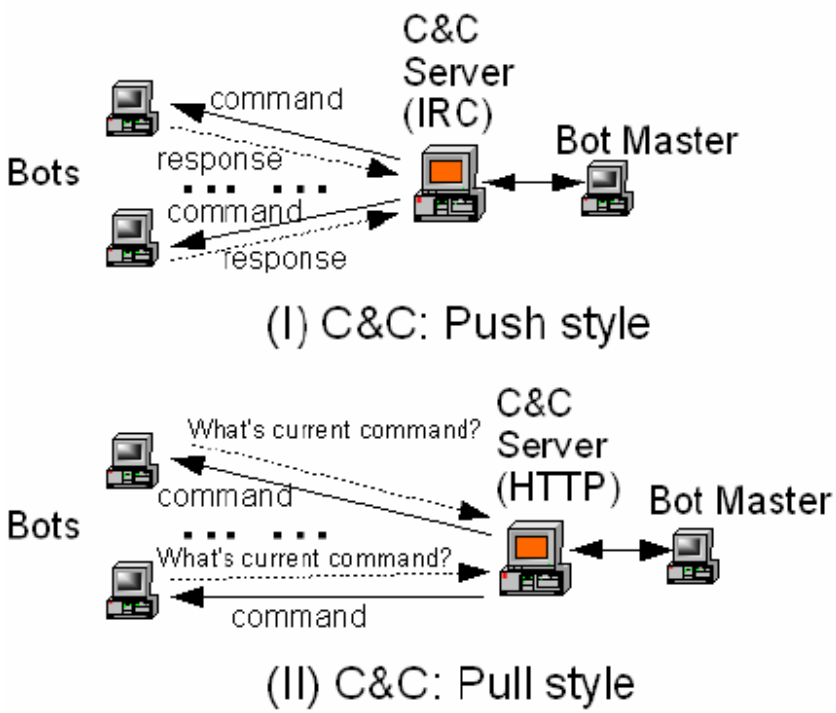
Related Work

- [Binkley,Singh 2006]: IRC-based bot detection combine IRC statistics and TCP work weight
- Rishi [Goebel, Holz 2007]: signature-based IRC bot nickname detection
- [Livadas et al. 2006]: (BBN) machine learning based approach using some general network-level traffic features (IRC botnet)
- [Karasaridis et al. 2007]: (AT&T) network flow level detection of IRC botnet controllers for backbone network (IRC botnet)
- [Gu et al. 2007]: BotHunter

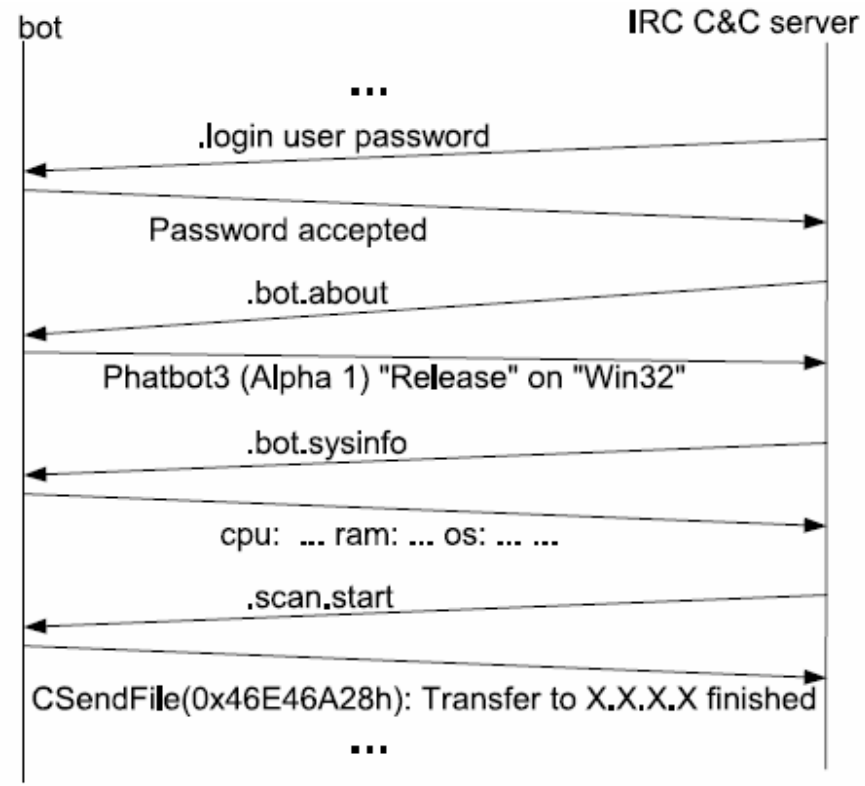
Our Approaches: General Picture



Botnet C&C Communication

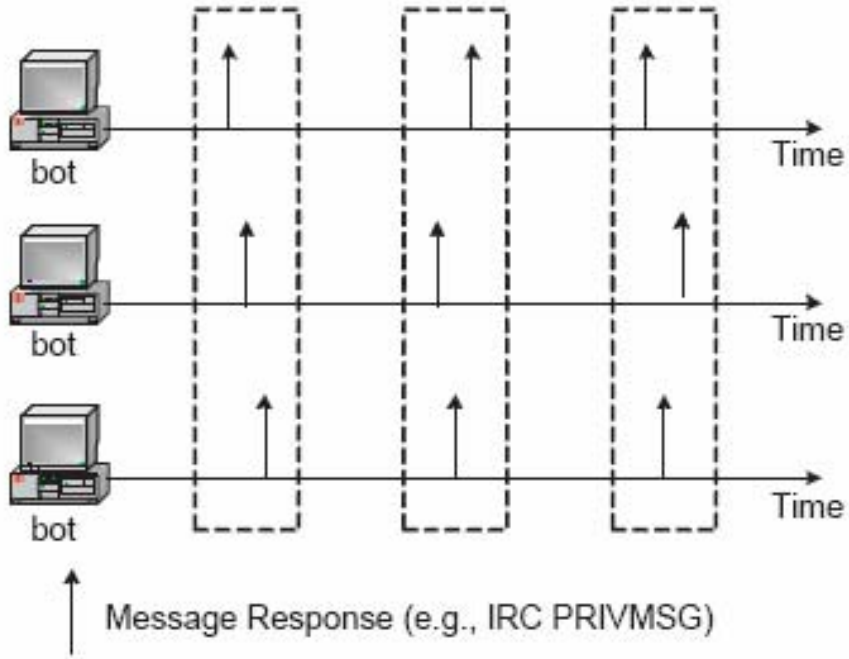


(a) Two styles of botnet C&C

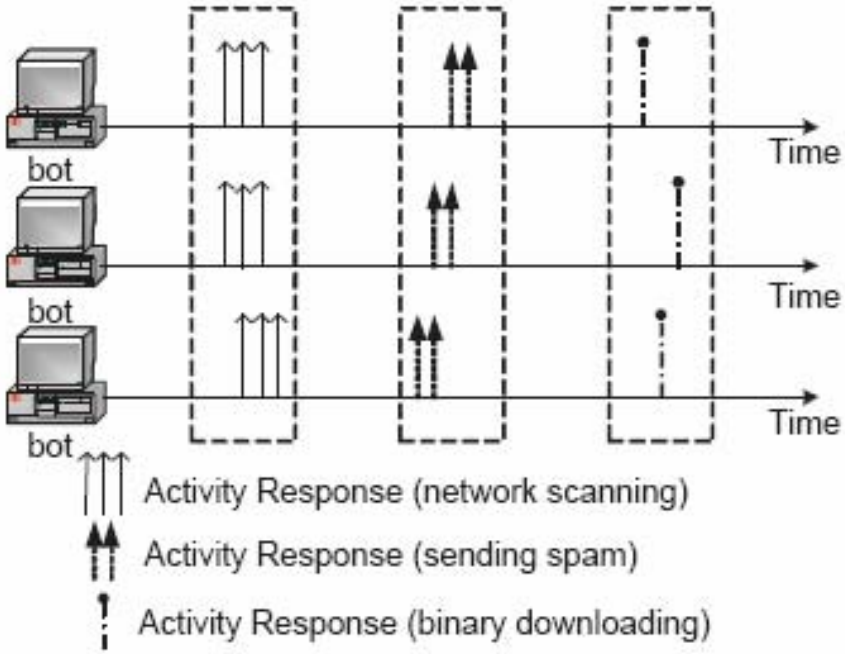


(b) An IRC-based C&C communication example

Botnet C&C: Spatial-Temporal Correlation and Similarity

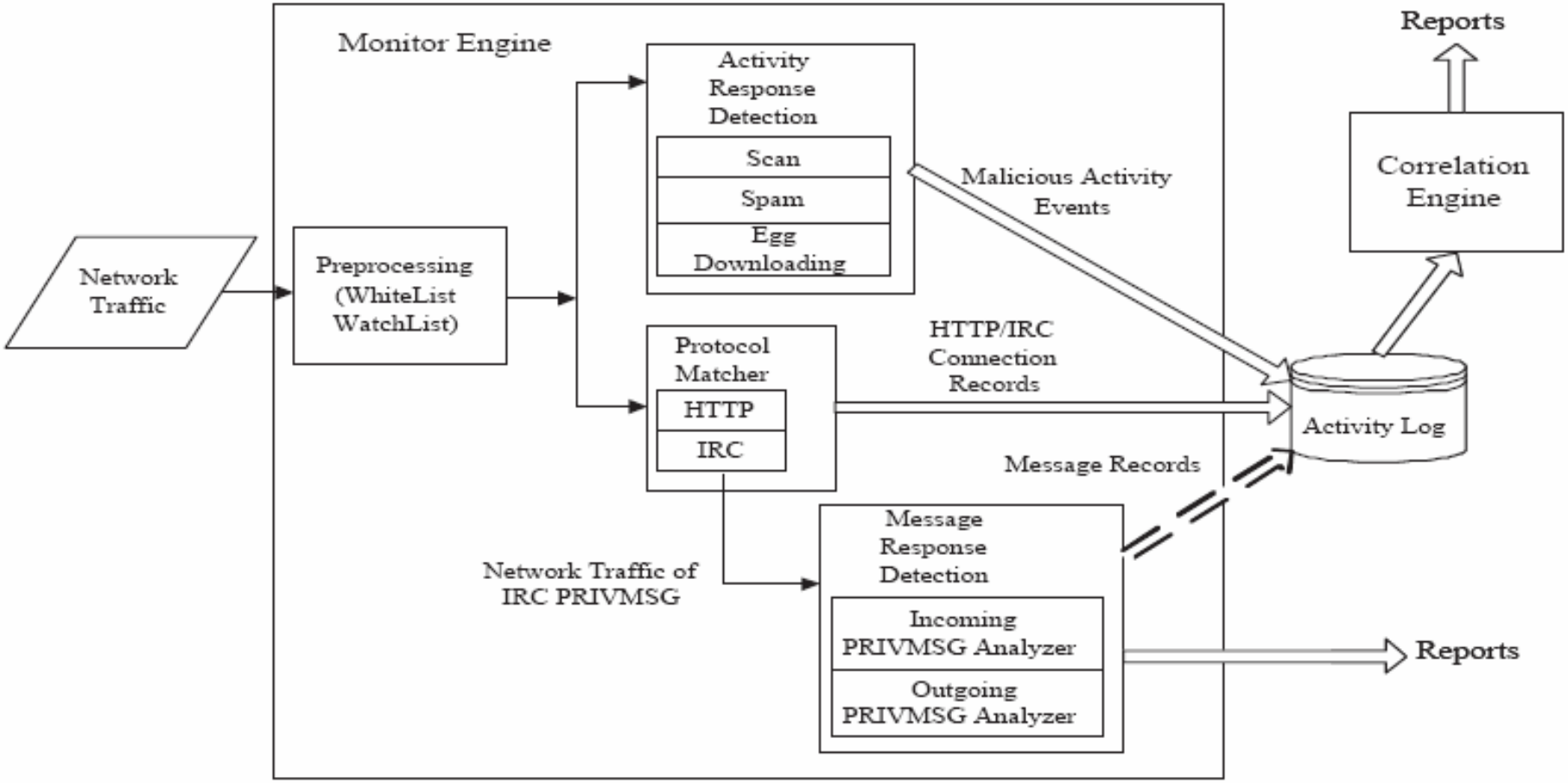


(a) Message response crowd



(b) Activity response crowd

BotSniffer Architecture



Correlation Engine

- Group clients according to their destination IP and Port pair (HTTP/IRC connection record)

- Perform a *group analysis* on spatial-temporal correlation and similarity property
  - Response-Crowd-Density-Check
  - Response-Crowd-Homogeneity-Check

Response-Crowd-Density-Check Algorithm

- Response crowd
  - a set of clients that have (message/activity) response behavior
- A Dense response crowd
  - the fraction of clients with message/activity behavior within the group is larger than a threshold (e.g., 0.5).
- Example: 5 clients connected to the same IRC/HTTP server, and all of them scanned at similar time (or send IRC messages at similar time)
- Accumulate the degree of suspicion
  - Sequential Probability Ratio Testing (SPRT)

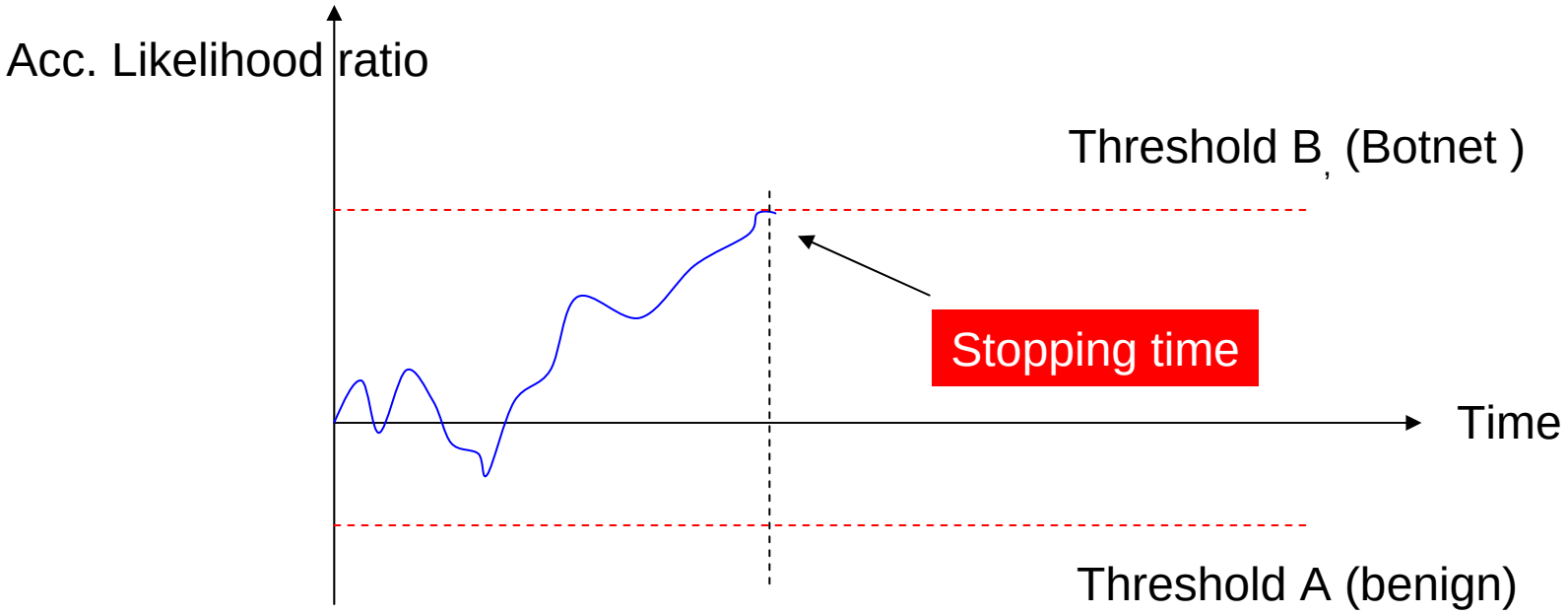
Sequential Probability Ratio Testing (SPRT)

- Each round, observe whether current crowd is dense or not (Y=1 or Y=0)
  - Hypothesis
    - Pr(Y=1|H1) very high (for botnet)
    - Pr(Y=1|H0) very low (for benign)
- Update accumulated likelihood ratio according to the observation Y

$$\Lambda_n = \ln \frac{Pr(Y_1, \ldots, Y_n | H_1)}{Pr(Y_1, \ldots, Y_n | H_0)} = \ln \frac{\prod_i Pr(Y_i | H_1)}{\prod_i Pr(Y_i | H_0)} = \sum_i \ln \frac{Pr(Y_i | H_1)}{Pr(Y_i | H_0)}$$

- After several rounds, we may reach a decision (which hypothesis is more likely, H1 or H0)

Sequential Probability Ratio Testing (cont.)



- Also called TRW (Threshold Random Walk)
- Bounded false positive and false negative rate (as desired), and usually needs only a few rounds

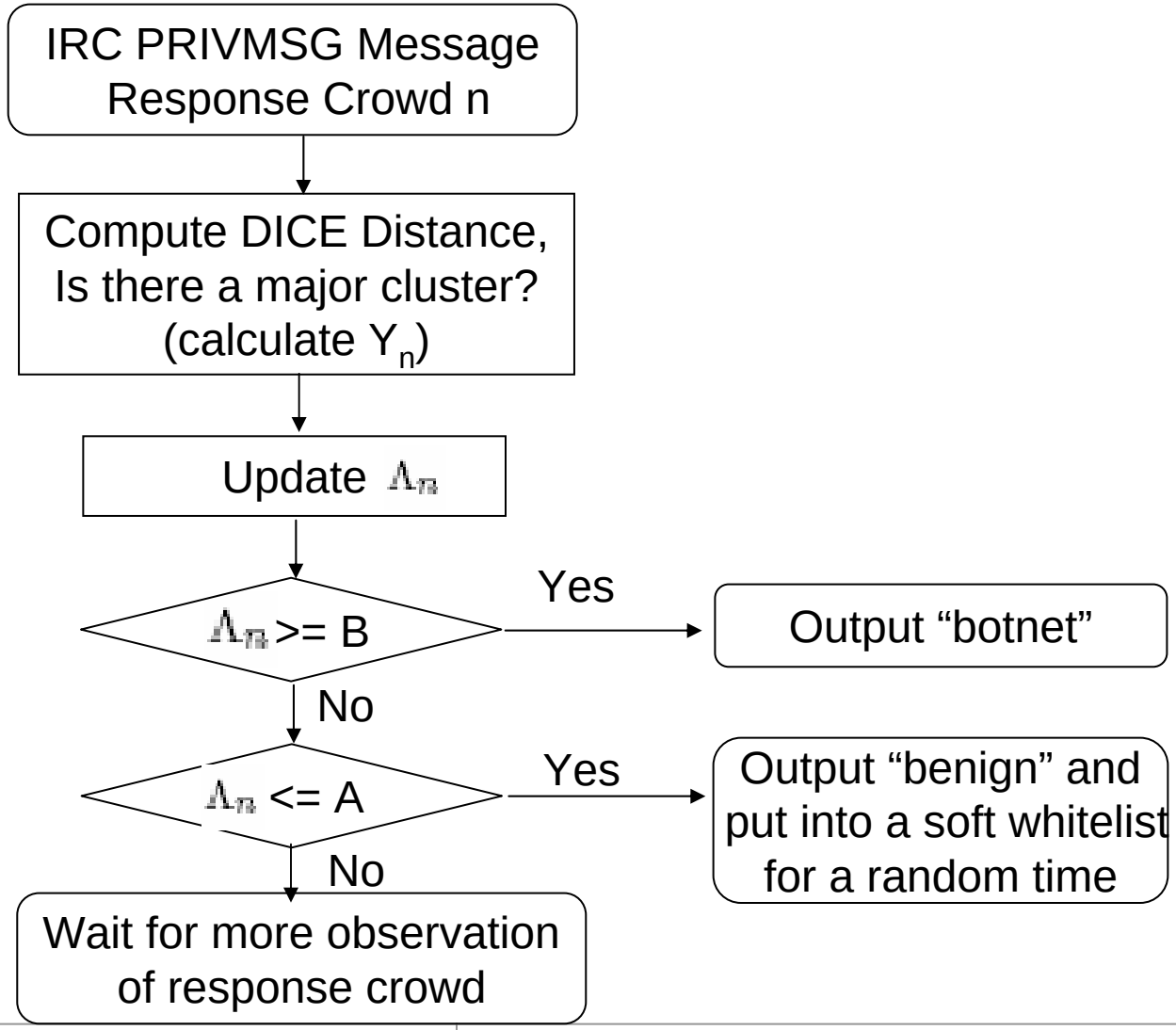
Response-Crowd-Homogeneity-Check Algorithm

- A homogeneous response crowd
  - Many members have very similar responses
- Similarity is defined
  - Message response
    - Similar payload (DICE distance)

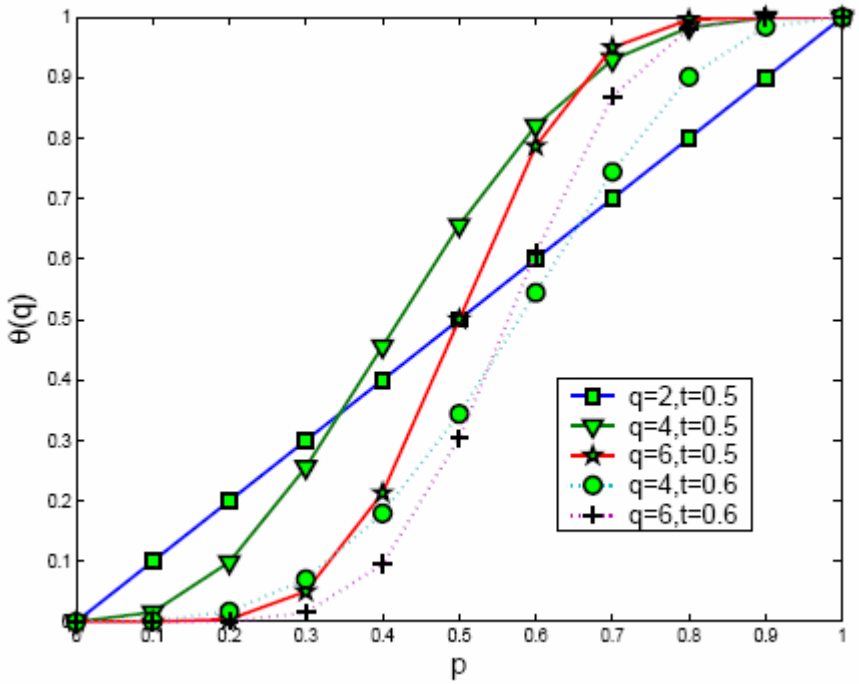
$$Dice(X,Y) = \frac{2|ngrams(X) \cap ngrams(Y)|}{|ngrams(X)| + |ngrams(Y)|}$$

    - E.g., “abcde” and “bcdef”, common 2-grams: “bc,cd,de”, DICE distance is 2*3/(4+4)=6/8=0.75
  - Activity response (examples)
    - Scan same ports
    - Download same binary
    - Send similar spams

Real-Time IRC Message Correlation Flow Diagram



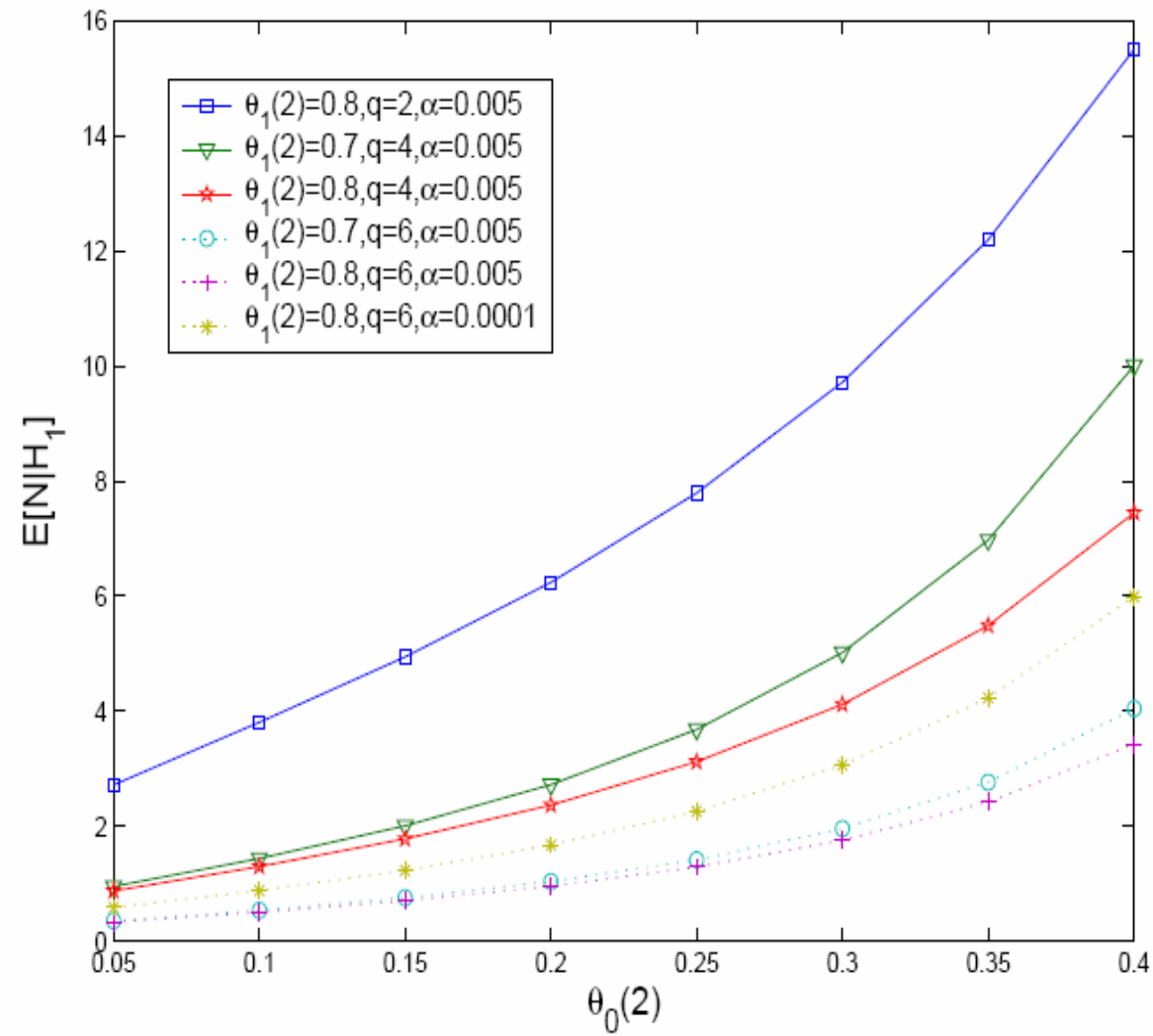
Crowd Homogeneity: Relationship with Number of Clients



For a botnet, more clients, higher probability of crowd homogeneity
For normal IRC channel, more clients, lower probability of crowd homogeneity

q: #clients t: threshold in clustering
P=θ(2): basic probability of two clients sending similar messages

Number of Rounds Needed



Experiment

189 days' of IRC traffic

Trace	trace size	duration	Pkt	TCP flows	(IRC/Web) servers	FP
IRC-1	54MB	171h	189,421	10,530	2,957	0
IRC-2	14MB	433h	33,320	4,061	335	0
IRC-3	516MB	1,626h	2,073,587	4,577	563	6
IRC-4	620MB	673h	4,071,707	24,837	228	3
IRC-5	3MB	30h	19,190	24	17	0
IRC-6	155MB	168h	1,033,318	6,981	85	1
IRC-7	60MB	429h	393,185	717	209	0
IRC-8	707MB	1,010h	2,818,315	28,366	2,454	1
All-1	4.2GB	10m	4,706,803	14,475	1,625	0
All-2	6.2GB	10m	6,769,915	28,359	1,576	0
All-3	7.6GB	1h	16,523,826	331,706	1,717	0
All-4	15GB	1.4h	21,312,841	110,852	2,140	0
All-5	24.5GB	5h	43,625,604	406,112	2,601	0

Experiment (cont.)

BotTrace	trace size	duration	Pkt	TCP flow	Detected
B-IRC-G	950k	8h	4,447	189	Yes
B-IRC-J-1	-	-	143,431	-	Yes
B-IRC-J-2	-	-	262,878	-	Yes
V-Rbot	26MB	1,267s	347,153	103,425	Yes
V-Spybot	15MB	1,931s	180,822	147,921	Yes
V-Sdbot	66KB	533s	474	14	Yes
B-HTTP-I	6MB	3.6h	65,695	237	Yes
B-HTTP-II	37MB	19h	395,990	790	Yes

Thanks David Dagon, Fabian Monrose, and Chris Lee
for providing some of the evaluation traces

BotSniffer Summary

- Exploiting the underlying spatial-temporal correlation and similarity property of botnet C&C (horizontal correlation)
- New anomaly-based detection algorithm
- New Botnet C&C detection system: BotSniffer
- Detected real-world botnets with a very low false positive rate

Future Work

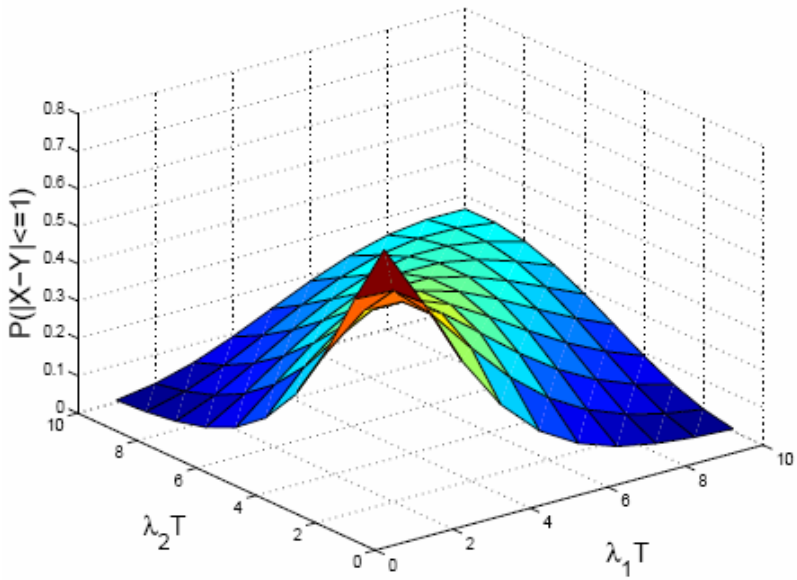
- Improving accuracy and resilience to evasion
- BotMiner: protocol- and structure-independent botnet detection technique

Thanks!

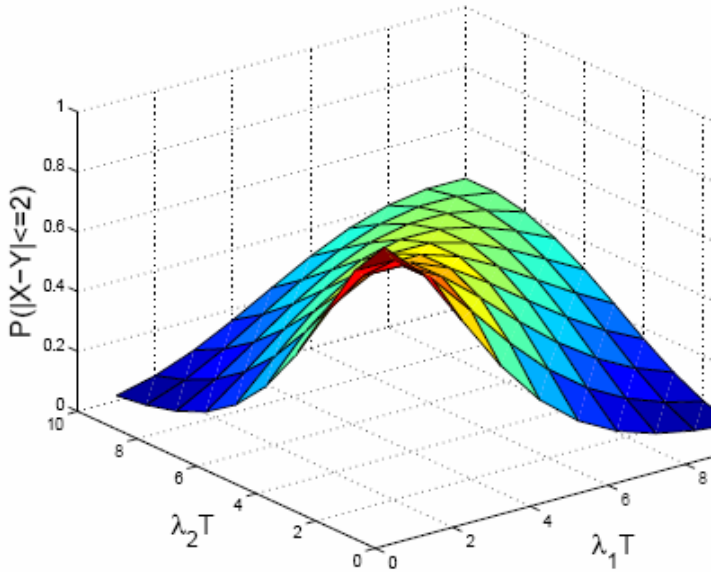
Q&A

Http://www.cc.gatech.edu/~guofei

Probability of Having Two Similar Length Messages



(a) Probability of $P(|X - Y| <= 1)$



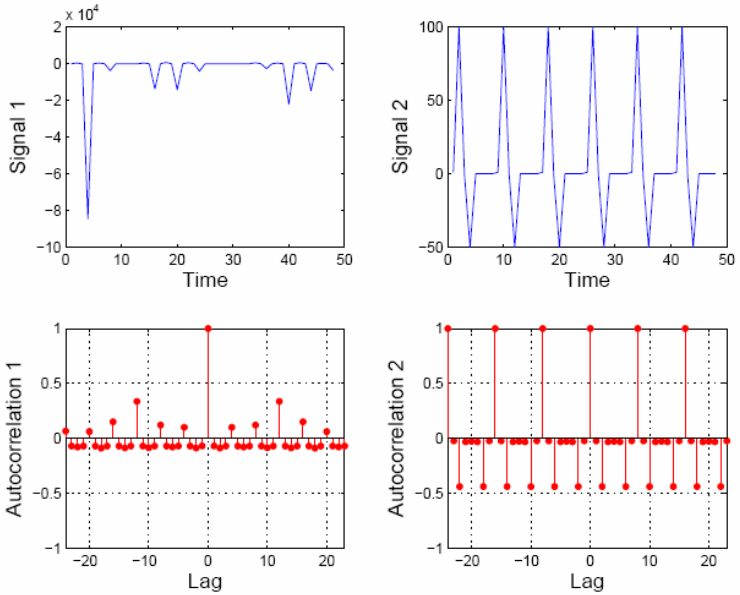
(b) Probability of $P(|X$
$Y| <= 2)$

Probability of having two similar content messages are even lower

Single Client C&C Detection Under Certain Conditions

- IRC: broadcast in the channel
  - similar to the case we can monitor multiple message responses from multiple clients in the group

- HTTP: AutoCorrelation to find periodic patterns from background noise



BotSniffer Extension and Limitation

- Improving BotSniffer
  - Using activity response crowd *homogeneity*
  - Extension of suspicious C&C protocol matchers
- Possible evasion
  - Effect of encryption
  - Evasion by exploiting time window
  - Evasion by using random delay/period, injecting random noise, injecting random garbage in the packet