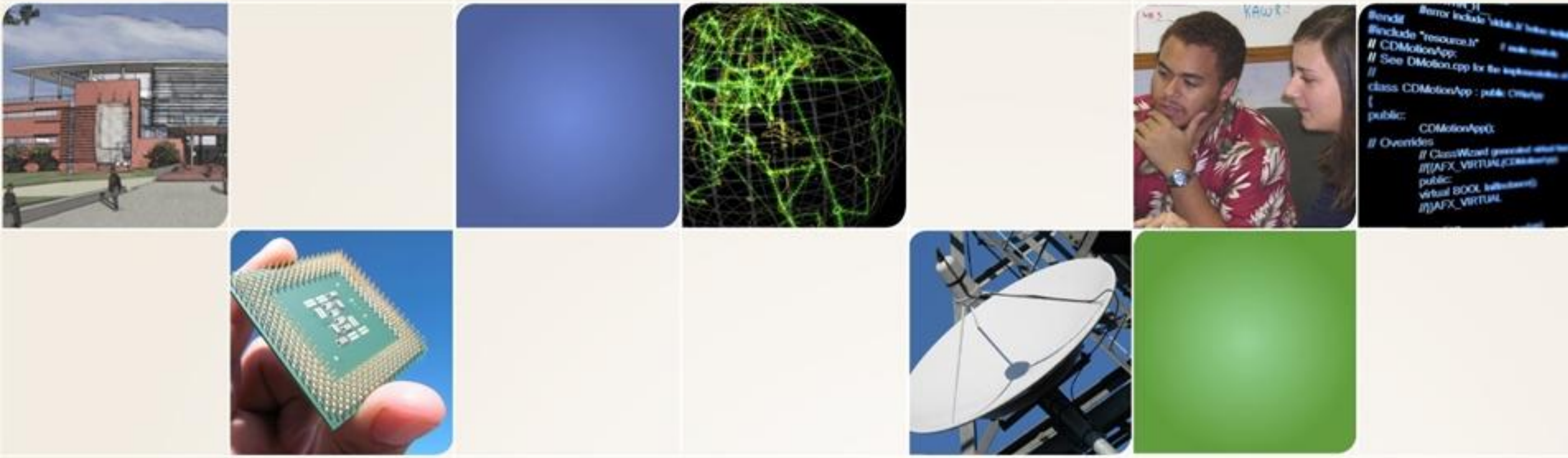

Detecting Spammers with SNARE: Spatio-temporal Network-level Automatic Reputation Engine

Shuang Hao, Nadeem Ahmed Syed, Nick Feamster,
Alexander G. Gray, Sven Krasser

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School of Computer Science

Spam: More than Just a Nuisance

Spam:
unsolicited bulk emails

Ham:
legitimate emails from desired contacts

- 95% of all email traffic is spam
  (Sources: Microsoft security report, MAAWG and Spamhaus)
  - In 2009, the estimation of lost productivity costs is $130 billion worldwide
    (Source: Ferris Research)

- Spam is the carrier of other attacks
  - Phishing
  - Virus, Trojan horses, …

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Current Anti-spam Methods

- Content-based filtering: What is in the mail?
  - More spam format rather than text (PDF spam ~12%)
  - Customized emails are easy to generate
  - High cost to filter maintainers

- IP blacklist: Who is the sender? (e.g., DNSBL)
  - ~10% of spam senders are from previously unseen IP addresses (due to dynamic addressing, new infection)
  - ~20% of spam received at a spam trap is not listed in any blacklists

SNARE: Our Idea

- Spatio-temporal Network-level Automatic Reputation Engine
  - Network-Based Filtering: How the email is sent?
    - Fact: > 75% spam can be attributed to botnets
    - Intuition: Sending patterns should look different than legitimate mail
  - Example features: geographic distance, neighborhood density in IP space, hosting ISP (AS number) etc.
  - Automatically determine an email sender's reputation
    - 70% detection rate for a 0.2% false positive rate

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Why Network-Level Features?

- Lightweight
  - Do not require content parsing
    - Even getting one single packet
    - Need little collaboration across a large number of domains
  - Can be applied at high-speed networks
  - Can be done anywhere in the middle of the network
    - Before reaching the mail servers
- More Robust
  - More difficult to change than content
  - More stable than IP assignment

Talk Outline

- Motivation
- **Data From McAfee**
- Network-level Features
- Building a Classifier
- Evaluation
- Future Work
- Conclusion

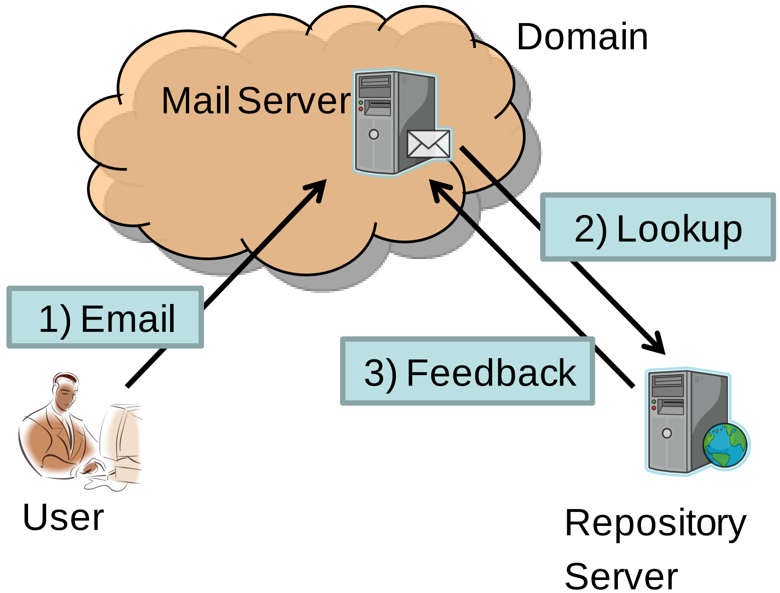
Data Source

- McAfee's TrustedSource email sender reputation system
  - – Time period: 14 days

    October 22 – November 4, 2007
  - – Message volume:

    Each day, 25 million email messages from 1.3 million IPs
  - – Reported appliances

    2,500 distinct appliances (≈ recipient domains)
  - – Reputation score: certain ham, likely ham, certain spam, likely spam, uncertain



by S. Hao, N. A. Syed, N. Feamster, A. Gray, S. Krasser

Finding the Right Features

- Question: Can sender reputation be established from just a single packet, plus auxiliary information?
  - Low overhead
  - Fast classification
  - In-network
  - Perhaps more evasion resistant

- Key challenge
  - What features satisfy these properties and can distinguish spammers from legitimate senders?

Network-level Features

- Feature categories
  - Single-packet features
  - Single-header and single-message features
  - Aggregate features
- A combination of features to build a classifier
  - No single feature needs to be perfectly discriminative between spam and ham
- Measurement study
  - McAfee's data, October 22-28, 2007 (7 days)

Summary of SNARE Features

Category	Features
Single-packet	geodesic distance between the sender and the recipient
	average distance to the 20 nearest IP neighbors of the sender
	probability ratio of spam to ham when getting the message
	status of email-service ports on the sender
	AS number of the sender's IP
Single-header/message	number of recipient
	length of message body
Aggregate features	average of message length in previous 24 hours
	standard deviation of message length in previous 24 hours
	average recipient number in previous 24 hours
	standard deviation of recipient number in previous 24 hours
	average geodesic distance in previous 24 hours
	standard deviation of geodesic distance in previous 24 hours

Total of 13 features in use

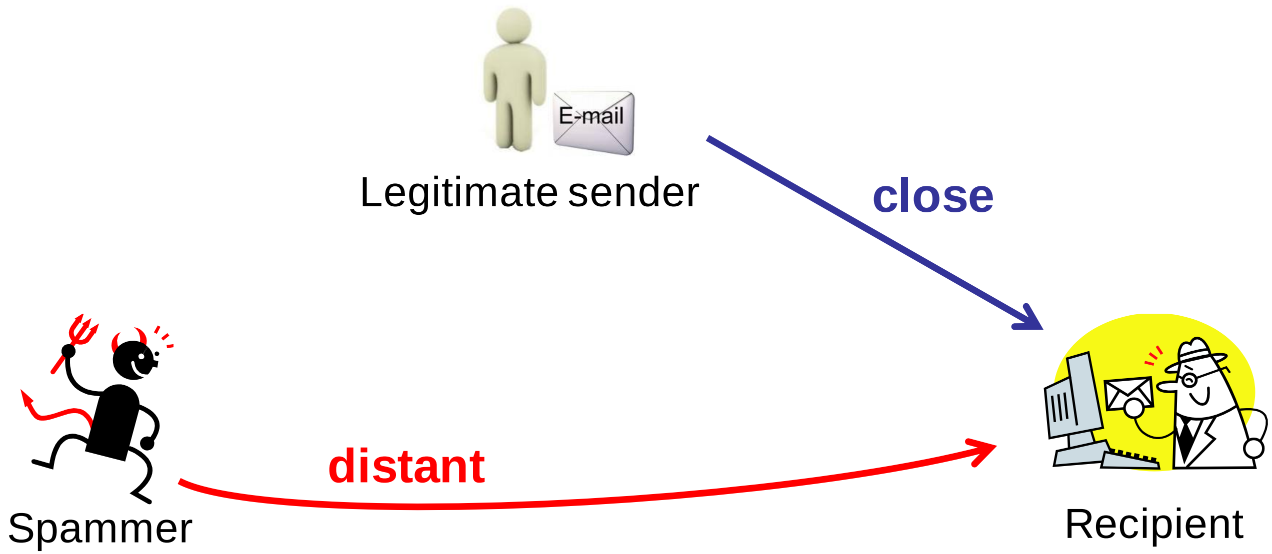
What Is In a Packet?

- Packet format (incoming SMTP example)

IP Header	TCP Header	SMTP
Source IP, Destination IP	Destination port : 25	Text Command Empty for the first packet

- Help of auxiliary knowledge:
  - Timestamp: the time at which the email was received
  - Routing information
  - Sending history from neighbor IPs of the email sender

Sender-receiver Geodesic Distance



- Intuition:
  - Social structure limits the region of contacts
  - The geographic distance travelled by spam from bots is close to random

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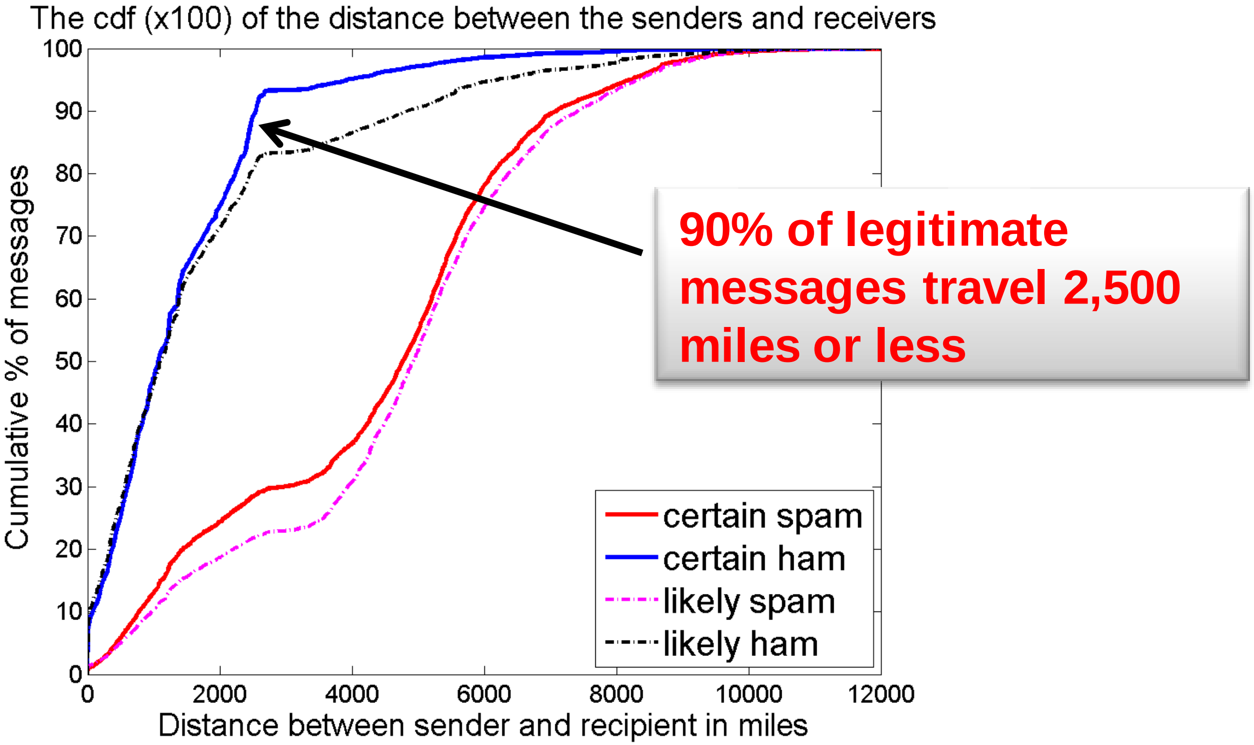
Distribution of Geodesic Distance

- Find the physical latitude and longitude of IPs based on the MaxMind's GeoIP database
- Calculate the distance along the surface of the earth



- Observation: Spam travels further

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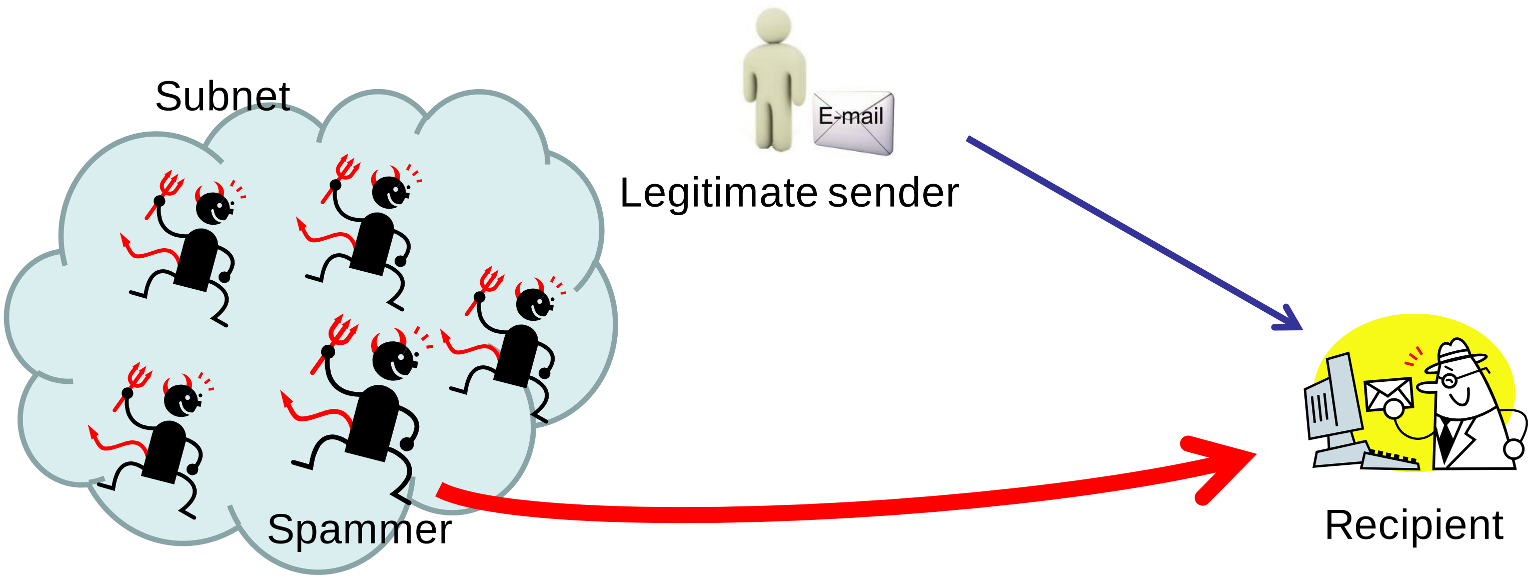
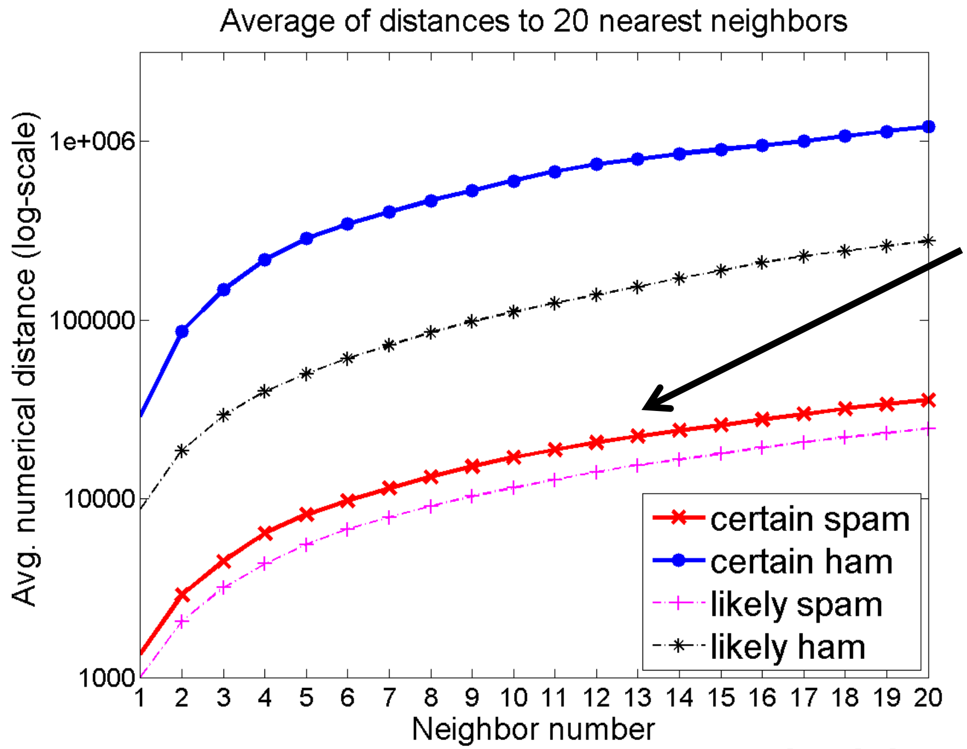
Sender IP Neighborhood Density



- Intuition:
  - The infected IP addresses in a botnet are close to one another in numerical space
  - Often even within the same subnet

Distribution of Distance in IP Space

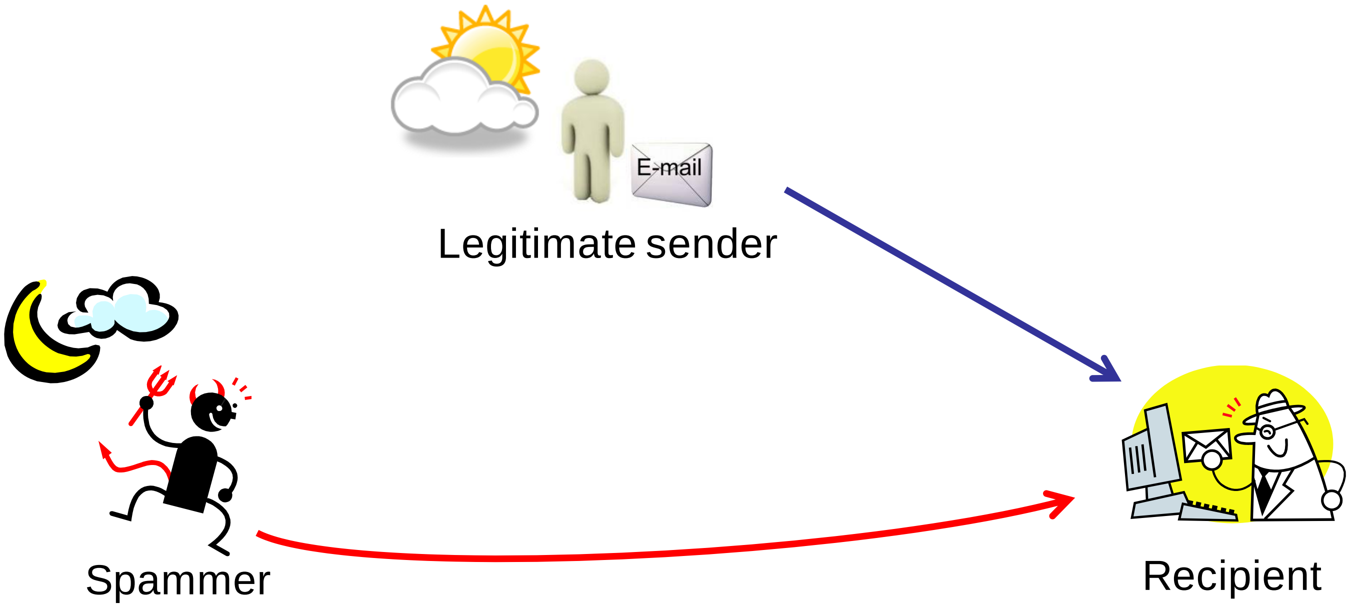
- IPs as one-dimensional space (0 to 2^{32}-1 for IPv4)
- Measure of email sender density: the average distance to its k nearest neighbors (in the past history)



For spammers, k nearest senders are much closer in IP space

- Observation: Spammers are surrounded by other spammers

Local Time of Day At Sender



- Intuition:
  - Diurnal sending pattern of different senders
  - Legitimate email sending patterns may more closely track workday cycles

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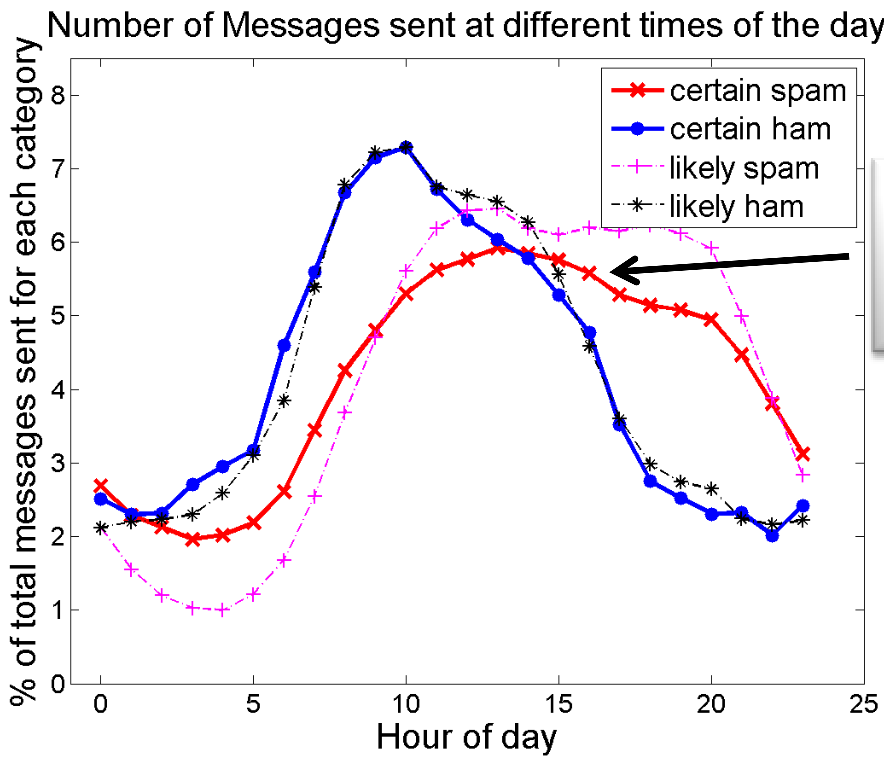
Differences in Diurnal Sending Patterns

- Local time at the sender's physical location
- Relative percentages of messages at different time of the day (hourly)



Spam "peaks" at different local time of day

- Observation: Spammers send messages according to machine power cycles

Status of Service Ports

- Ports supported by email service provider

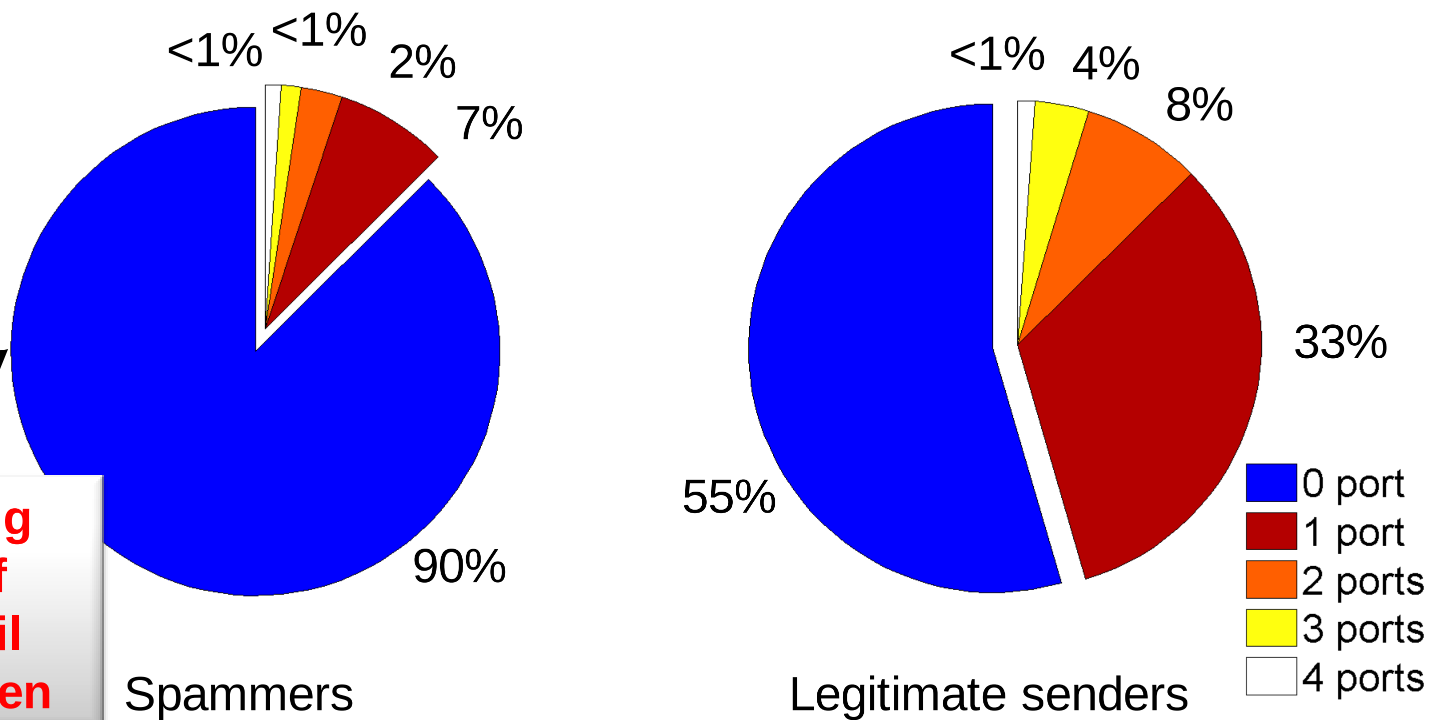
Protocol	Port
SMTP	25
SSL SMTP	465
HTTP	80
HTTPS	443

- Intuition:
  - Legitimate email is sent from other domains' MSA (Mail Submission Agent)
  - Bots send spam directly to victim domains

by S. Hao, N. A. Syed, N. Feamster, A. Gray, S. Krasser

Distribution of number of Open Ports

- Actively probe back senders' IP to check out what service ports open
- Sampled IPs for test, October 2008 and January 2009



90% of spamming IPs have none of the standard mail service ports open

- Observation: Legitimate mail tends to originate from machines with open ports

AS of sender's IP

- Intuition: Some ISPs may host more spammers than others

- Observation: A significant portion of spammers come from a relatively small collection of ASes*
  - More than 10% of unique spamming IPs originate from only 3 ASes
  - The top 20 ASes host ~42% of spamming IPs

*RAMACHANDRAN, A., AND FEAMSTER, N. Understanding the network-level behavior of spammers. In Proceedings of the ACM SIGCOMM (2006).

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	average geodesic distance in previous 24 hours
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Total 13 features in use

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SNARE: Building A Classifier

- RuleFit (ensemble learning)
  - $F(x) = a_0 + \sum_{m=1}^{M} a_m f_m(x)$
  - $F(x)$ is the prediction result (label score)
  - $f_m(x)$ are base learners (usually simple rules)
  - a_m are linear coefficients

- Example

	$F(x)$	a_m	$f_m(x)$
Rule 1	**0.080**	0.080	Geodesic distance > 63 AND AS in (1901, 1453, …)
	+		
Rule 2	**0**	0.257	Port status: no SMTP service listening

Feature instance of a message

Geodesic distance = 92, AS=1901, port SMTP is open

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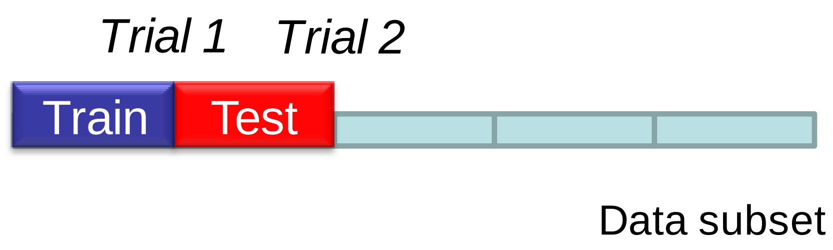
Talk Outline

- Motivation
- Data From McAfee
- Network-level Features
- Building a Classifier
- **Evaluation**
  - Setup
  - Accuracy
  - Detetcting “Fresh” Spammers
  - In Paper: Retraining, Whitelisting, Feature Correlation
- Future Work
- Conclusion

Evaluation Setup

- Data
  - 14-day data, October 22 to November 4, 2007
  - 1 million messages sampled each day (only consider certain spam and certain ham)
- Training
  - Train SNARE classifier with equal amount of spam and ham (30,000 in each categories per day)
- Temporal Cross-validation
  - Temporal window shifting

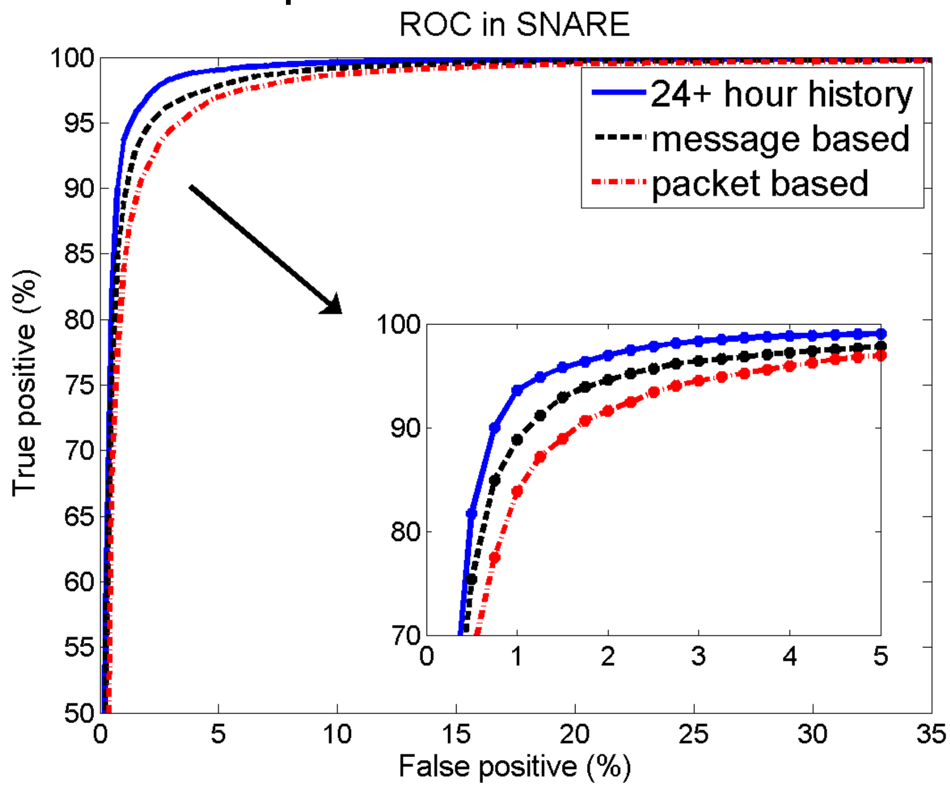


Receiver Operator Characteristic (ROC)

- False positive rate = Misclassified ham/Actual ham
- Detection rate = Detected spam/Actual spam (True positive rate)

FP under detection rate 70%

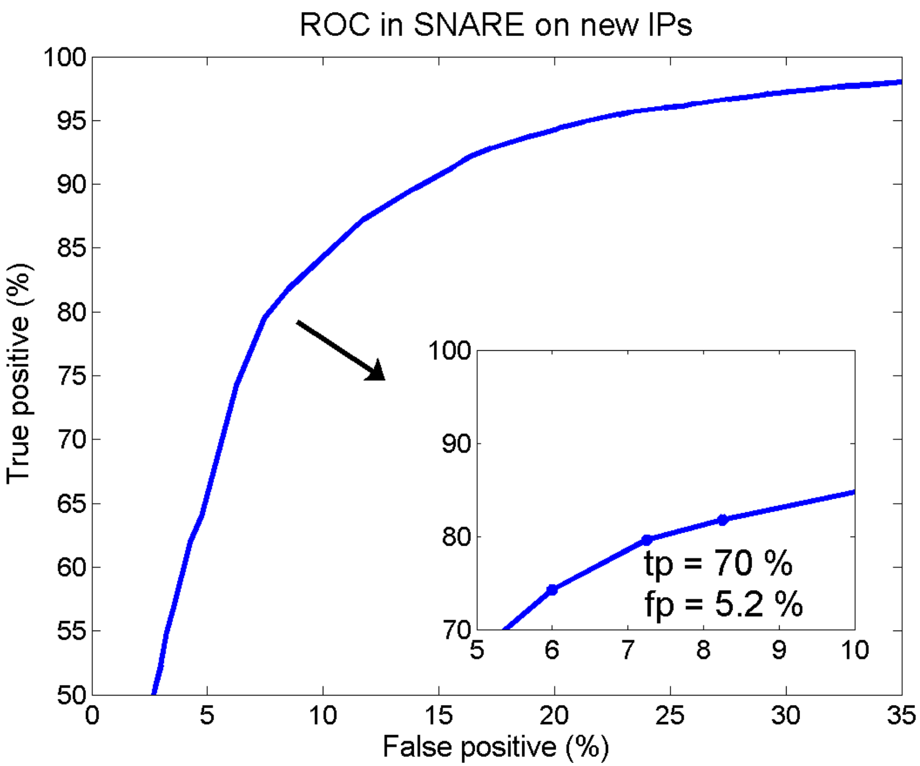
	False Positive
Single Packet	0.44%
Single Header/Message	0.29%
24+ Hour History	0.20%



As a first of line of defense, SNARE is effective

Detection of “Fresh” Spammers

- “Fresh” senders
  - IP addresses not appearing in the previous training windows
- Accuracy
  - Fixing the detection rate as 70%, the false positive is 5.2%



SNARE is capable of automatically classifying ‘fresh’ spammers (compared with DNSBL)

by S. Hao, N. A. Syed, N. Feamster, A. Gray, S. Krasser

Future Work

- Combine SNARE with other anti-spam techniques to get better performance
  - Can SNARE capture spam undetected by other methods (e.g., content-based filter)?
- Make SNARE more evasion-resistant
  - Can SNARE still work well under the intentional evasion of spammers?

Conclusion

- Network-level features are effective to distinguish spammers from legitimate senders
  - Lightweight: Sometimes even by the observation from one single packet
  - More Robust: Spammers might be hard to change all the patterns, particularly without somewhat reducing the effectiveness of the spamming botnets

- SNARE is designed to automatically detect spammers
  - A good first line of defense