Analyzing Cooperative Containment Of Fast Scanning Worms

Jayanthkumar Kannan

UC Berkeley

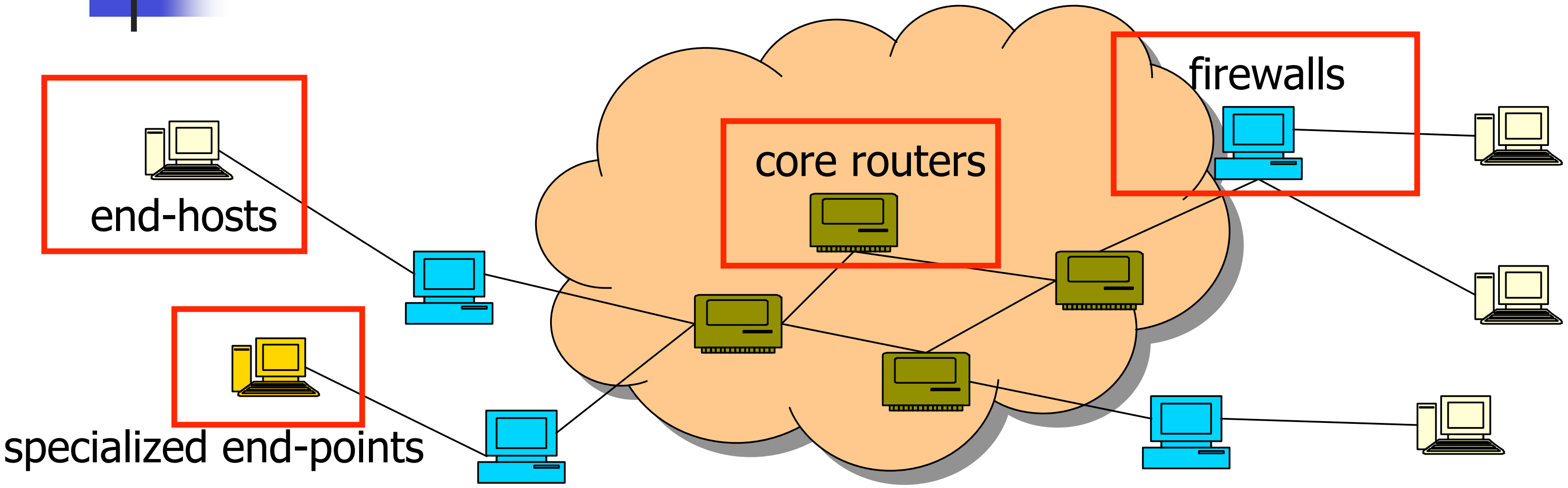
Joint work with

Lakshminarayanan Subramanian, Ion Stoica, Randy Katz

Motivation

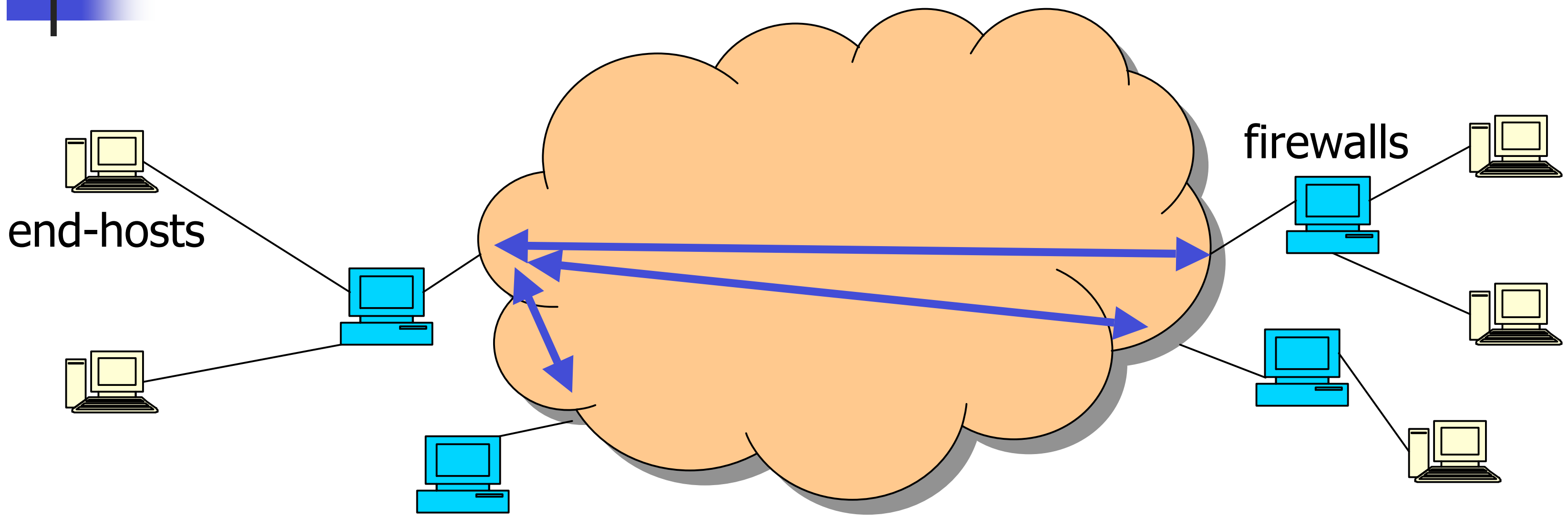
- Automatic containment of worms required
  - Faster: Slammer infected over 95% of vulnerable population in 10 mins (MPSSSW 03)
  - Easier to write: Worm = “Propagation” toolkit + new exploit

Worm containment strategies



- End-host instrumentation (eg: NS 05)
- Core-router augmentation (eg: WWSGB 04)
- Specialized end-points (eg: honeyfarms - P 04)
- Firewall-level containment (eg: WSP 04)

Decentralized Cooperation



- Internet firewalls exchange information with each other to contain the worm
  - Suggested recently: WSP 04, NRL 03, AGIKL 03
- Pros of decentralization:
  - Scales with the system size
  - No single point of failure / administrative control

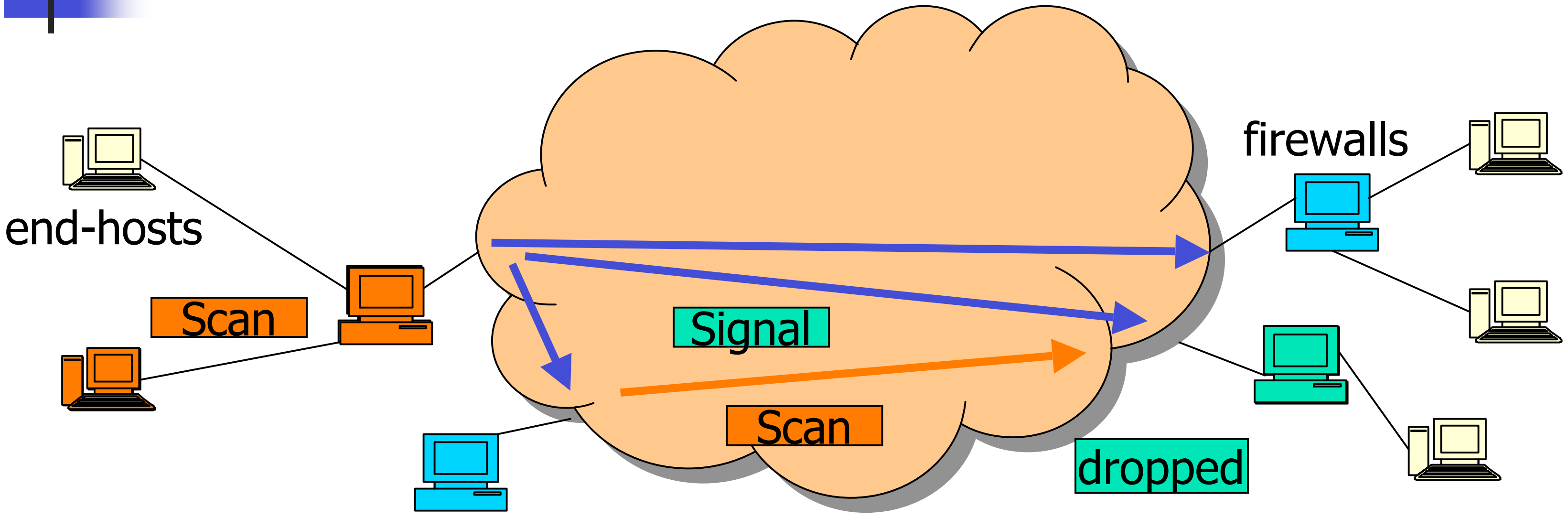
Questions we seek to answer

- Cost of decentralization
  - Modes of information exchange
  - Effect of finite communication rate between firewalls on containment
- Effect of malice
  - Trust Model: Only “few” malicious participants
  - How does one deal with malicious firewalls?
- Performance under partial deployment

Roadmap

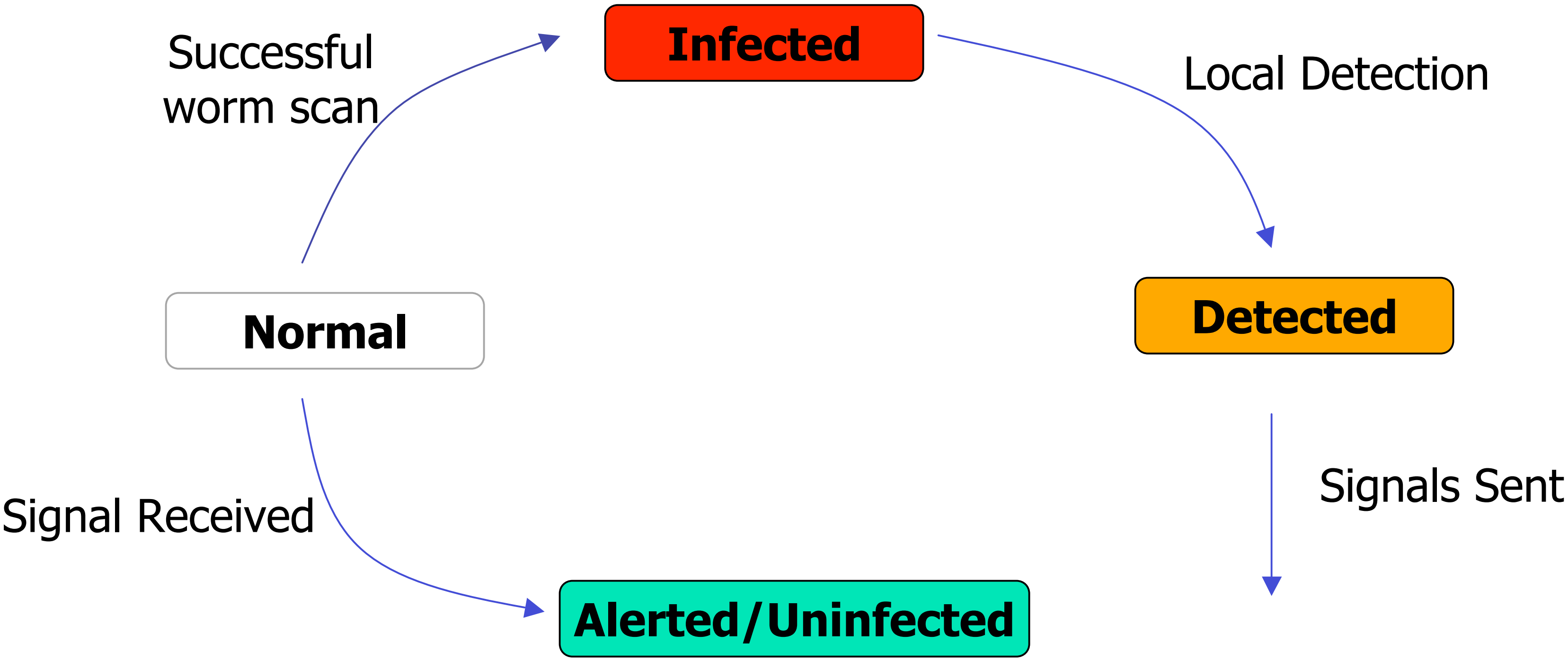
- Abstract model of cooperation
- Analysis of cooperation model
- Numerical Results
  - Analytical, Simulation
- Conclusion

Model Of Cooperation



- Local Detection: Identify when its network is infected by analyzing outgoing traffic
- Signaling: Informs other firewalls of its own infection along with filters
- Filtering: An informed firewall drops incoming packets

Firewall states



Successful worm scan

Infected

Local Detection

Normal

Detected

Signal Received

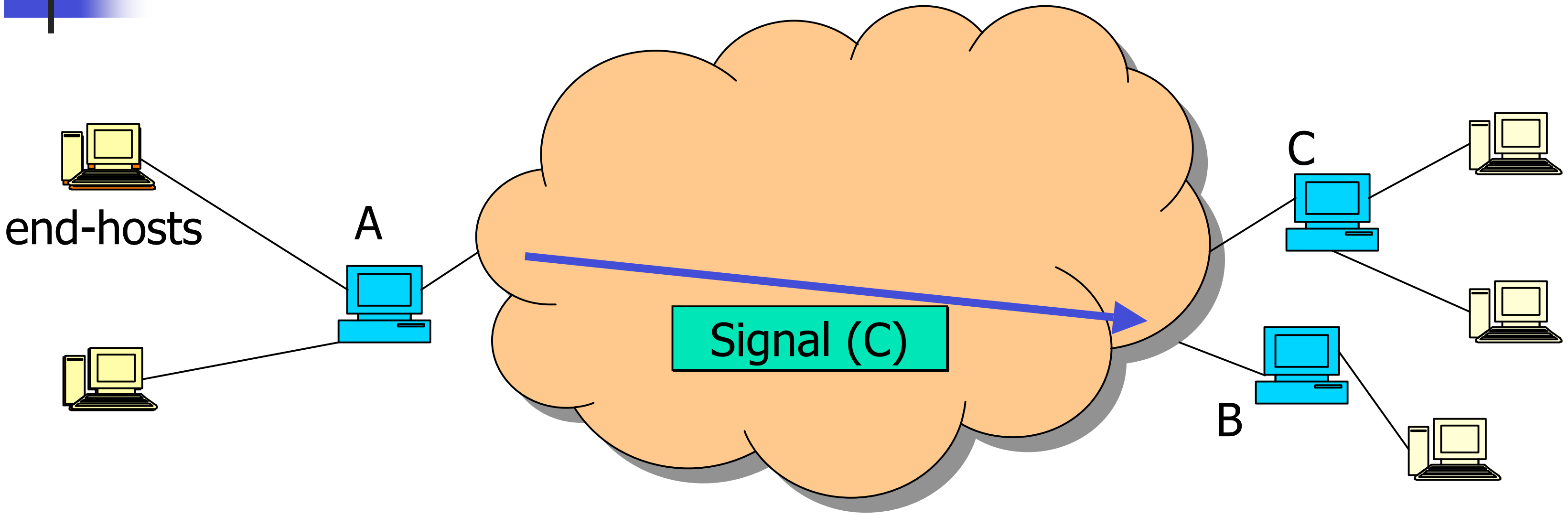
Signals Sent

Alerted/Uninfected

Model of Signaling

- Two kinds of signaling:
  - Implicit: Piggyback signals on outgoing packets
  - Explicit: Signals addressed to other firewalls
- How to do robust signaling in face of malicious firewalls?

Robust Signaling



- Security parameter: T
  - Equivalent to using partial deployment state after receiving signals from T different firewalls
- **False Positives:**
  - Attack: A sends signal to B claiming C is infected
  - Defense: Challenge-response "Verification" of signals
- **False Negatives:**
  - Attack: Firewall suppresses signal when infected
  - Even if about 25% firewalls behave this way, good containment is possible

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Analytical results

- Main focus: Containment metric C:
    - C = fraction of networks that escape infection
- Cost of Decentralization
    - Effect of type of signaling:
    - Dependence of containment on signaling rate
    - Is Signaling Necessary?
- Effect of malice:
    - Dependence of containment on Threshold T

Parameters used in analysis

- Worm model:
  - Scanning: Topological scanning (zero time) followed by global uniform scanning
  - Scanning rate = **s**
  - Probability of successful probe = **p**
  - Vulnerable hosts uniformly distributed behind these firewalls, initial number of seeds small
- Local detection model:
  - After infection, the time required for the infection to be detected is an exponential variable with mean $\mathbf{t}_{d}$
- Signaling model:
  - Explicit signals sent at rate **E**

No Signaling

- Worm probes only in interval between “infection” and “detection”

- _ is the expected number of successful infections made by a infected network before detection
  - _ = p s t_d

- Result: If _ < 1, C = 1 for large N (WSP 04)
  - Analogy to birth-death process
- Implications
  - Earlier worms like Blaster satisfied this constraint

No Signaling (2)

- Surprisingly, even if _>1, containment possible without signaling for **random** scanning worm

- Intuition:
  - As the infection proceeds, harder to find new victims
  - _ (= p s t_d) effectively decreases over time

- For _ = 1.5, about 40% containment
- For _ = 2.0, about 20% containment
  - _ = O(2) for a Slammer-like worm

Need for Signaling

- Signaling required if _ > 1

- Differential equation model

- For _ > 1 and _ = (_-1)/t_d , the containment metric C is lower-bounded by

$$1 - \frac{(log(N)+(T-1)log(log(N)))t_d\sigma^2)}{(s+E)}(\frac{1}{t_d\sigma} + 1)$$

Need for Signaling (2)

- Implicit Signaling:
  - Spread rate of worm (ps) outpaced by signaling rate (s)
  - Implicit signaling relies on (p << 1)
  - Linear drop with time to detection (t_d)
  - Linear drop with threshold (T)
- Explicit Signaling:
  - Explicit signals essential for high p
  - Linear drop with 1/E
  - Tunable parameter

Summary

- _ < 1: no signaling required for good containment
- _ >= 1: without signaling, only moderate containment
- _ >= 1, low p: implicit signaling works
- _ >= 1, high p: explicit signaling required

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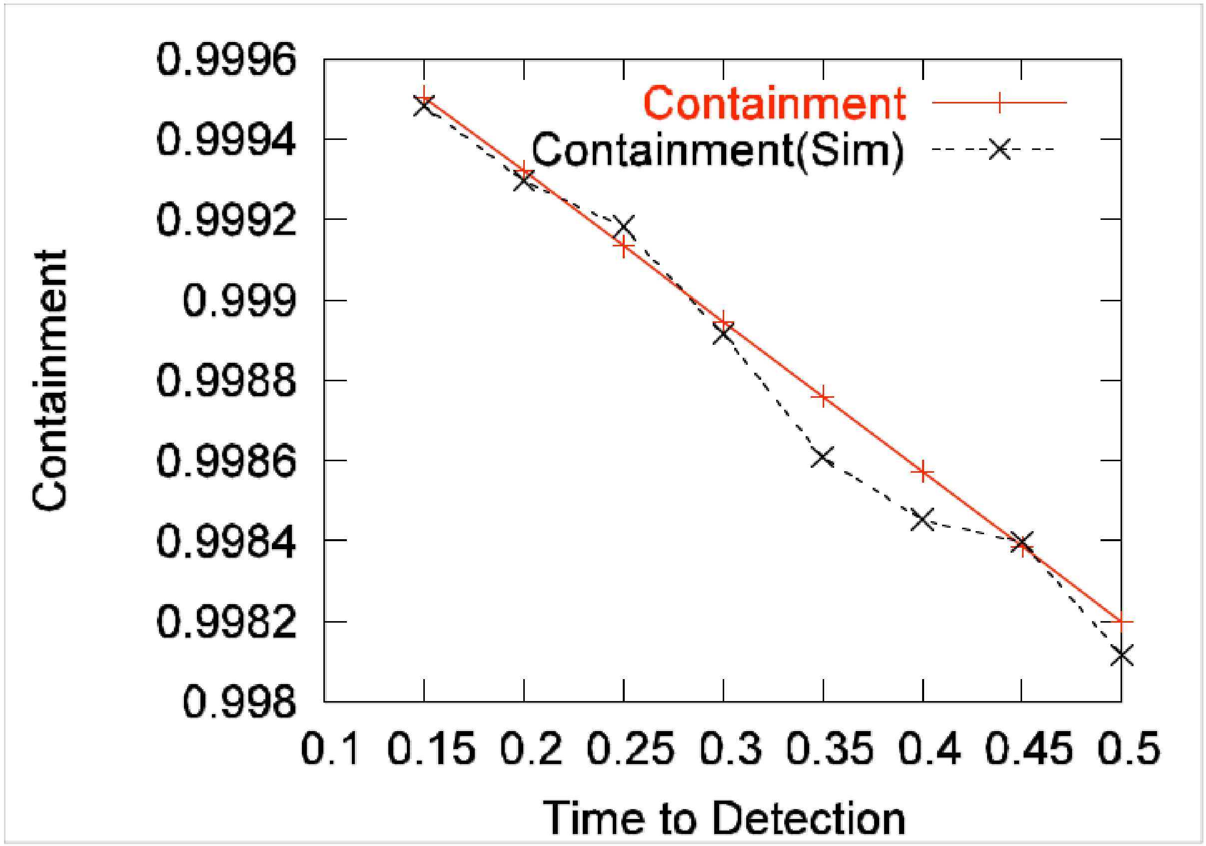
Numerical Results

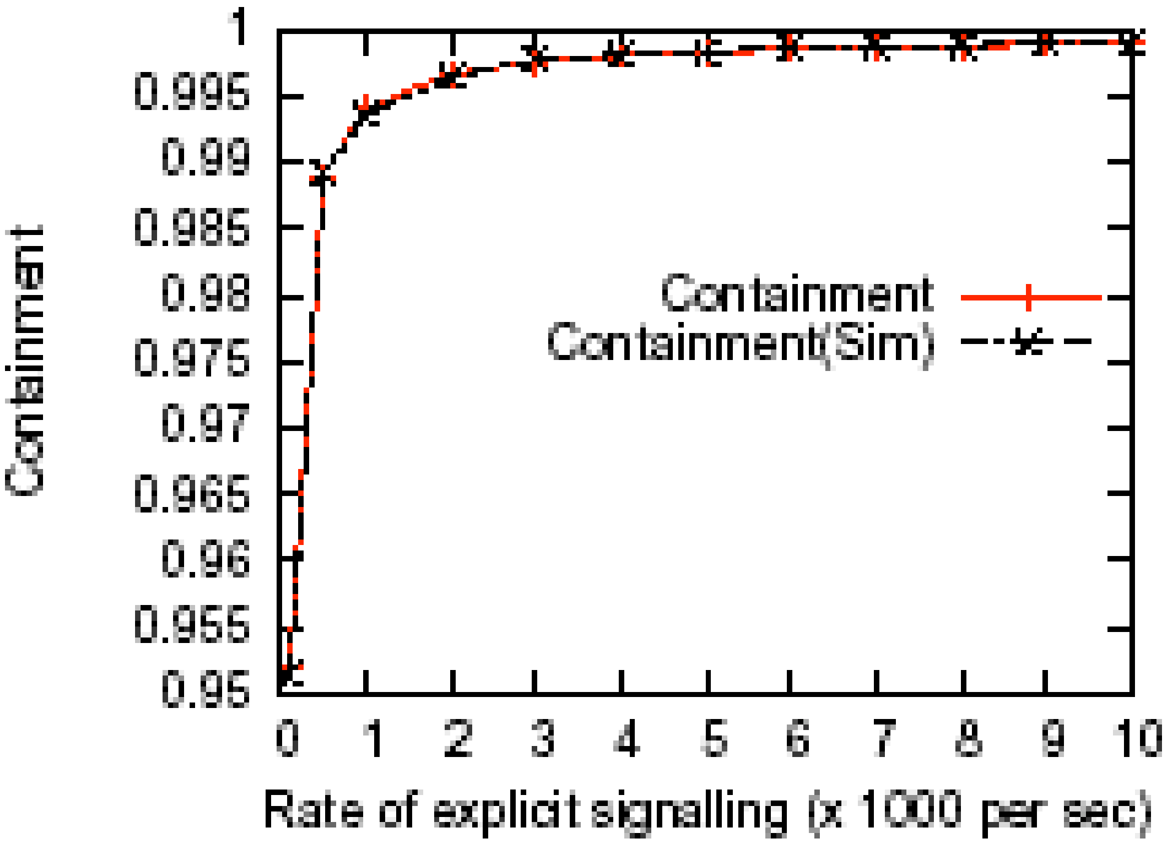
- Parameter Settings:
  - Scan rate set to that of Slammer
  - Size of vulnerable population = 2 x Blaster
  - 100,000 networks: 20 vulnerable hosts per network
  - Start out with 10 infected networks and track worm propagation
  - Time to infect is about 2 secs

Cost of Decentralization



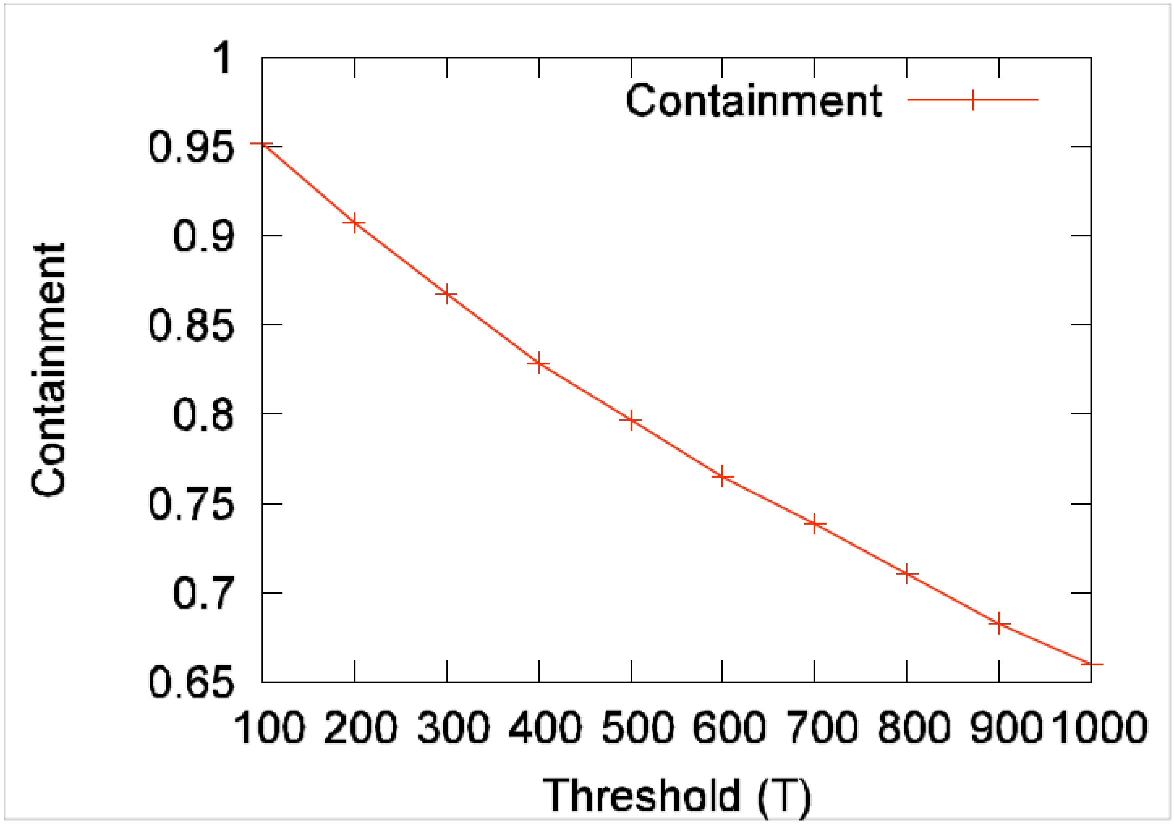
Higher the detection time, lower the containment

Cost Of Decentralization (2)



Even for low explicit signaling rate, good containment

Effect of Malice

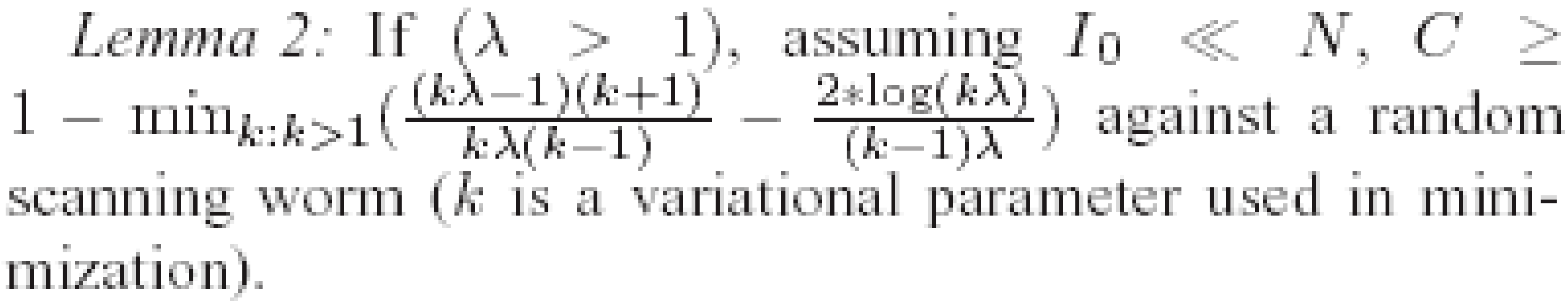


Defends against a few hundred malicious firewalls

Conclusion

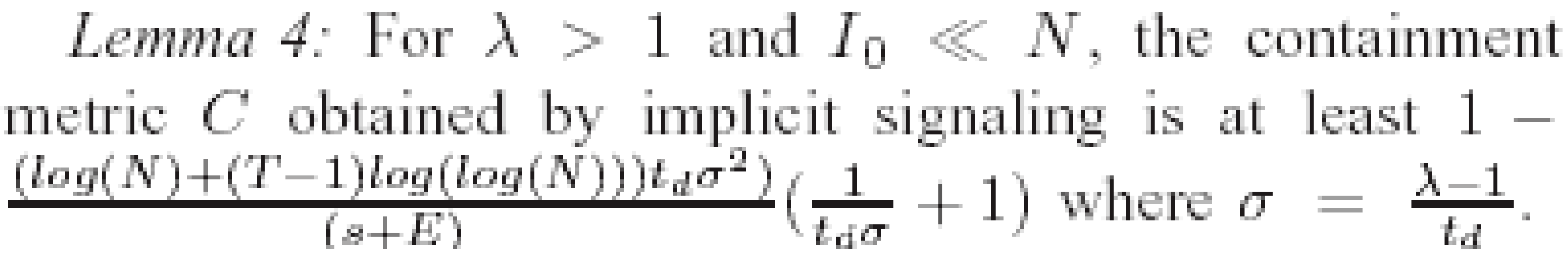
- Contribution: Characterize necessity, efficacy, and limitations of cooperative worm containment
- Cost of Decentralization:
  - With moderate overhead, good containment can be achieved
- Effect of Malice:
  - Can handle a few hundred malicious firewalls in the cooperative
- Cost of Deployment:
  - Even with deployment levels as low as 10%, good containment can be achieved

Detection and Filtering



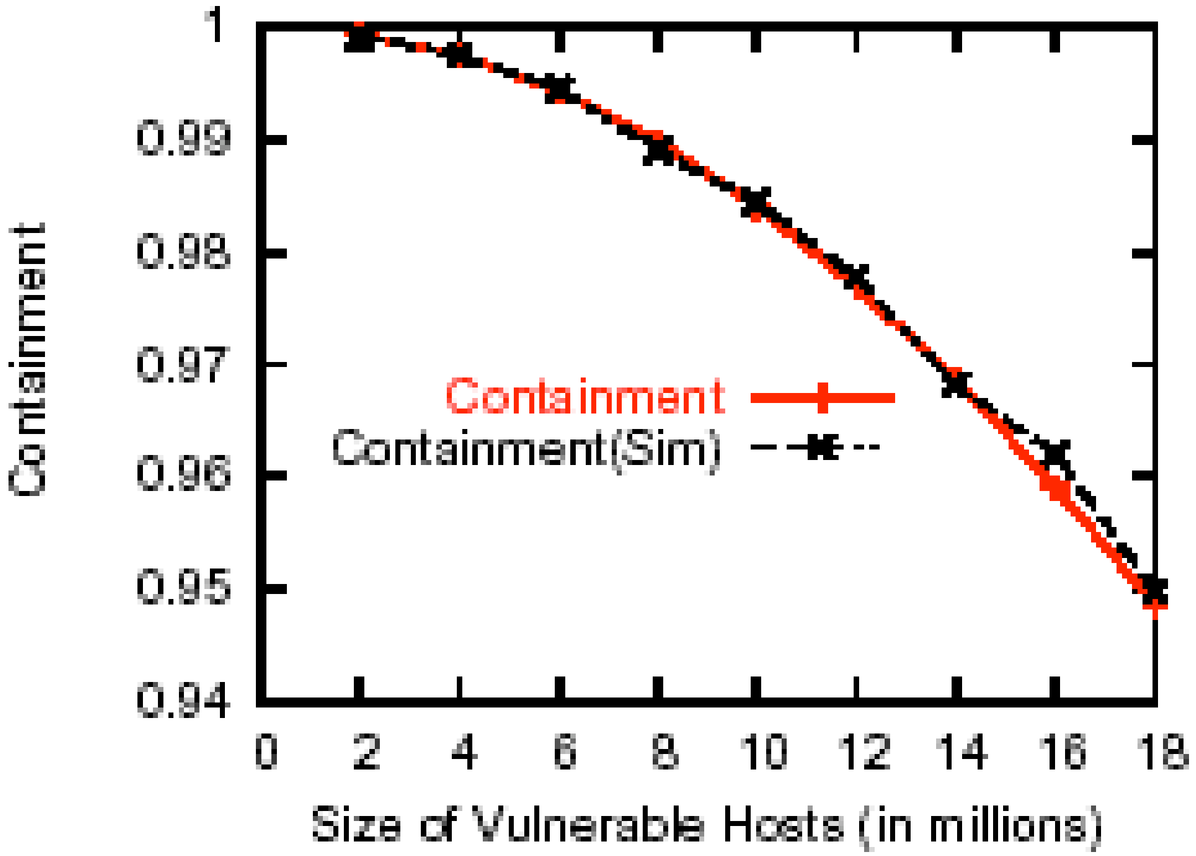
Lemma 2: If $(\lambda > 1)$, assuming $I_0 \ll N$, $C \geq 1 - \min_{k:k>1}\left(\frac{(k\lambda-1)(k+1)}{k\lambda(k-1)} - \frac{2*\log(k\lambda)}{(k-1)\lambda}\right)$ against a random scanning worm (k is a variational parameter used in minimization).

Signaling

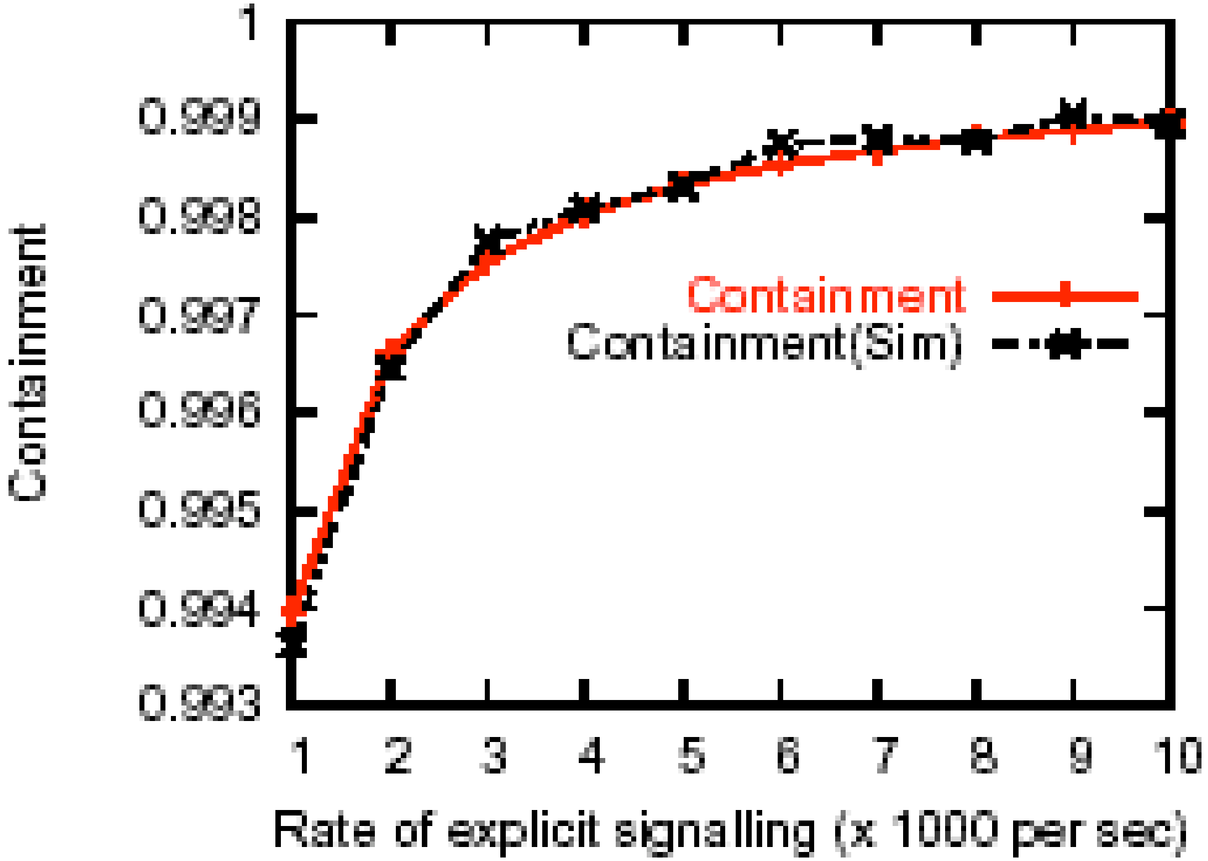


Lemma 4: For $\lambda > 1$ and $I_0 \ll N$, the containment metric C obtained by implicit signaling is at least $1 - \frac{(log(N)+(T-1)log(log(N)))t_d\sigma^2)}{(s+E)}(\frac{1}{t_d\sigma}+1)$ where $\sigma = \frac{\lambda-1}{t_d}$.

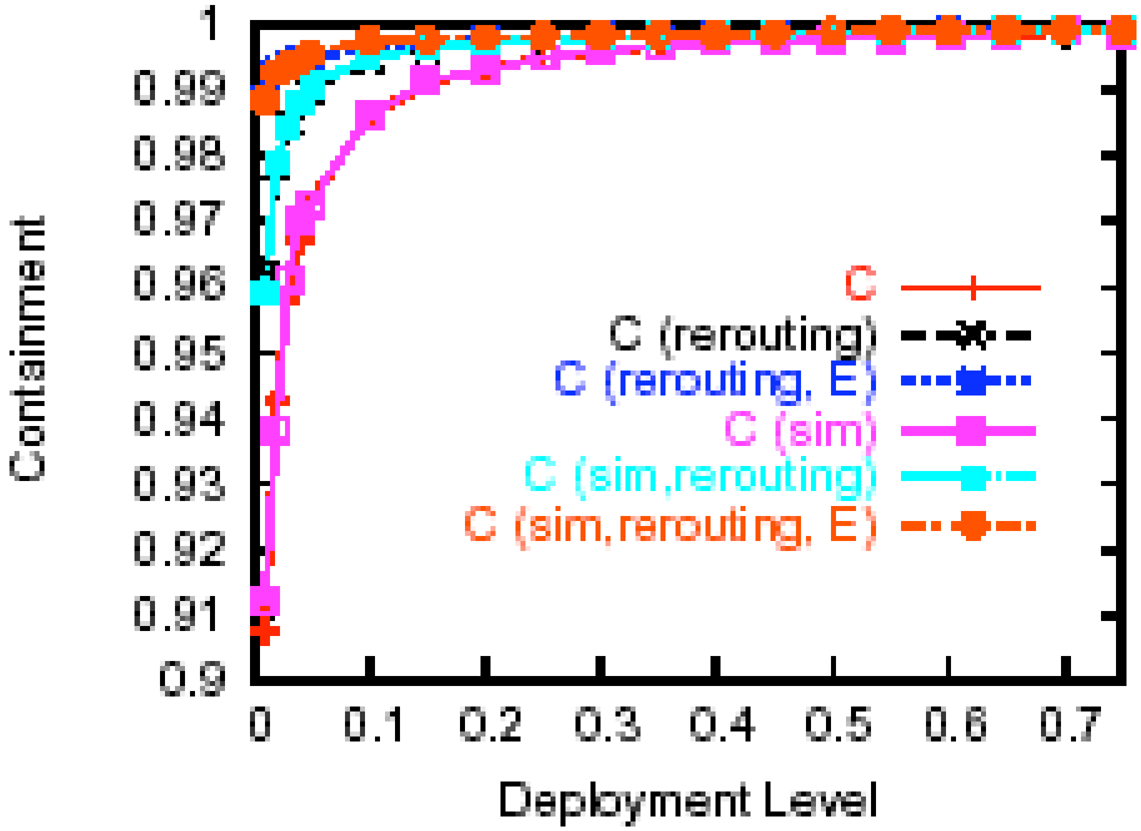
Containment vs Vulnerable population size



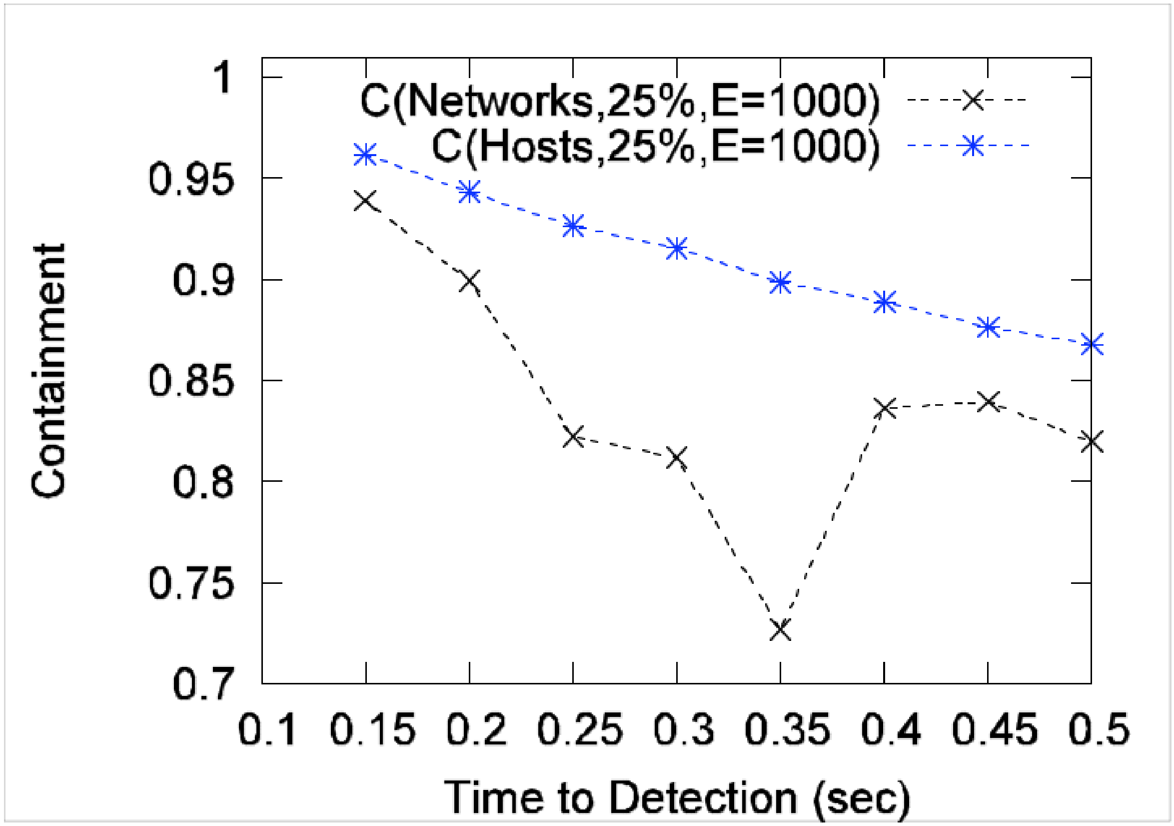
Containment vs Signaling Rate



Containment vs Deployment



Internet-like Scenario



Works well even under non-uniform distributions

Conclusions

- Main result: with moderate overhead, cooperation can provide good containment even under partial deployment
  - For earlier worms, cooperation may have been unnecessary
  - Required for the fast scanning worms of today
- Our results can be used to benchmark local detection schemes in their suitability for cooperation
- Our model and results can be applied to:
  - Internet-level / enterprise-level cooperation
  - More sophisticated worms like hit-list worms
- Room for improvement in terms of robustness
  - Verifiable signals
- Hybrid architecture:
  - Fit in “well-informed” participants in the cooperative