Forensic Investigation of the OneSwarm Anonymous FileSharing System

Swagatika Prusty
Brian Neil Levine   Marc Liberatore

http://forensics.umass.edu

Dept. of Computer Science
UMass Amherst

This work was supported in part by NSF award CNS-1018615

Forensic Investigation and P2P Systems

Why investigate?

- Primary Use of P2P Systems: File Sharing

- Social and legal concern when used for sharing files containing child pornography (CP).

- **Goal** of forensic investigation is to acquire enough evidence to support a warrant.

  - To acquire evidence, meeting "**probable cause**" standards that an IP address is associated with possession or distribution of CP.

“Probable Cause” for Search Warrant

- The standard by which an officer or agent of the law has grounds to obtain a search warrant.
- P2P communications observed by law enforcement are in “plain view” and not protected by the 4th Amendment.
- This plain view evidence becomes the probable cause that permits search and seizure at a physical location.
- "Probable cause” is not quantitatively defined.
  - “a fair probability”

State of the Art

- Law Enforcement tries to identify and gather evidence against peers responsible for distribution of CP.

- Gnutella and other P2P networks are actively monitored by law enforcement:
  - Investigators join P2P network as ordinary peers.
  - They query for CP files.
  - Get replies directly from peers that possess these files.
  - This reveals the IP address of peers sharing CP.
  - With a subpoena, they track down a physical location.
  - Finally, a warrant is issued now that the “probable cause” standard is met.

The Challenge

- Investigations are thwarted in anonymity systems.
- Network identity of query originators and data sources is obscured.

- **OneSwarm** is one such P2P system designed with the goal of privacy preservation.
  - [Isdal et al., ACM SIGCOMM 2010]
  - An attractive venue for trafficking in child pornography files.

- **Can plain view evidence sufficient for probable cause be acquired from OneSwarm?**

Our Contributions

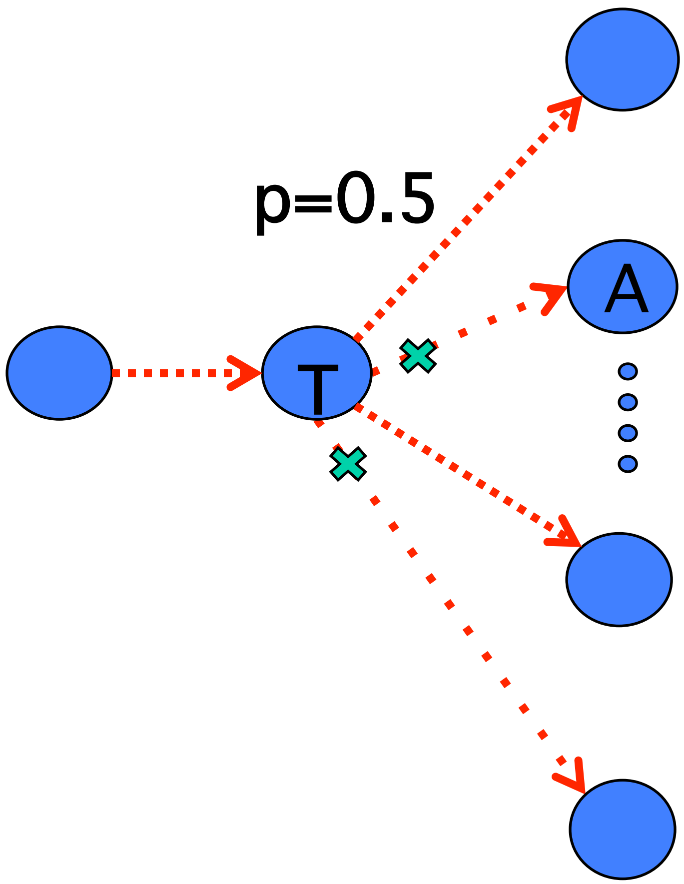
- We developed techniques for identification of peers sharing child pornography in the OneSwarm network.
  - Our techniques work within the constraints of criminal procedure.
  - In general, our techniques allows anybody to identify sources of files of interest.
    - Civil investigations (MPAA) for copyright infringement have a lower standard to meet than we do here.
  - We prove that OneSwarm does not sufficiently provide anonymity against third party monitoring.

Brief Overview of OneSwarm

- It is an anonymous P2P file sharing system.
- Message Routing
  - Peers search for files by sending keyword/infohash queries.
  - **Queries** for files are **forwarded** until sources are found.
  - **Reply** travels along the **reverse path** of search query.
- Trust Relations
  - A peer can categorize its neighbors as either "**trusted friends**" or **"untrusted friends**".
  - A peer subscribes to a **community server** that assigns links to up to 39 untrusted friends.
  - A peer can add its real-world friends as "trusted friends" on OneSwarm by out-of-band methods.
    - Google talk import, LAN import or manual public key exchange.

OneSwarm: Anonymity Mechanisms

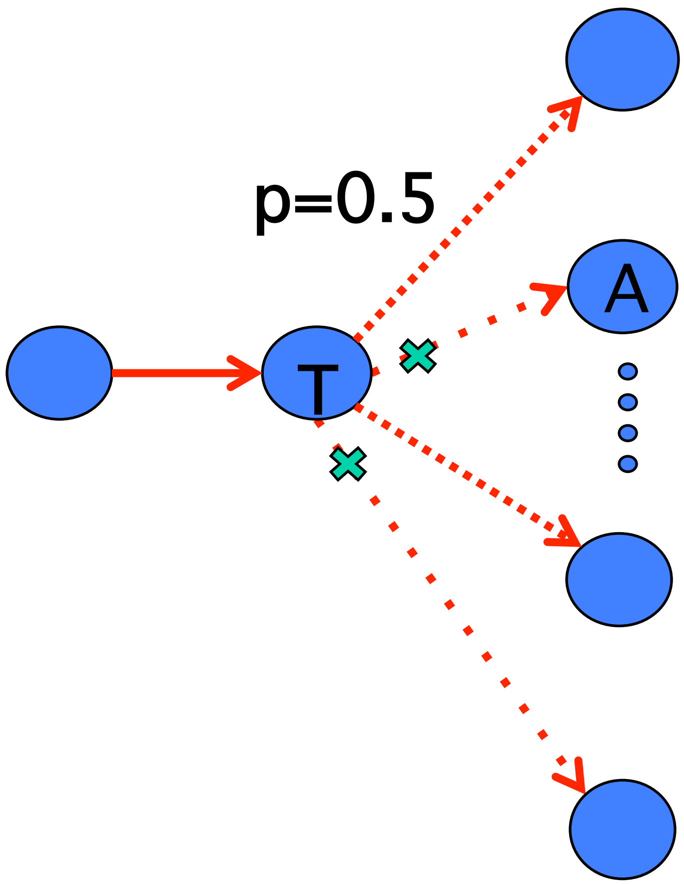
Probabilistic Query Forwarding



1. A peer sends a query to its neighbors.
2. If the query receiving peer has the requested file, it replies back.
3. Else, it **forwards** the query to its neighbors **with probability p.**
4. This thwarts **Collusion Attack**.

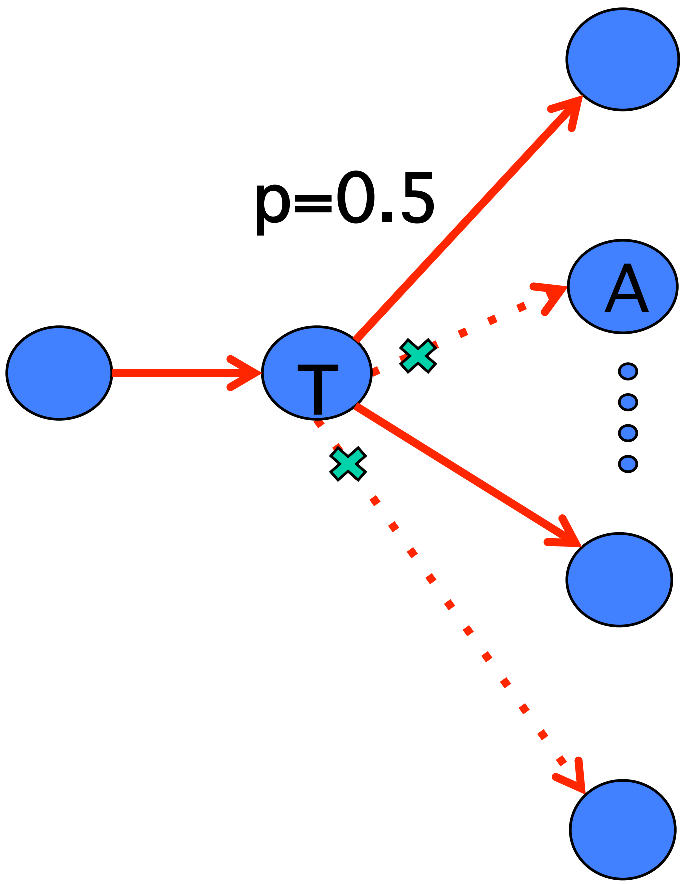
OneSwarm: Anonymity Mechanisms

Probabilistic Query Forwarding



1. A peer sends a query to its neighbors.
2. If the query receiving peer has the requested file, it replies back.
3. Else, it **forwards** the query to its neighbors **with probability p.**
4. This thwarts **Collusion Attack**.

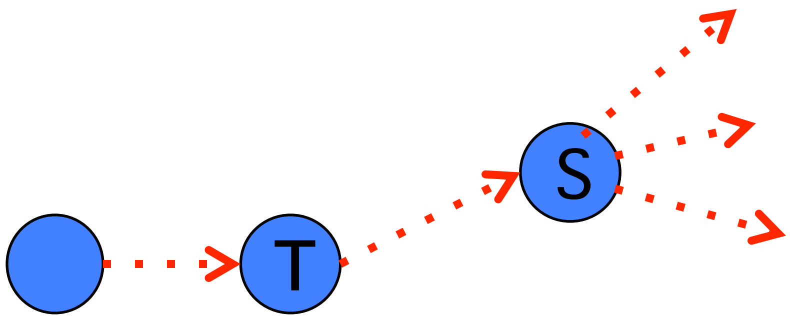
Probabilistic Query Forwarding



1. A peer sends a query to its neighbors.
2. If the query receiving peer has the requested file, it replies back.
3. Else, it **forwards** the query to its neighbors **with probability p.**
4. This thwarts **Collusion Attack**.

OneSwarm: Anonymity Mechanisms

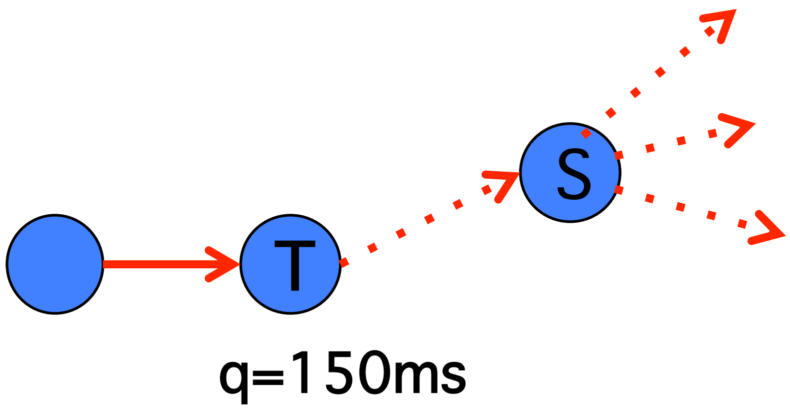
Untraceable Queries



1. Queries do not contain a Time-Time-Live field.
   - Avoids traceback and attribution.
2. **Search Cancel** messages are introduced.
3. Queries are forwarded only after a **delay of 150ms**.
4. Cancel messages aren't delayed.
5. This delay allows "search cancel" messages to catch up, mitigating flooding

OneSwarm: Anonymity Mechanisms

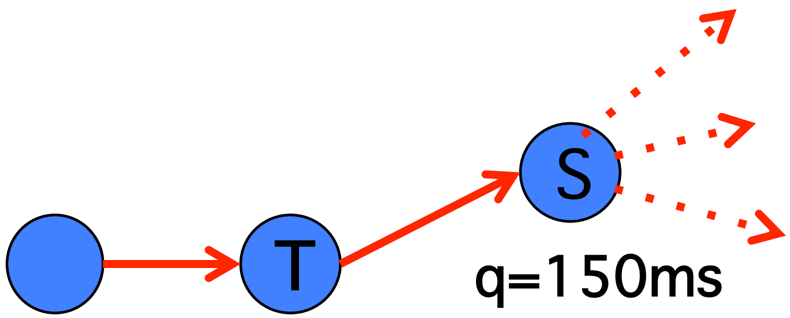
Untraceable Queries



1. Queries do not contain a Time-Time-Live field.
   - Avoids traceback and attribution.
2. **Search Cancel** messages are introduced.
3. Queries are forwarded only after a **delay of 150ms**.
4. Cancel messages aren't delayed.
5. This delay allows "search cancel" messages to catch up, mitigating flooding

OneSwarm: Anonymity Mechanisms

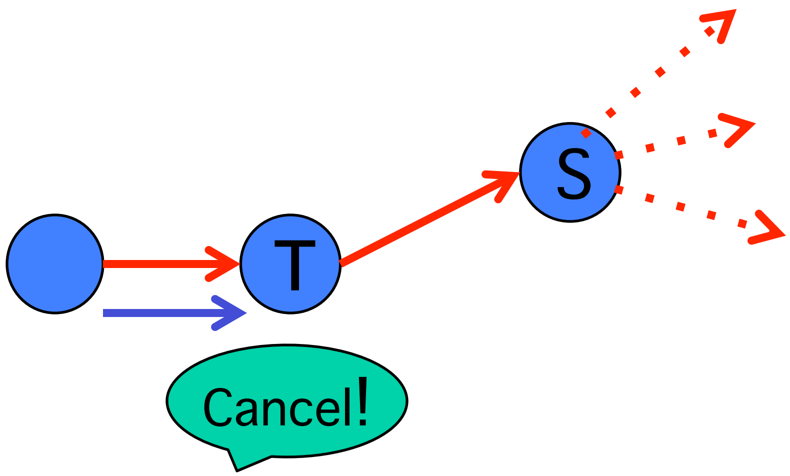
Untraceable Queries



1. Queries do not contain a Time-Time-Live field.
   - Avoids traceback and attribution.
2. **Search Cancel** messages are introduced.
3. Queries are forwarded only after a **delay of 150ms**.
4. Cancel messages aren't delayed.
5. This delay allows "search cancel" messages to catch up, mitigating flooding

OneSwarm: Anonymity Mechanisms

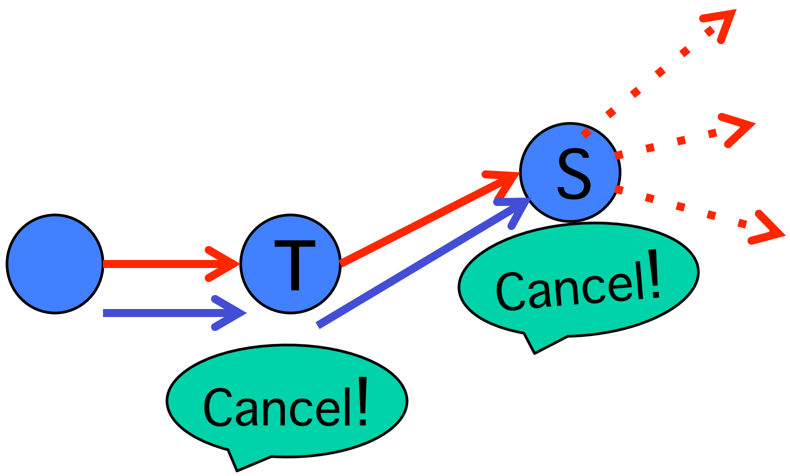
Untraceable Queries



1. Queries do not contain a Time-Time-Live field.
   - Avoids traceback and attribution.
2. **Search Cancel** messages are introduced.
3. Queries are forwarded only after a **delay of 150ms**.
4. Cancel messages aren't delayed.
5. This delay allows "search cancel" messages to catch up, mitigating flooding

OneSwarm: Anonymity Mechanisms

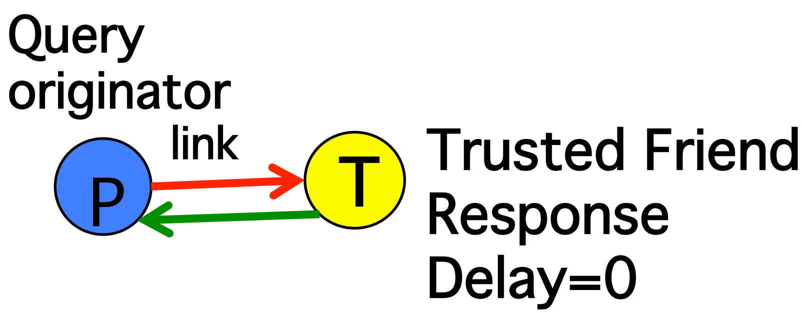
Untraceable Queries



1. Queries do not contain a Time-Time-Live field.
   - Avoids traceback and attribution.
2. **Search Cancel** messages are introduced.
3. Queries are forwarded only after a **delay of 150ms**.
4. Cancel messages aren't delayed.
5. This delay allows "search cancel" messages to catch up, mitigating flooding.

OneSwarm: Anonymity Mechanisms

Delayed Response to Untrusted Friends

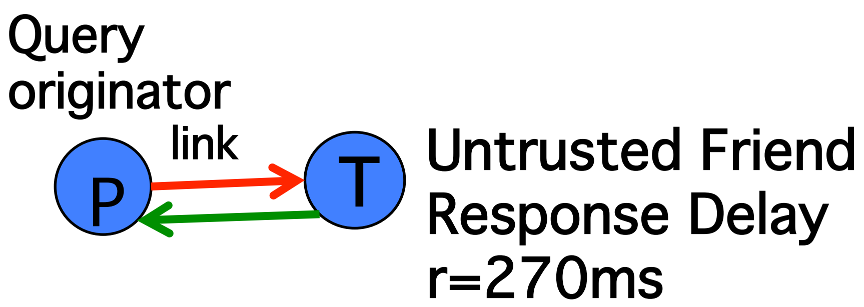


- **T, trusted friend of P, is source.**
  Response Time=RTT

1. Delayed response to queries from untrusted peers.
2. **Basic timing attack is prevented.**
   - Receiving a reply in less than 150 ms would reveal the responder as a data source to potentially untrusted peers.
3. Delay value chosen between **150-300 ms** to emulate the delay of a longer path.

OneSwarm: Anonymity Mechanisms

Delayed Response to Untrusted Friends



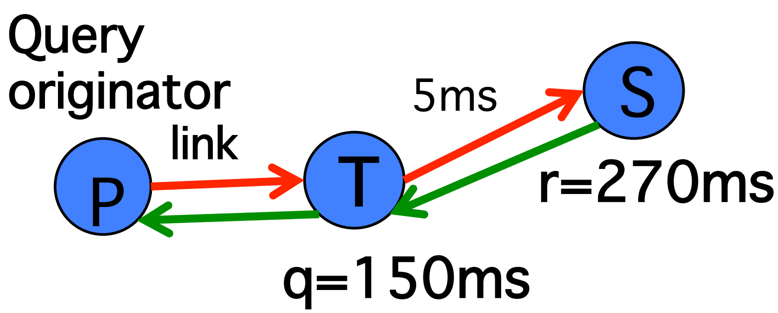
- **T, untrusted friend of P is source**

  Response Time= RTT+270

1. Delayed response to queries from untrusted peers.
2. **Basic timing attack is prevented.**
   - Receiving a reply in less than 150 ms would reveal the responder as a data source to potentially untrusted peers.
3. Delay value chosen between **150-300 ms** to emulate the delay of a longer path.

OneSwarm: Anonymity Mechanisms

Delayed Response to Untrusted Friends

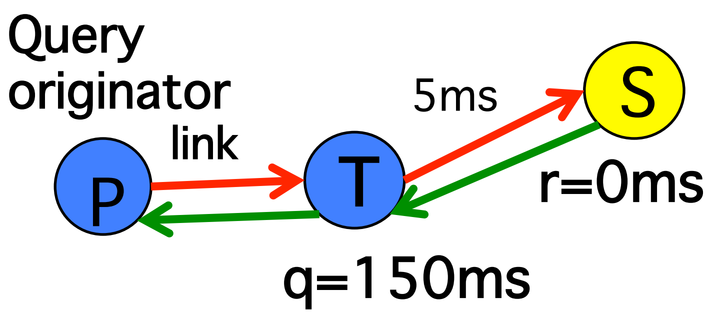


- T, untrusted friend of P is source
  Response Time= RTT+270
- **S, untrusted friend of T is source (2 hops from querier)**
  Response Time =
  RTT+q+2*5+r = RTT+430

1. Delayed response to queries from untrusted peers.
2. **Basic timing attack is prevented.**
   - Receiving a reply in less than 150 ms would reveal the responder as a data source to potentially untrusted peers.
3. Delay value chosen between **150-300 ms** to emulate the delay of a longer path.

OneSwarm: Anonymity Mechanisms

Delayed Response to Untrusted Friends



- T, untrusted friend of P is source
  Response Time= RTT+270
- **S, trusted friend of T is source and is 2 hops away from querier**
  Response Time =
  RTT+q+2*5+r = RTT+160

1. Delayed response to queries from untrusted peers .
2. **Basic timing attack is prevented.**
   - Receiving a reply in less than 150 ms would reveal the responder as a data source to potentially untrusted peers.
3. Delay value chosen between **150-300 ms** to emulate the delay of a longer path.

OneSwarm : Trust Relationships

TRUSTED FRIENDS	UNTRUSTED FRIENDS
No delays when responding to queries from trusted friends.	Delays introduced for queries from untrusted friends.
Can see each others' file lists.	**Cannot** see each other's file list.

Outline

- Forensics applied to P2P filesharing systems ✔
- OneSwarm Overview ✔
- Attacks on OneSwarm
- Lessons learnt

Three Attacks that Allow Forensic Investigation

- We discovered three weaknesses in OneSwarm that allow forensic investigation of CP crimes:

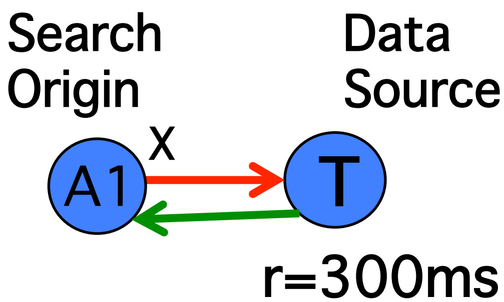
1. We identify a new **timing attack**.

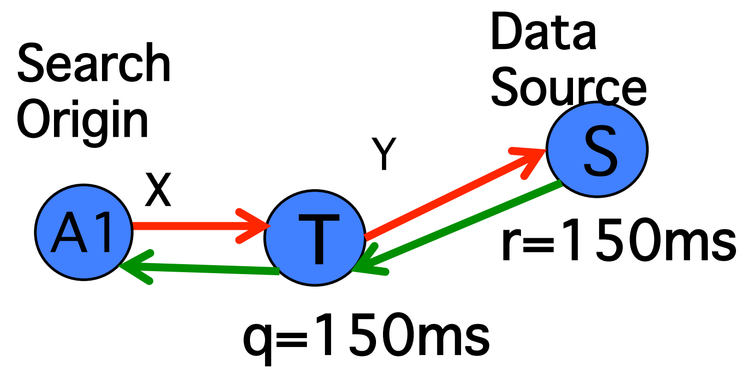
2. Correct **collusion attack** analysis to include file popularity.
   - For comparison: "achieving 95% precision requires that at least k = 6 attackers; chances of success, when C = 30 of the N = 1000 peers are attackers is much less than 1%."

3. Show novel application of a **TCP-based attack**.
   (not in this talk; detailed in paper.)

Timing Attack: Problem Statement

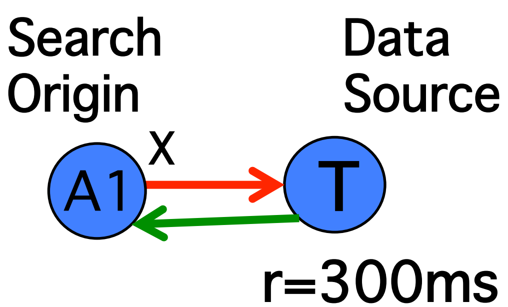
Scenario A OR Scenario B ?

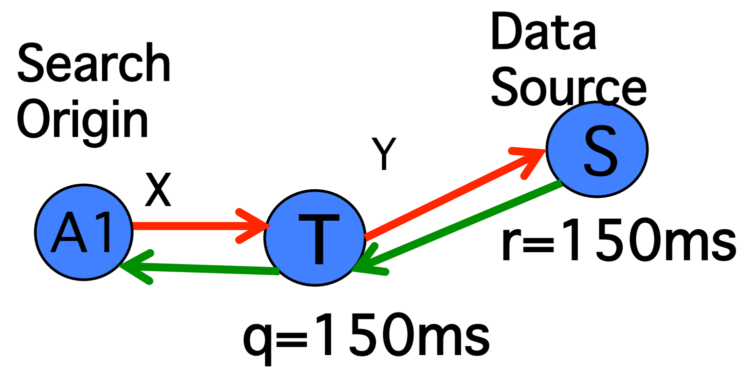




Timing Attack: Problem Statement

Scenario A OR Scenario B ?

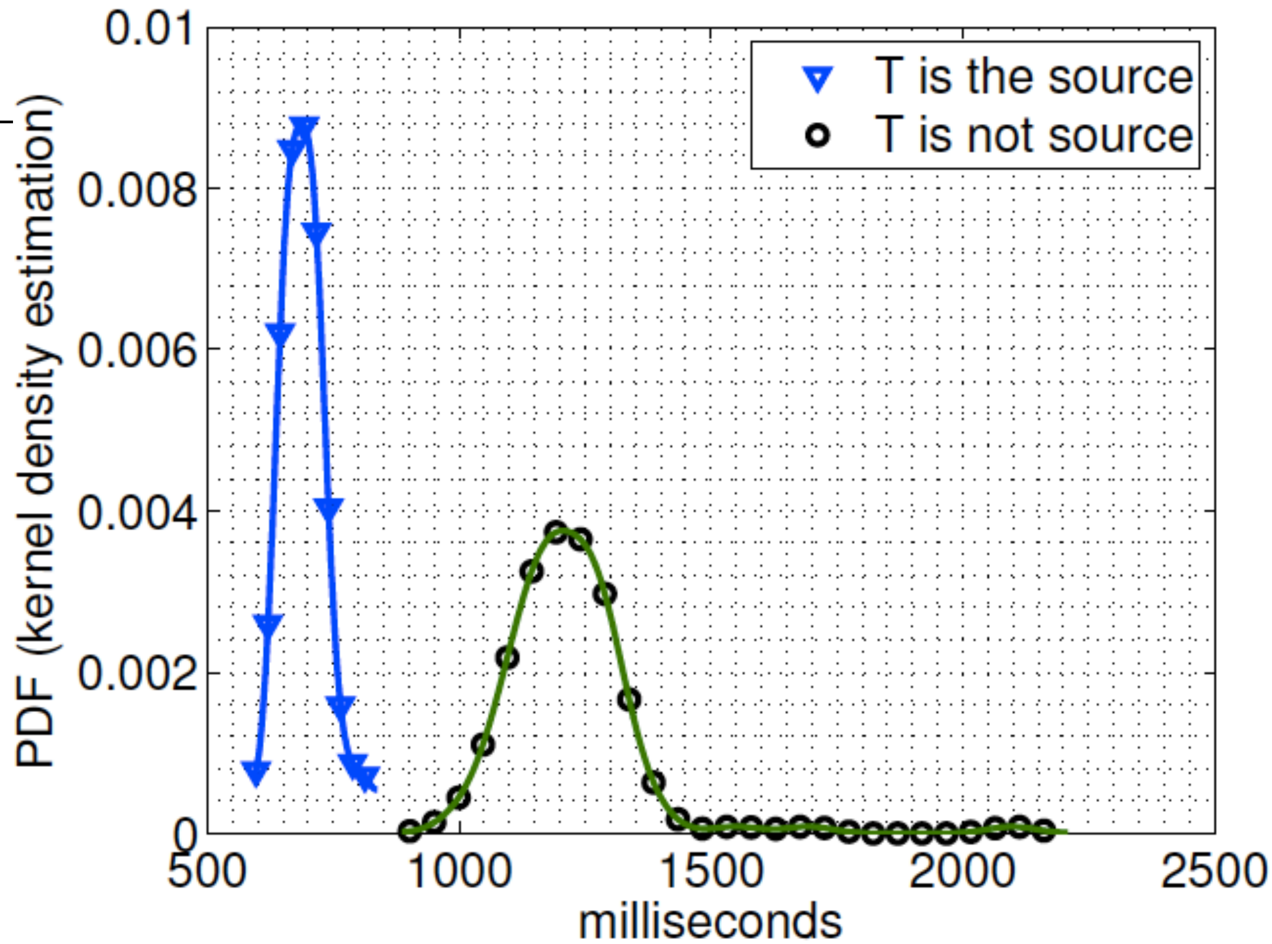




- **T is source:**
- Response Time, δ
- $\delta = RTT_X + r$
- **$(\delta - RTT_X)$** $\leq$ 300ms

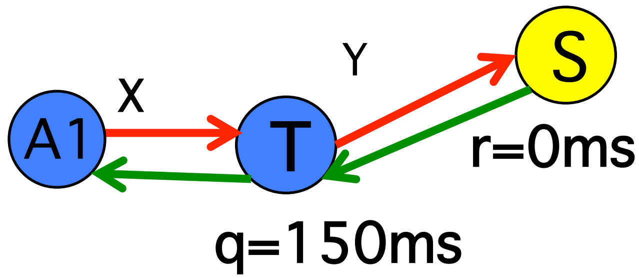
- **S is source:**
- S is untrusted friend of T
- Response Time, δ
- $\delta = RTT_X + q + RTT_Y + r$
- **$(\delta - RTT_X)$** $\geq$ 300ms

Timing Attack



- Real system has undocumented steps and delays
- But the attack still holds.
- The graph shows the attack carried out on a LAN.

Timing Attack : Trusted Friend Scenario



- **S is source:**
- S is trusted friend of T
- Response Time, δ
- $\delta = RTT_X + q + RTT_Y + r$
- **$(\delta - RTT_X)$** $= 150ms + RTT_Y$
  - This quantity can be less than or greater than 300!

Inference From Attack Result

Attack Result	Attacker's Conclusion	Actual Case
δ–RTT ≤ 300ms	Target is the source	Either target or its trusted friend is the source
δ–RTT > 300ms	Target is not the source	Target is not source

- **Net result:**
  - Sources are always detected correctly. (No False Negatives)
  - Trusted friend of source is sometimes detected as source.
    - This is not a false positive in context of criminal liability.

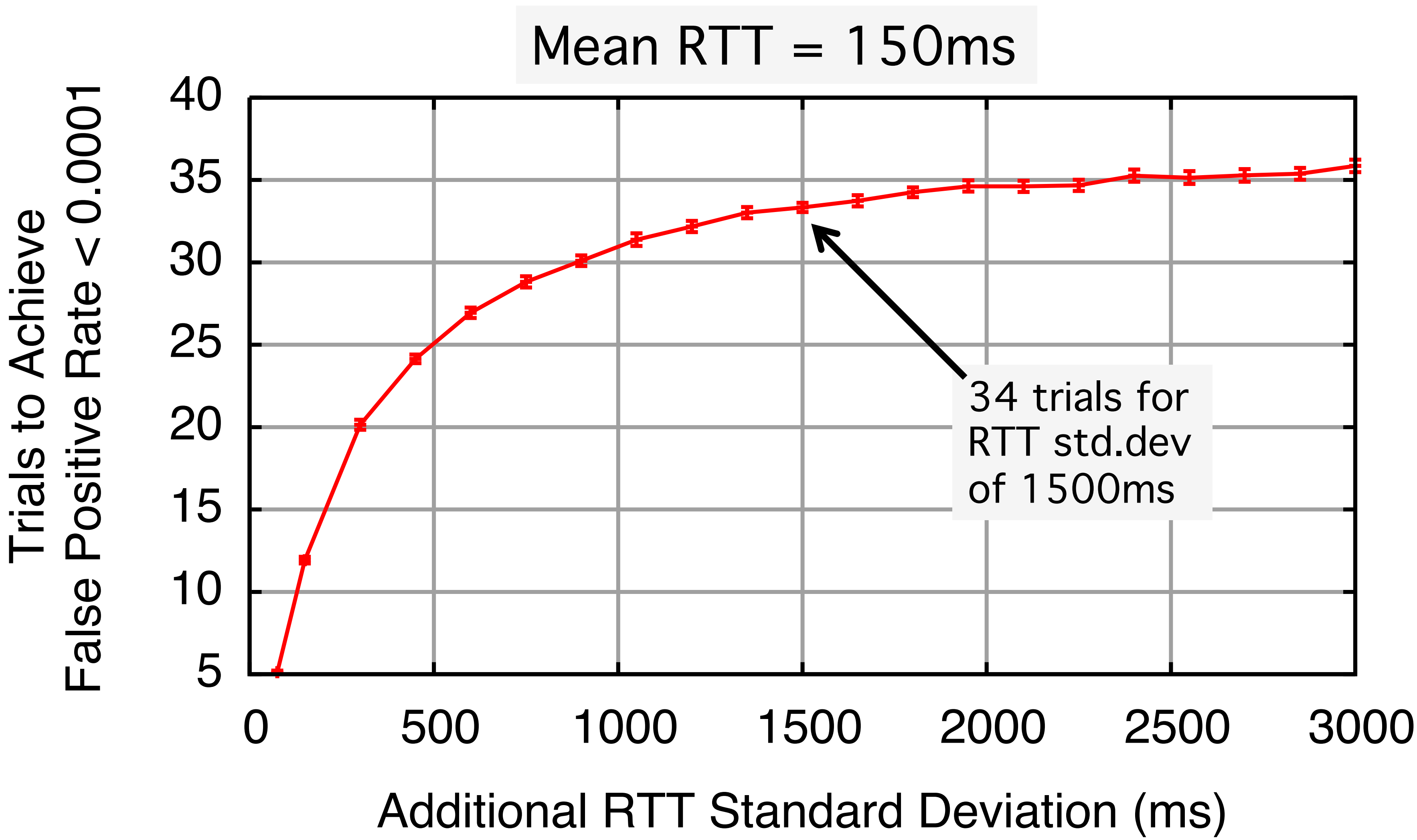
Trusted Relationship Raises Criminal Liability

- OneSwarm peer *knowingly* acts as a proxy for its trusted friend's shared files.
- OneSwarm peer can see the filenames (very explicit!) of its trusted peers in the GUI. Target is distributing CP with ***knowing intent***.
  - *See 18 U.S.C. § 2252A(b)(1).*
- Setting a trusted relationship gives target a non-pecuniary benefit of performance, which incurs greater punishment.
  - *see U.S. v. Schaefer, 472 F.3d 1219 sentencing memo, and U.S.S.G. § 2G2.2(b)(3)(B)*
- Evidence found at the target supports a search warrant of the trusted peer that is the actual source of CP.

Timing Attack: Feasibility and Success

- Requires just one attacker , all its neighbors are targets of investigation but one at a time
- Given network of *N* peers of which *C* are attackers:
  - **Hypergeometric CDF** gives probability that at least *k* of the *U* untrusted friends assigned by the Community Server are attackers.
- E.g., if attackers comprise 10% of OneSwarm network, 90% of the remaining peers are connected to one attacker.
- Attack has zero false positive rate and a 100% precision given that forensics goal is
  - to identify peers that either share CP files themselves
  - or are conspirators of the actual sources.

Does RTT variance affect attack success? No.



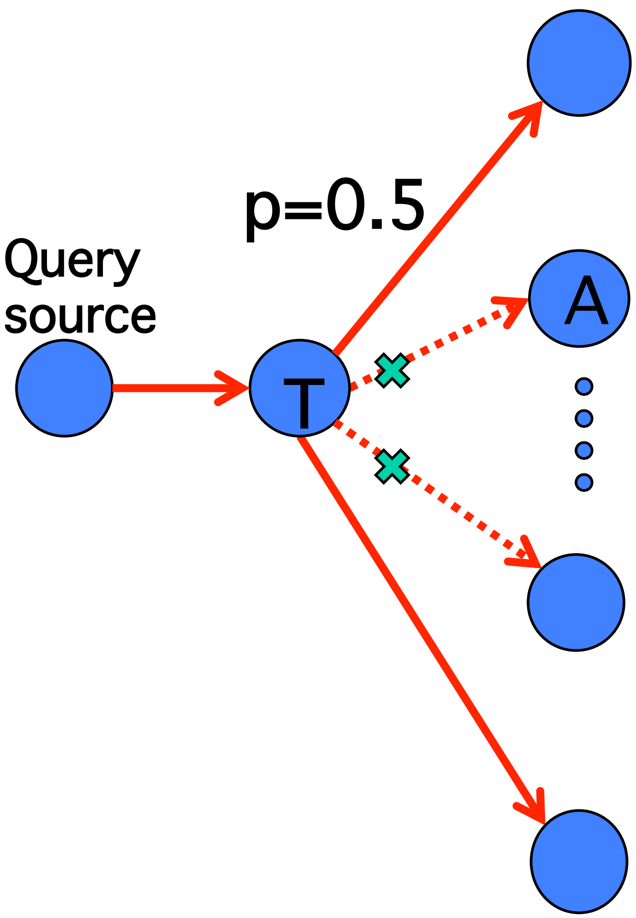
Timing Attack Defenses

- We prove that the attack is defeated if delays enforced by OneSwarm are modified.
- **Option 1:** increase source response delay, *r*?
  - Yes, but delays are 4 times worse than Onion Routing.
- **Option 2:** decrease query forwarding delays, *q*?
  - Yes, but then search cancel messages don't prevent flooding of queries to entire network.

- Detailed proof in paper; based on constraint satisfaction.

- In the end, to defeat the attack, minimal delays must be enforced that are higher than Onion Routing.
  - Reestablishes the tradeoff between privacy and performance.
  - OneSwarm does not achieve both.

Collusion Attack

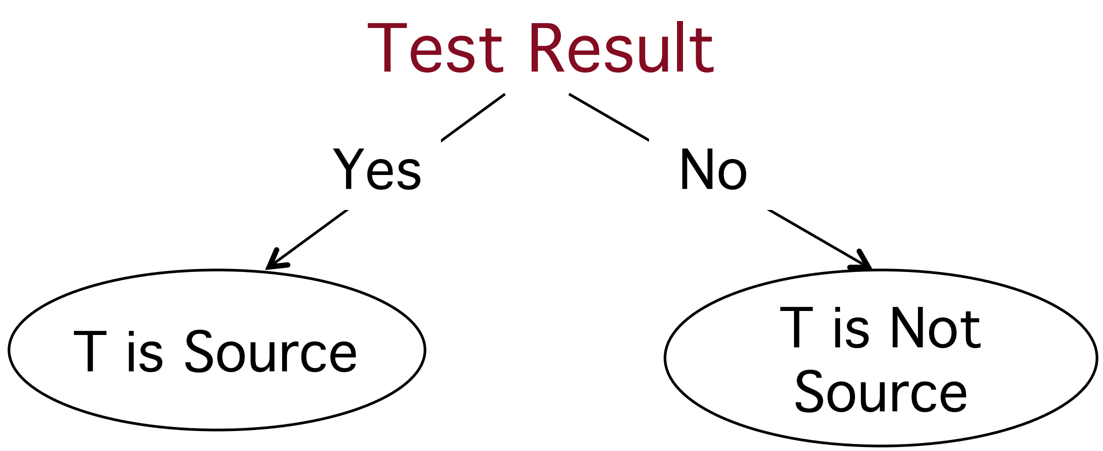


- Queries are sent to all neighbors
- If neighbor has the content:
  - query is **not** forwarded
- If doesn't have content:
  - Forwarding only with prob *p*.
- One attacker can't determine if T has content or just didn't forward.

- Smaller p: higher FPR, but harder to find content.
  - p=0.5 in the paper
  - p=0.95 in the source code.

Collusion Attack Classification Test

- Test Setting: k colluding attackers get connected to a target. One of them queries the target.
- Test: Do no colluders get a forwarded query?



- Twin Timing Attack was deterministic; this is probabilistic.
  - Prior probability of file possession is important.

Precision and False Positive Rate

- Given that the test concludes that T is the source, what is the probability that T is indeed the source?

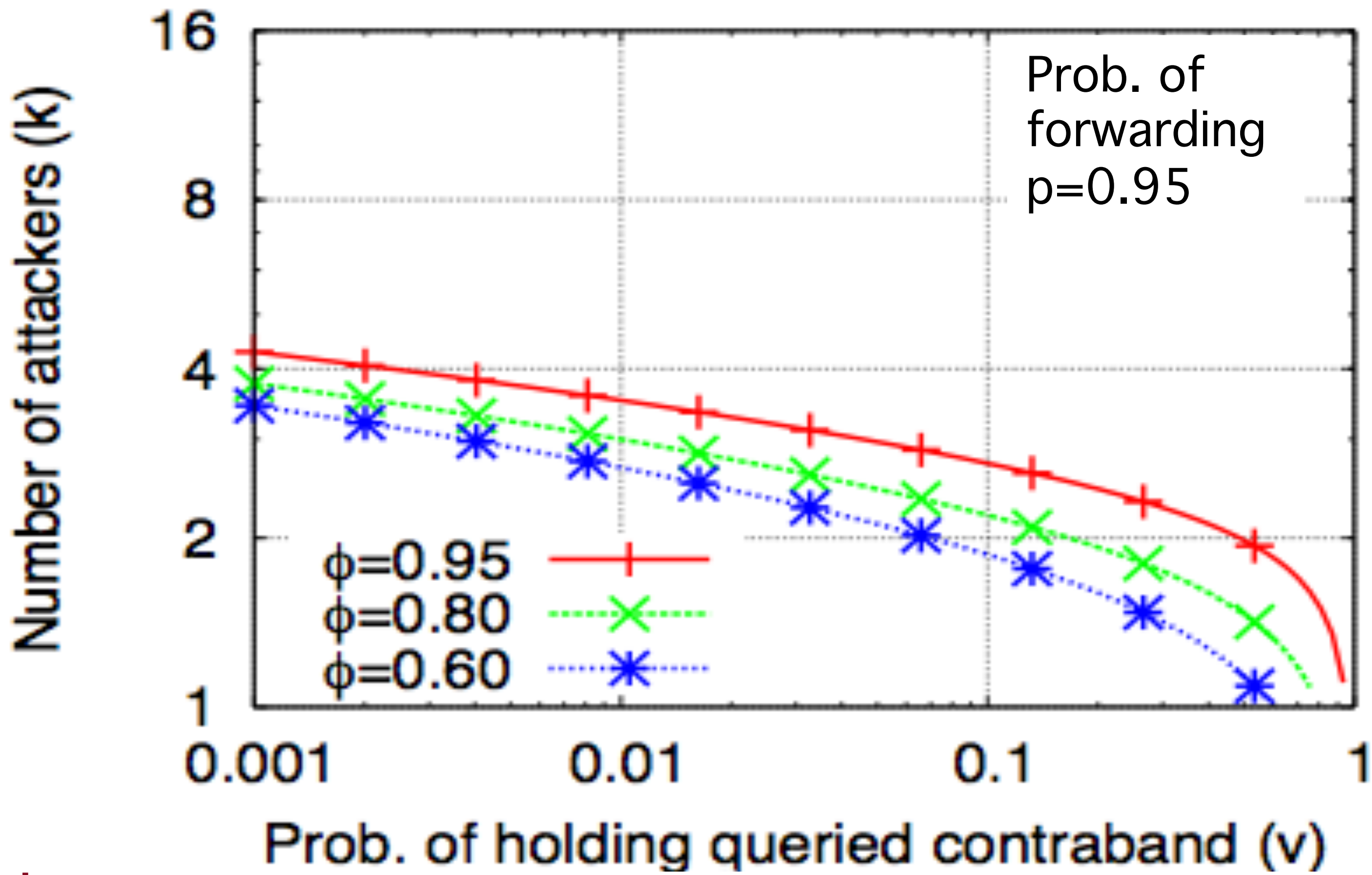
$$\text{Precision} = \frac{v}{v + (1-v)(1-p)^{k-1}}$$ (Applying Bayes' Rule)

k: Number of colluding attackers attached to the target
v : Probability that T has the file (content popularity)
p : Forwarding Probability

Probability that the test wrongly infers a non-source as source

$$fpr = (1-p)^{k-1}$$

Collusion Attack: Success and Feasibility



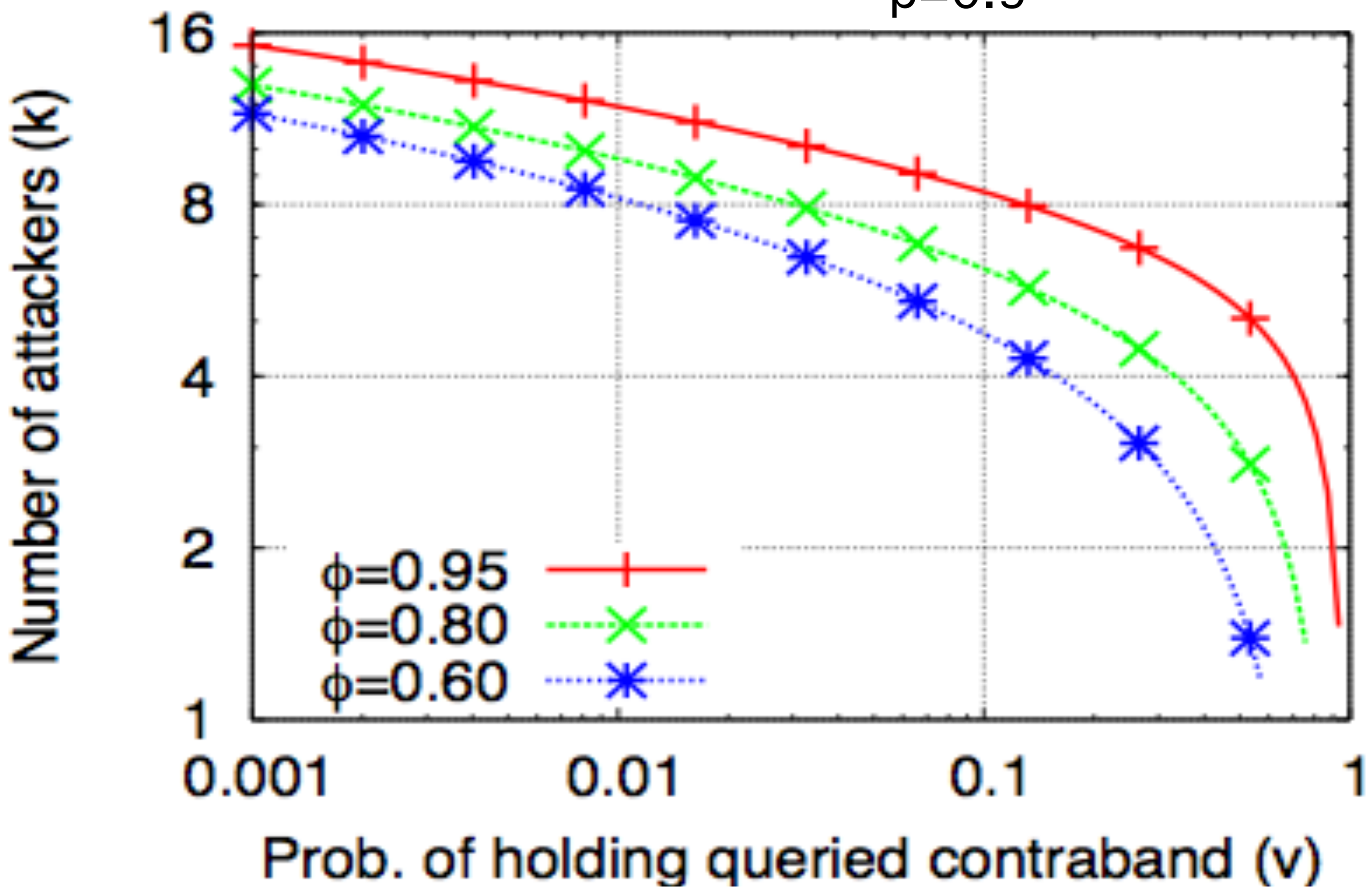
ϕ is precision

Collusion Attack: Success and Feasibility

- 4 colluding attackers are sufficient to acquire probable cause evidence for content that is sourced at only one in a hundred peers.
- False Positive Rate is less than 0.0025.

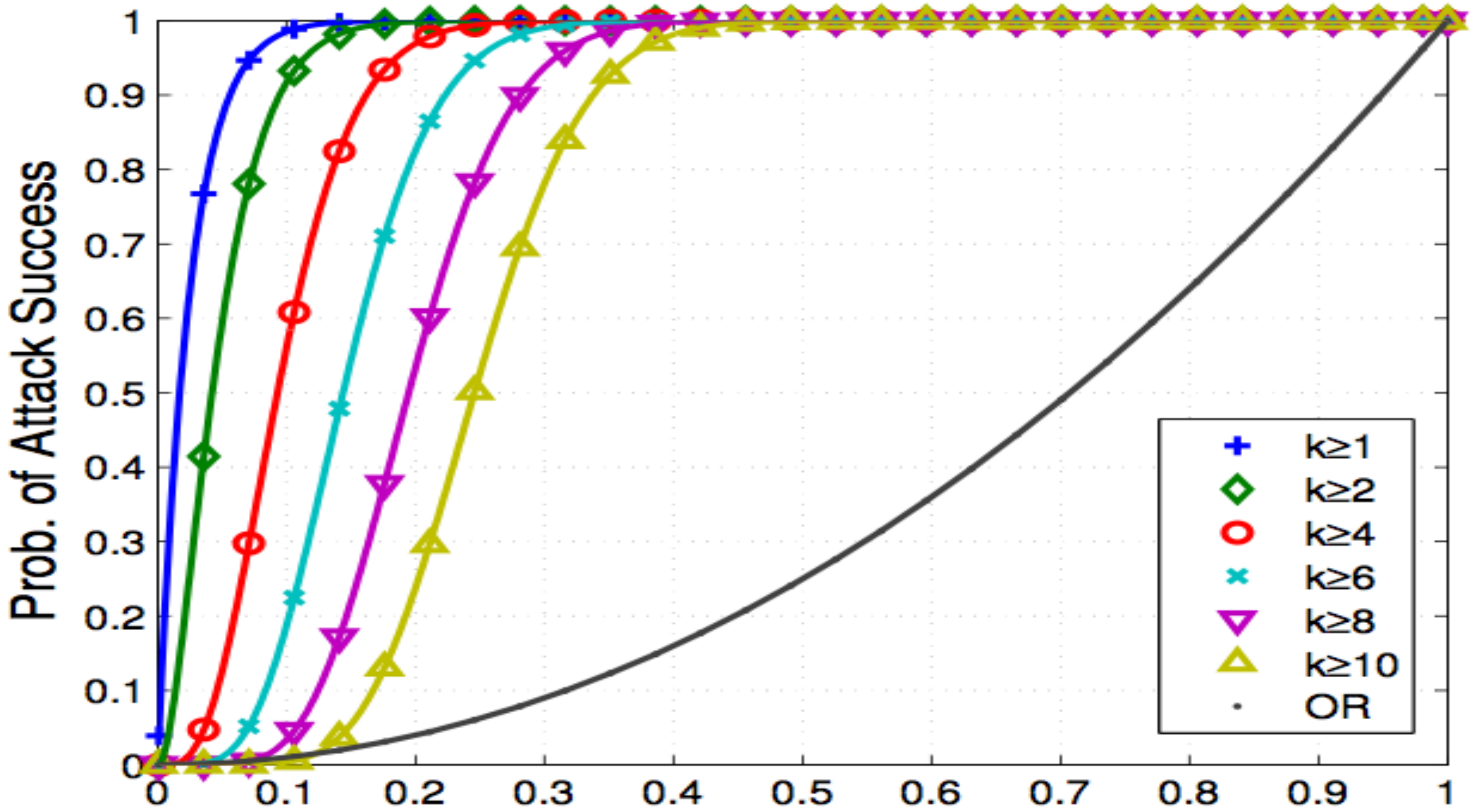
Collusion Attack: Success and Feasibility

Prob. of forwarding
p=0.5



ϕ is precision

Collusion Attack: Success and Feasibility



Fraction of Peers that are attackers

Collusion Attack: Success and Feasibility

- For p=0.5 (paper)
  - if investigators comprise 25% of the network
    - 50% of peers vulnerable (80% prec.; 1/100 content)
  - If investigators comprise 15% of the network
    - 5% of peers vulnerable (80% prec.; 1/100 content)
- For p=0.95 (software)
  - If investigations comprise 10% of the network:
    - 35% of peers vulnerable (95% prec.; 1/100 content)
  - If investigators comprise 25% of the network
    - 98% of peers vulnerable (95% prec.; 1/100 content)
- Investigators can easily rejoin.

Developer's Response

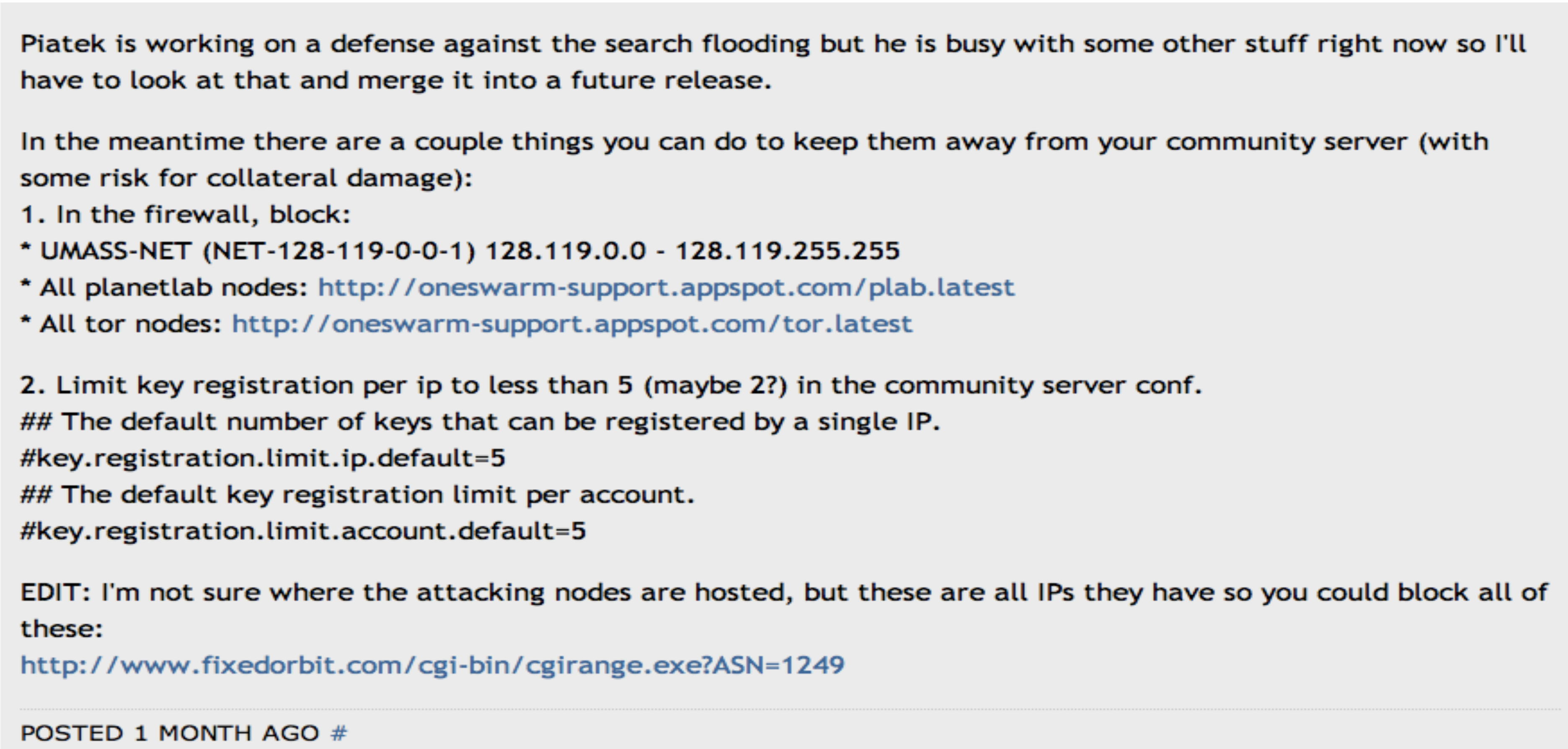
- Informed developers in May 2011
- In August, new version of OneSwarm was released
- It does not enforce delays required to defeat Timing Attack
- It has a reduced the probability of forwarding queries, back to p=0.5
  - Mitigates collusion attack, but does not prevent it for popular content
- It was suggested to blacklist all Tor IPs, PlanetLab IPs, and UMass IPs. (http://forum.oneswarm.org/topic/1927)

Conclusion

- We show that plain view evidence sufficient for probable cause can be acquired from OneSwarm.
  - Following a constrained criminal procedure.
  - Sybil attack increases effectiveness of single investigator.
  - Leveraging "trusted friends" introduces criminal liability rather than protecting privacy.
- Our work proves that OneSwarm design does not suffice to achieve complete anonymity and privacy preservation.
  - There is a tradeoff between privacy and performance which OneSwarm does not overcome.
- We introduced a new threat model, based on digital forensics and computer crime law.
  - All anonymity systems should take legal procedure and definitions into account when protecting privacy.

Appendix-a: Developers' Response

- http://forum.oneswarm.org/topic/1927



Piatek is working on a defense against the search flooding but he is busy with some other stuff right now so I'll have to look at that and merge it into a future release.

In the meantime there are a couple things you can do to keep them away from your community server (with some risk for collateral damage):
1. In the firewall, block:
* UMASS-NET (NET-128-119-0-0-1) 128.119.0.0 - 128.119.255.255
* All planetlab nodes: http://oneswarm-support.appspot.com/plab.latest
* All tor nodes: http://oneswarm-support.appspot.com/tor.latest

2. Limit key registration per ip to less than 5 (maybe 2?) in the community server conf.
The default number of keys that can be registered by a single IP.
#key.registration.limit.ip.default=5
The default key registration limit per account.
#key.registration.limit.account.default=5

EDIT: I'm not sure where the attacking nodes are hosted, but these are all IPs they have so you could block all of these:
http://www.fixedorbit.com/cgi-bin/cgirange.exe?ASN=1249

POSTED 1 MONTH AGO #

Appendix-b: Proof Outline (Privacy-Performance Tradeoff)

- Constraint based system of (in)equations
- Constraint1: Basic timing attack must be impossible

  min(r) = 1rtt = 2l (avg value taken)
- Constraint2: Twin Timing Attack must not work

  max(SumA-(RTT1+RTT2)) > min(SumB-(RTT1+RTT2))

  => max(r) > min(q)+min(r)+2l
- Constraint3: For a querier's cancel messages to stop all instances of the query message within h hops of querier,

  max(r)+2l + h l < h(min(q) + l)

  => max(r)+2l < h(min(q))

  => min(q) > (max(r)+2l)/h
- Constraint4: For a graph where a peer's outdegree is at least 39, h=2.

  h=3 => query reaches 59000 peers.

Appendix-c: comparison with O.R.

- Our analysis of **OneSwarm** with modified delays that thwart timing attack:
- Expected time t to receive a response from a source x hops away is E[t] = $8xl$.

  For x=1, E[t] = 8l
  For x=3, E[t] = 24l

- **Onion Routing**: with chain of 3 proxies, the delay in receiving data from a Torrent search engine is

  E[t] = 6l.

- Tradeoff between Privacy and Performance.
  - OneSwarm does not achieve both.