Peer-to-peer Sender Authentication for Email

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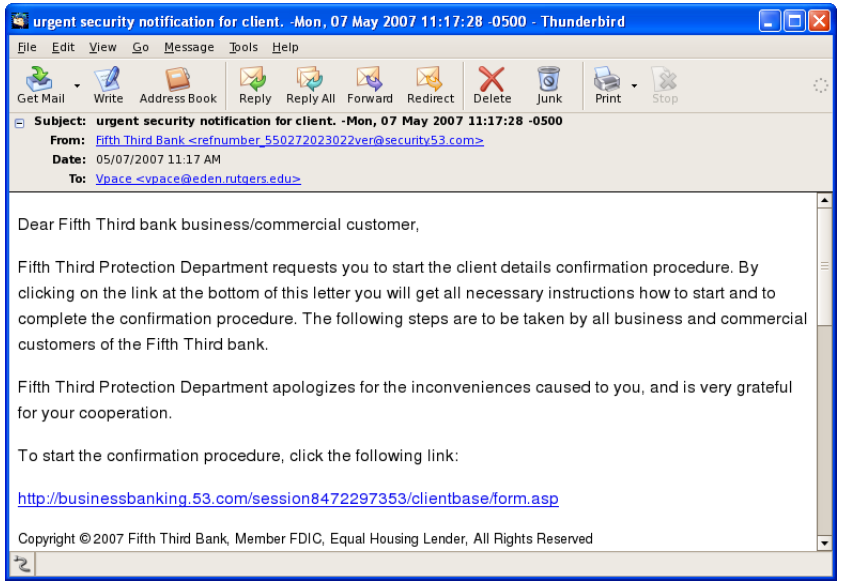
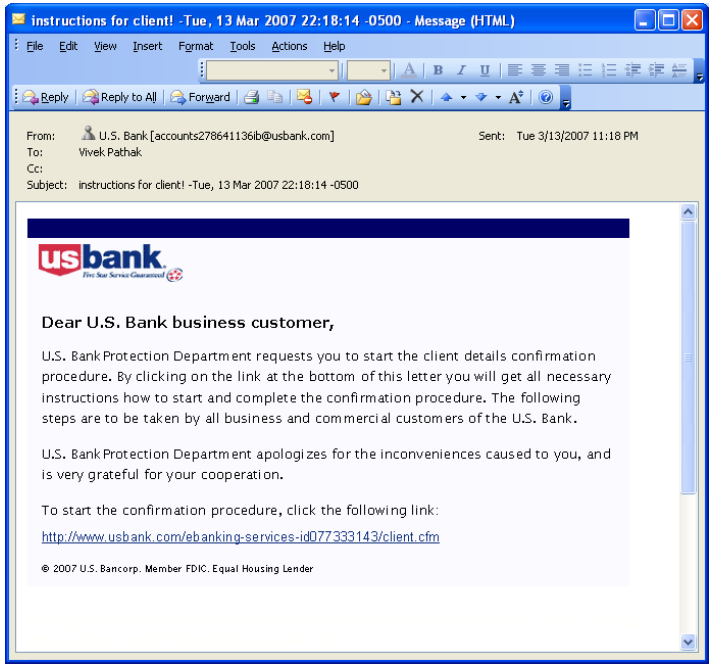
Email Trustworthiness

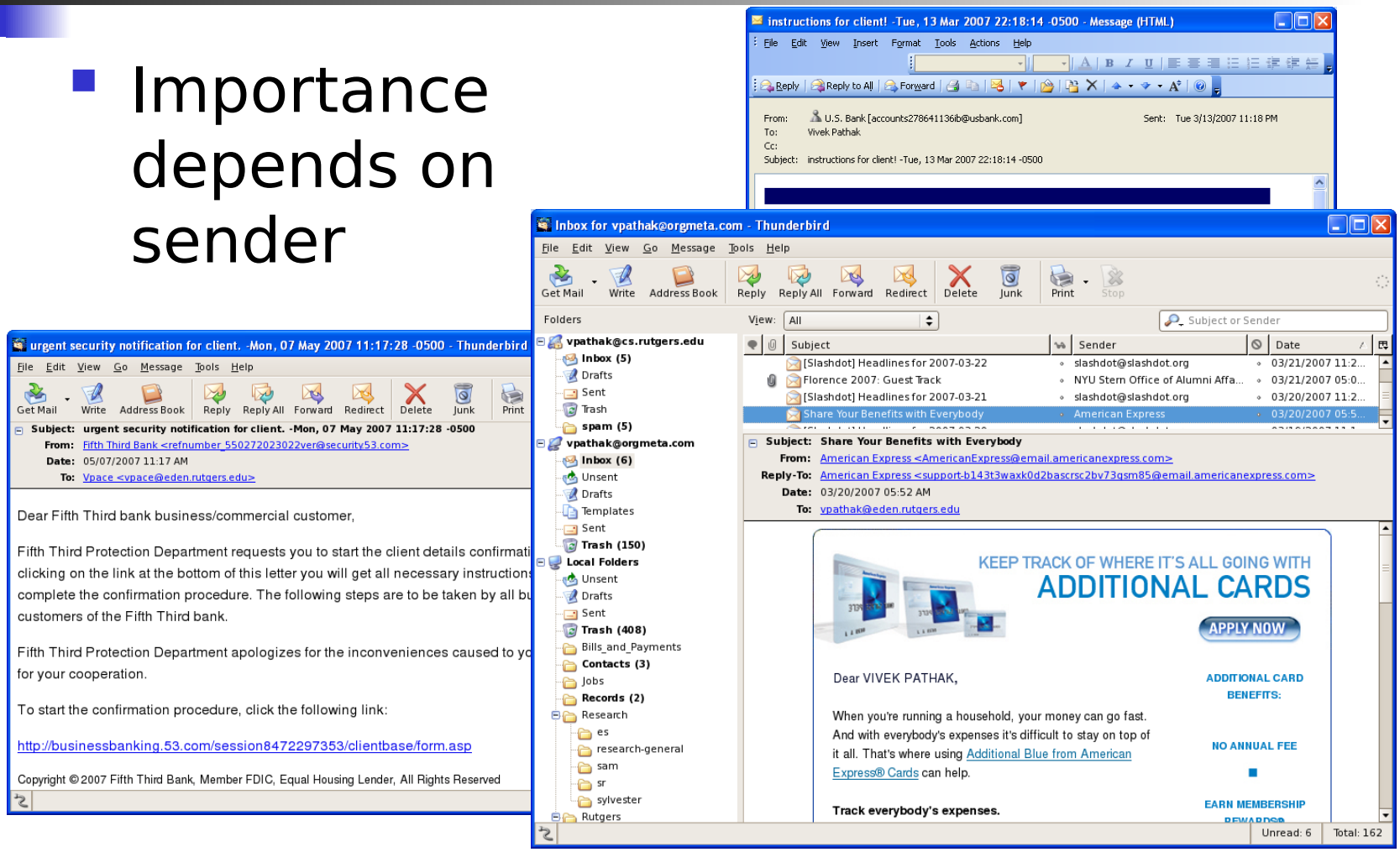
- Sender can be spoofed





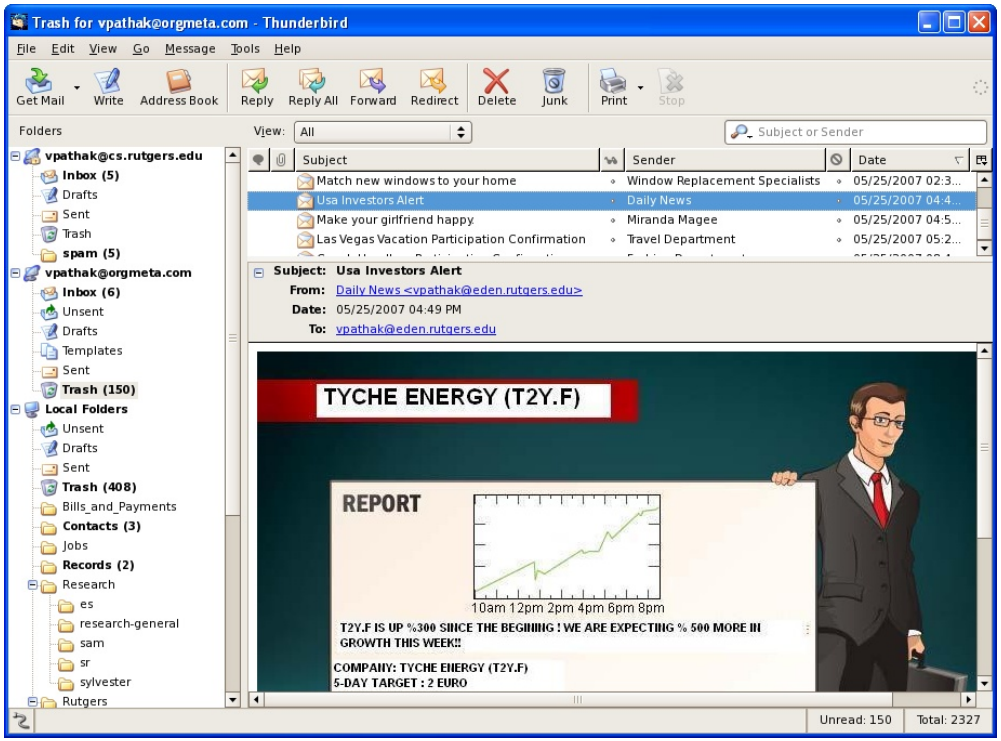
Need for Sender Authentication

- Importance depends on sender

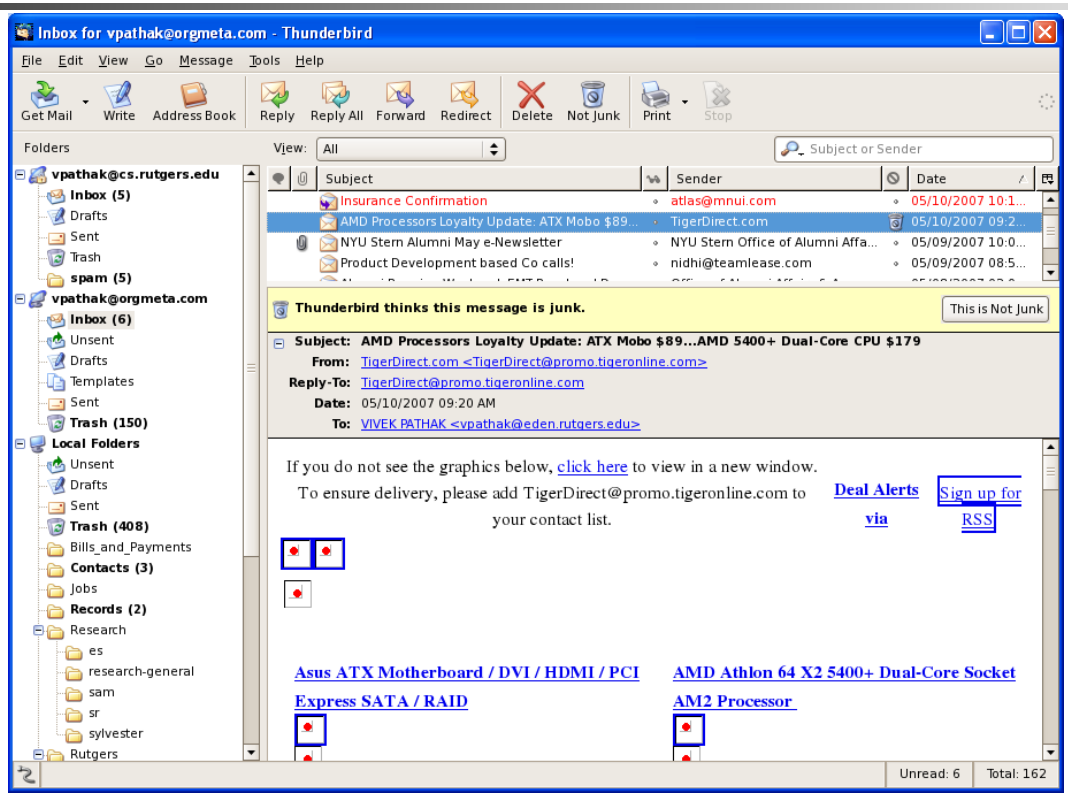


Update on Spam Filters

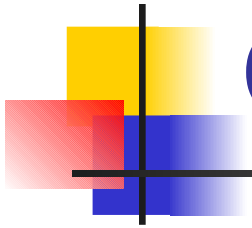
- Circumvention of content based spam classification
- False positives



End-to-end Issues



- Can the mail server decide importance for the receiver?



Characteristics of Email

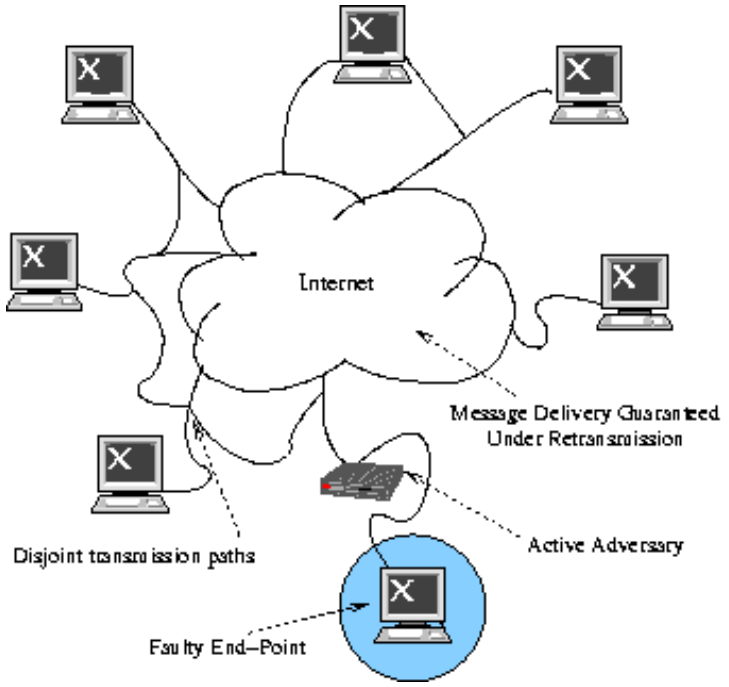
- Social networks of collaborating users
  - Limited trust infrastructure
- Usability expectation
  - Automatic authentication
- Asynchronous
  - Delayed authentication is better than none

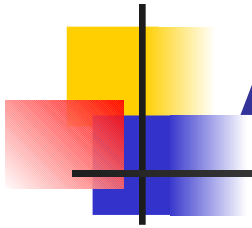
Outline

- Byzantine fault tolerant public key authentication
  - Basis of sender authentication for email
- Application to Email
  - Thunderbird sender authentication plugin
- Usability
  - Micro-benchmark
  - Simulation on University and Industry mail trace

Public-key Authentication Model

- Mutually authenticating peers
  - Associate network end-point to public key
  - Asynchronous network
    - No partitioning
    - Eventual delivery after retransmissions
  - Disjoint message transmission paths
    - Man-in-the-middle attack on Ø fraction of peers



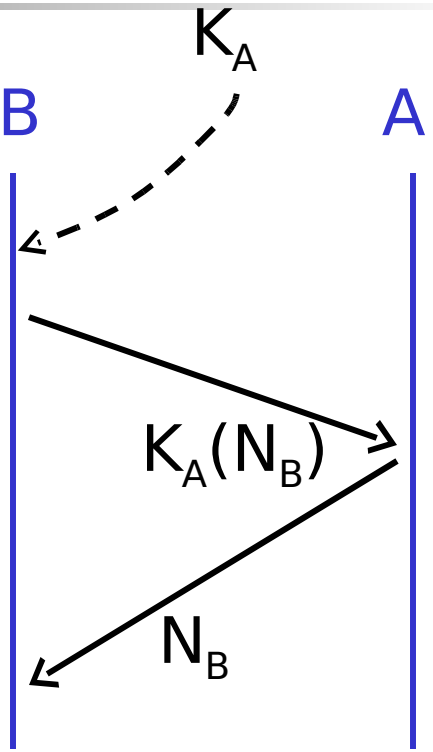


Attack Model

- Malicious peers
  - Honest majority
  - At most t of the n peers are faulty or malicious peers where $t = {}^{1-6\emptyset}/_{3}\, n$
- Passive adversaries
- Active adversaries
  - Relax network-is-the-adversary model
    - Unlimited spoofing
    - Limited power to prevent message delivery

Authentication Sketch

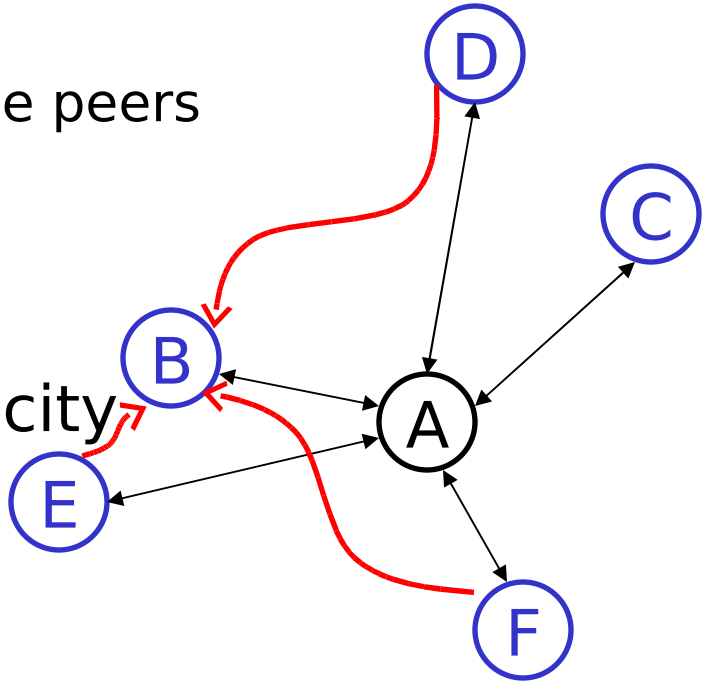
- Challenge-response protocol
  - No active attacks
- Man in the middle attack
  - Limited number of attacks
- Proof of possession of K_a



$\{b,a,Challenge,K_a(N_b)\}_b$, $\{a,b,Response, N_b\}_a$

Authentication Sketch

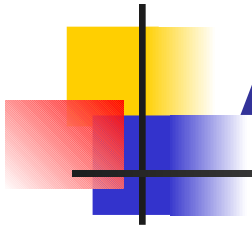
- Distributed Authentication
  - Challenge response from multiple peers
  - Gather proofs of possession



- Lack of consensus on authenticity
  - Malicious peers
  - Man-in-the-middle attack

- Detect and correct through Byzantine agreement on authenticity of K_A

Scalability of Authentication



- Authentication cost and group size
  - Scale to large peer-to-peer network
    - Operate on local trusted group
  - Tolerate bad group selection
    - Periodic recycling of group members
    - Eventual authentication
  - Operate through epidemic algorithm
    - Eliminate direct connectivity requirement
    - Improve messaging cost

Outline

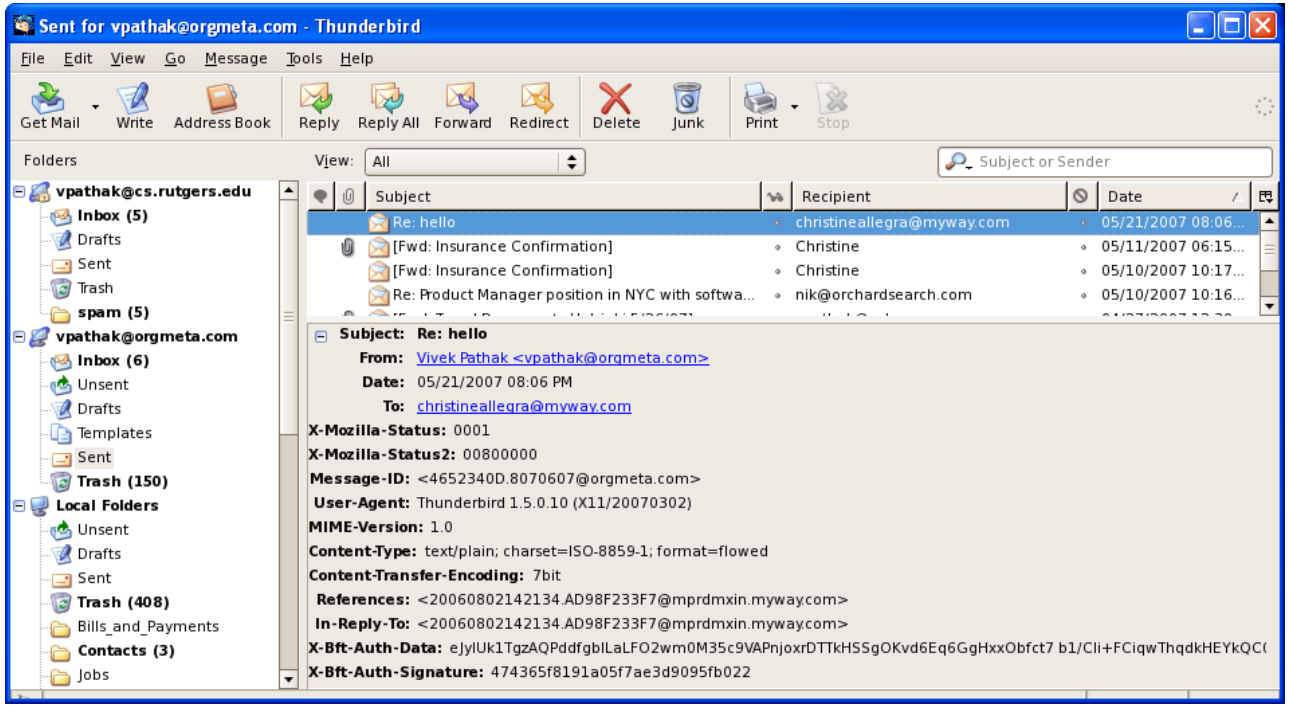
- Byzantine fault tolerant public key authentication
  - Basis of sender authentication for email

- Application to Email
  - Thunderbird sender authentication plugin

- Usability
  - Micro-benchmark
  - Simulation on University and Industry mail trace

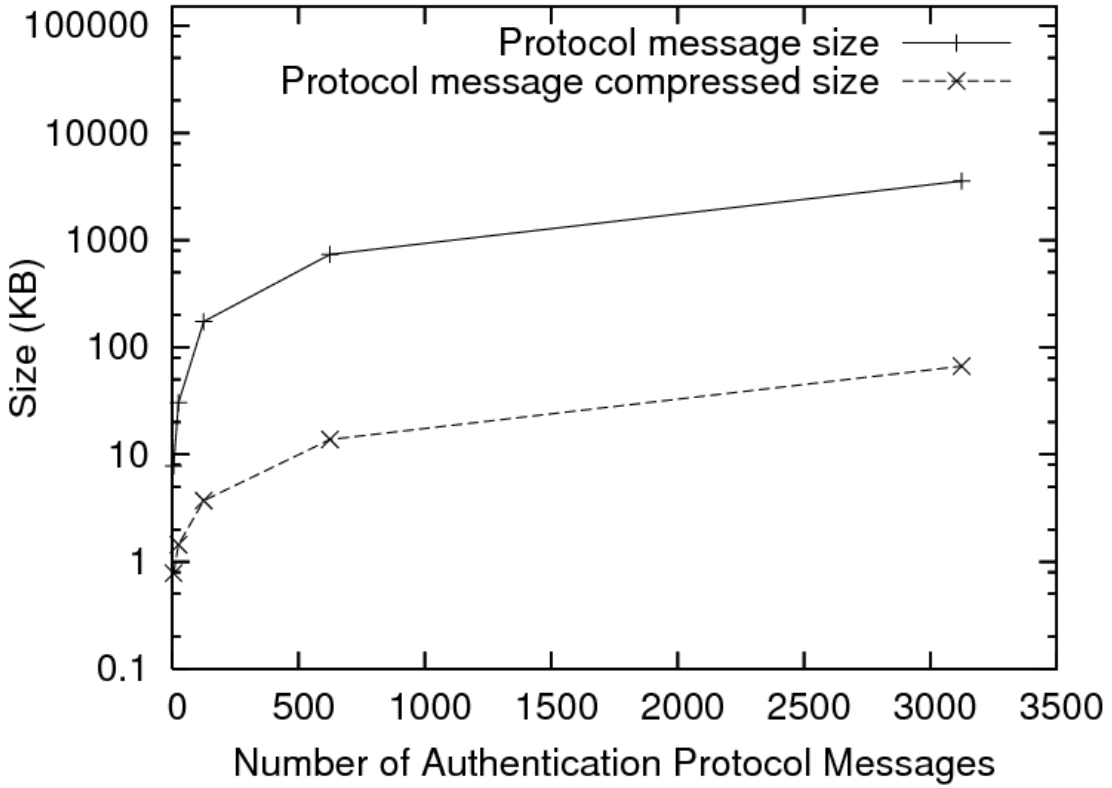
Sender Authentication Design

- Backward Compatibility
  - SMTP ignores user defined fields
  - Operate as an overlay on SMTP

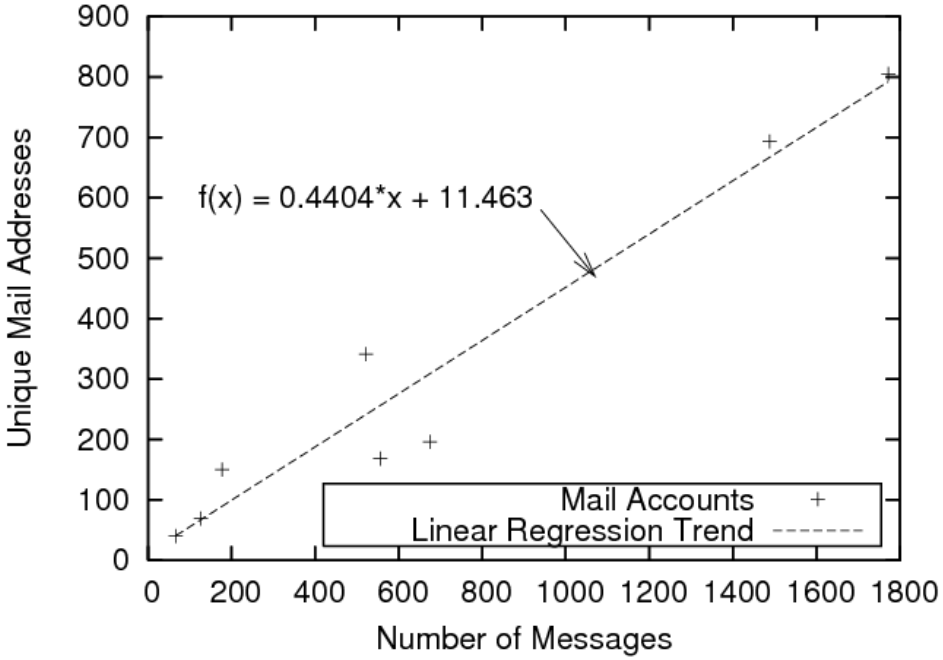


Overlay Limits

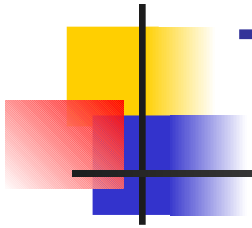
- Size limit 32Kb on SMTP header
- High compression for XML format protocol messages
  - 300 message limit



Authentication Load



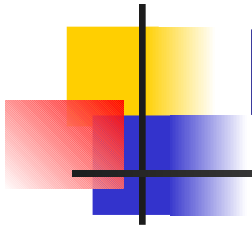
- About 20% emails are to new peers



Trusted Group Size

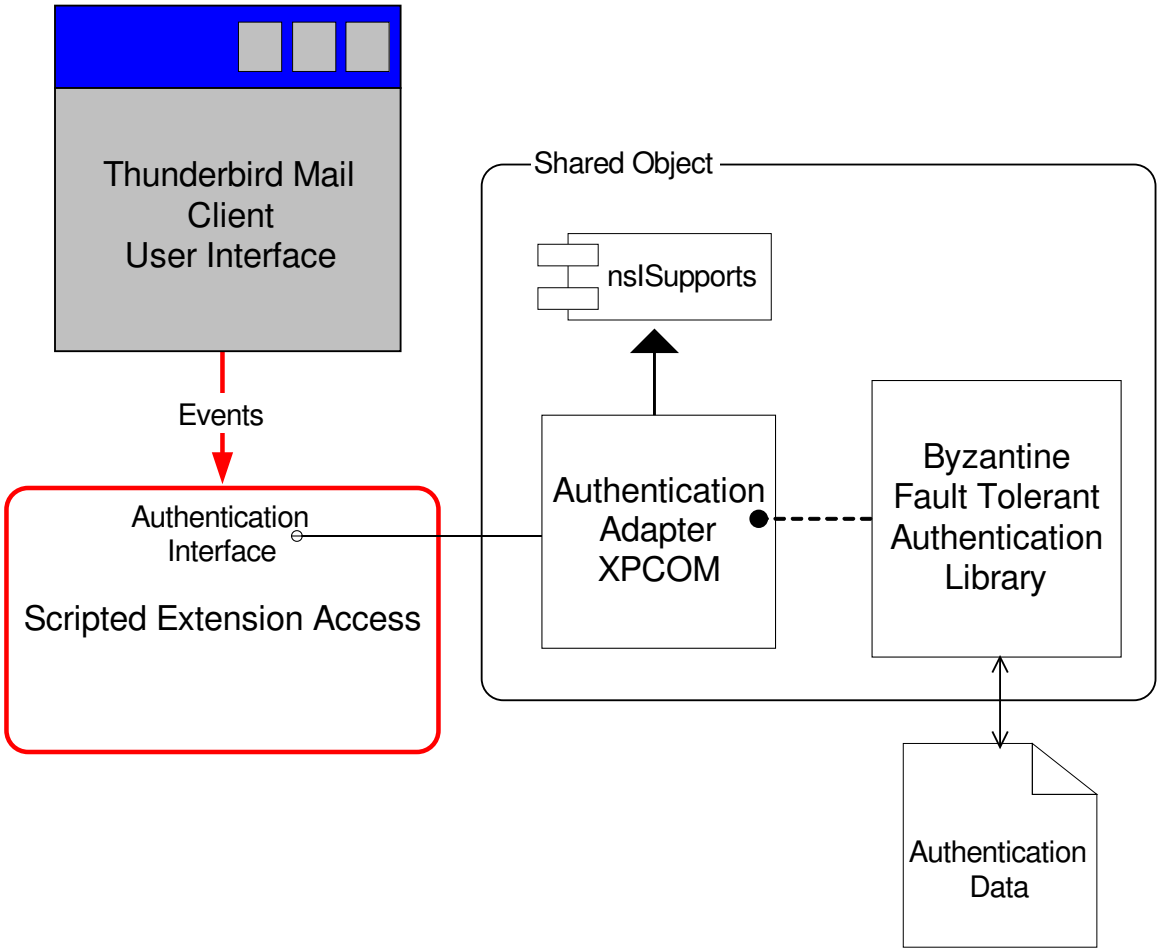
- Authentication messages per email
  - System limitation 300
- Peers to authenticate per email
  - Mailbox observation 1/5
- Quota of 1500 messages per peer
  - Protocol messaging cost analysis
  - Trusted group size limit 75

Sender Authentication Plugin

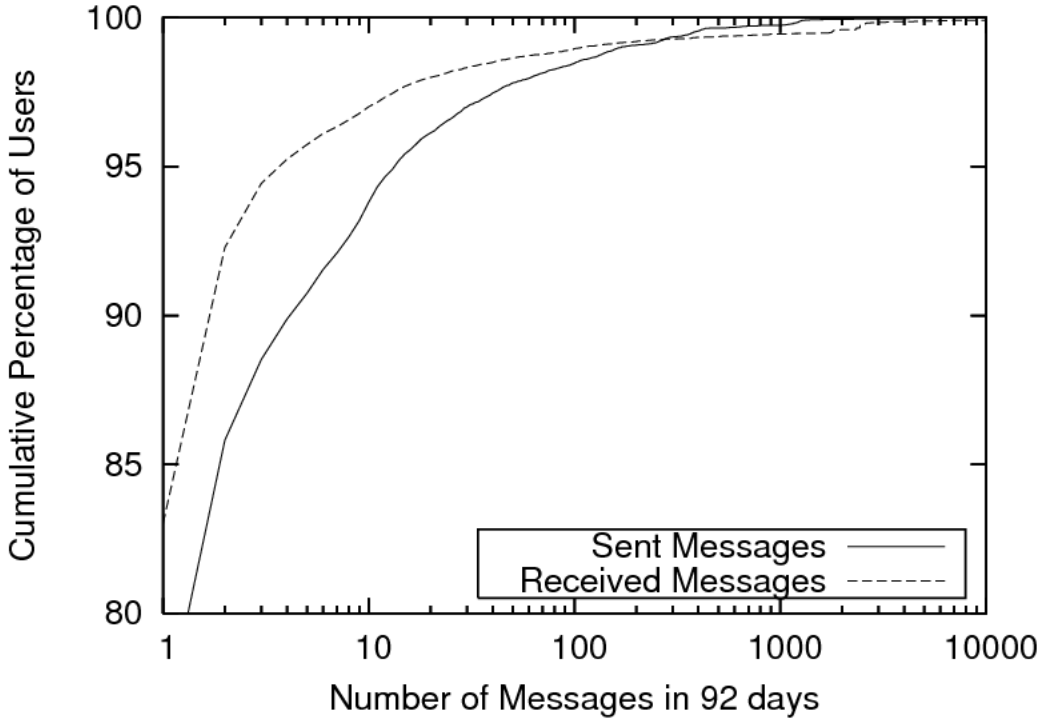


- Thunderbird mail client
  - XPCOM layer
    - Implements Public-key authentication
  - Javascript layer
    - Transfer protocol messages to and from SMTP extension fields

Sender Authentication Plugin



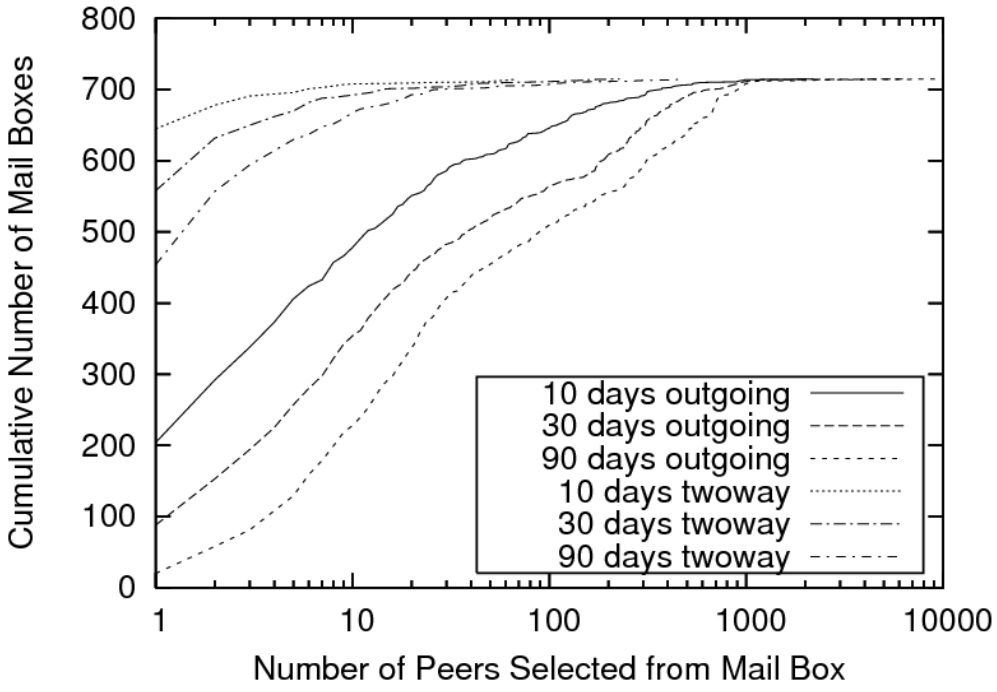
Bootstrapping Trusted Group

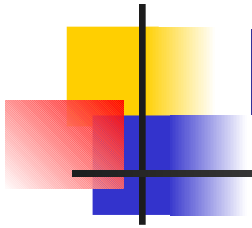


- University mail trace shows Receiving bias

Bootstrapping Trusted Group

- Required for automatic operation
- Select trusted group
  - Two-way
  - Outgoing
- Selected 53 peers with 10 or more trusted peers using Two-way rule

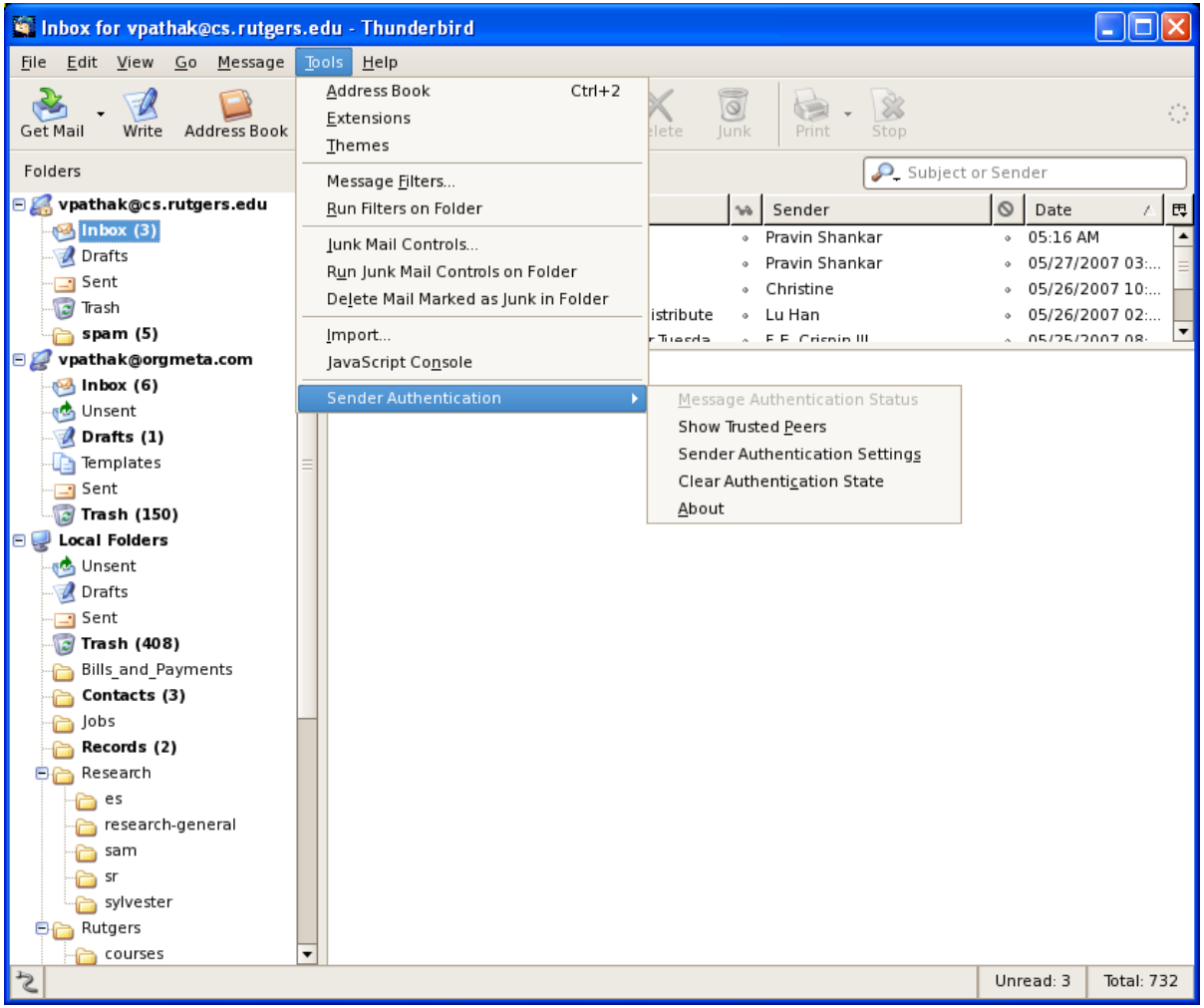




Implementation Status

- Email application
  - Automatic sender authentication
  - Overlay authentication protocol on SMTP
- Available as Thunderbird extension module
  - Tested on 32bit and 64bit Linux
  - http://discolab.rutgers.edu/sam

Implementation Screenshot



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- Usability
  - Micro-benchmark
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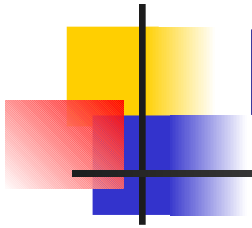
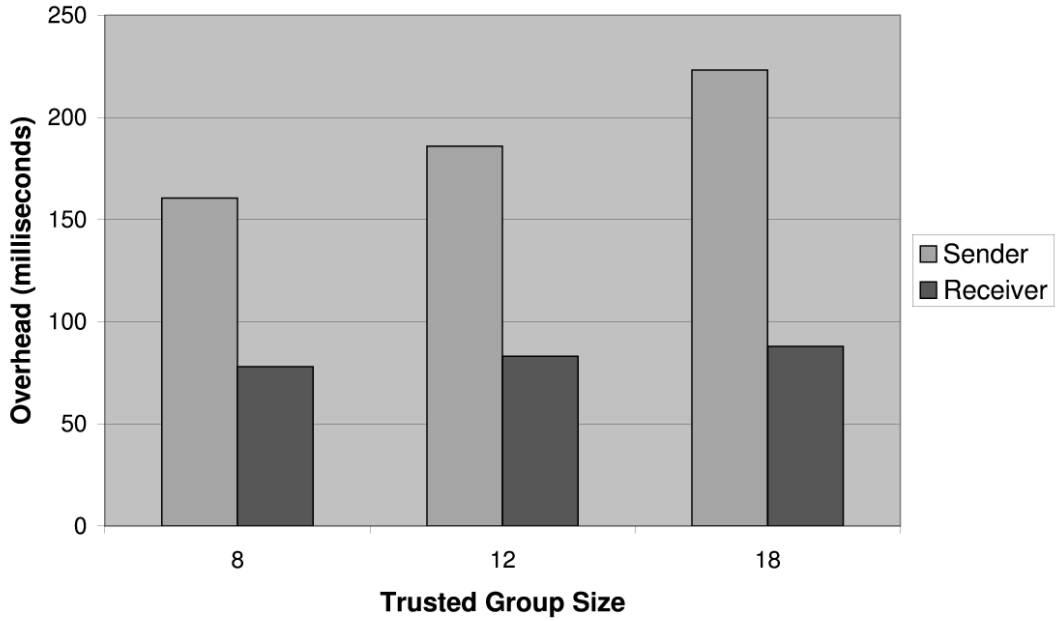


Micro-benchmarks

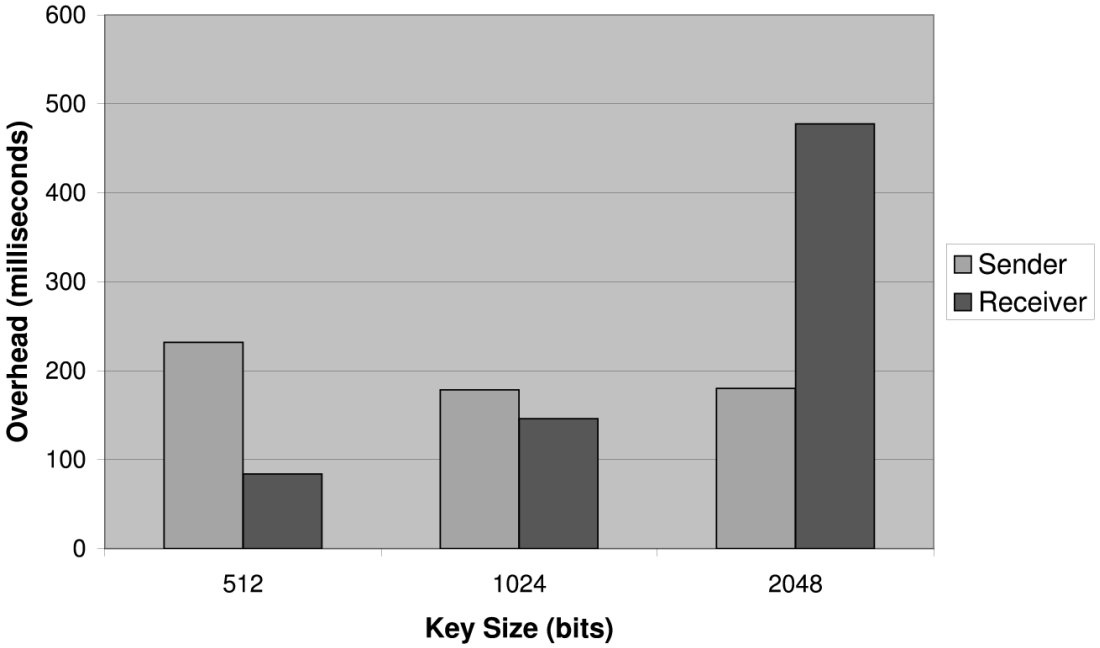
- Record the processing time overhead
  - Average over multiple messages
- Operational parameters
  - Public key length
  - Trusted group size

Overhead with Trusted Group Size



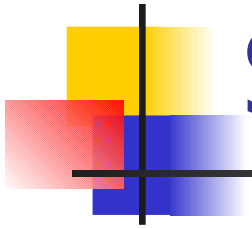
- Increasing on Sender
  - Serialization and compression of larger messages

Overhead with Key Length



- Increasing on receiver
  - Digital signature verification
  - Responding to challenges

Micro-benchmark Summary

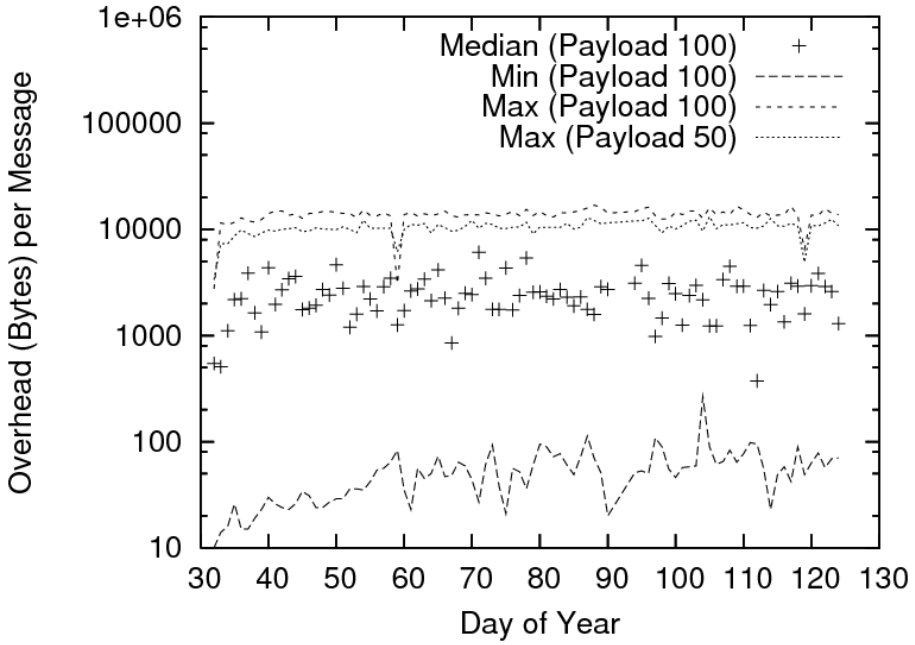


- Sending path overhead of 250ms
- Receiving path overhead of 500ms
  - Can be done asynchronously
- Acceptable level of overhead

Simulation Study

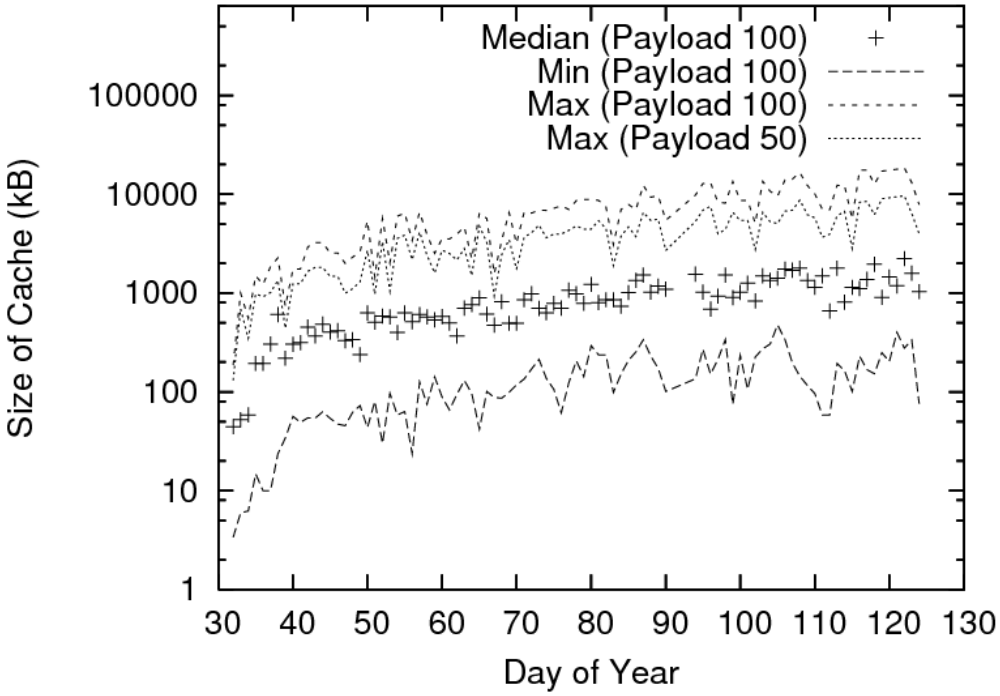
- Process the entire email trace on a single machine
  - Anonymous log records from mail server
  - Exact times have been removed
- University trace of 92 days and 1.19M messages
- Industry trace of 56 days and 2.5M messages

Overhead on Email Size



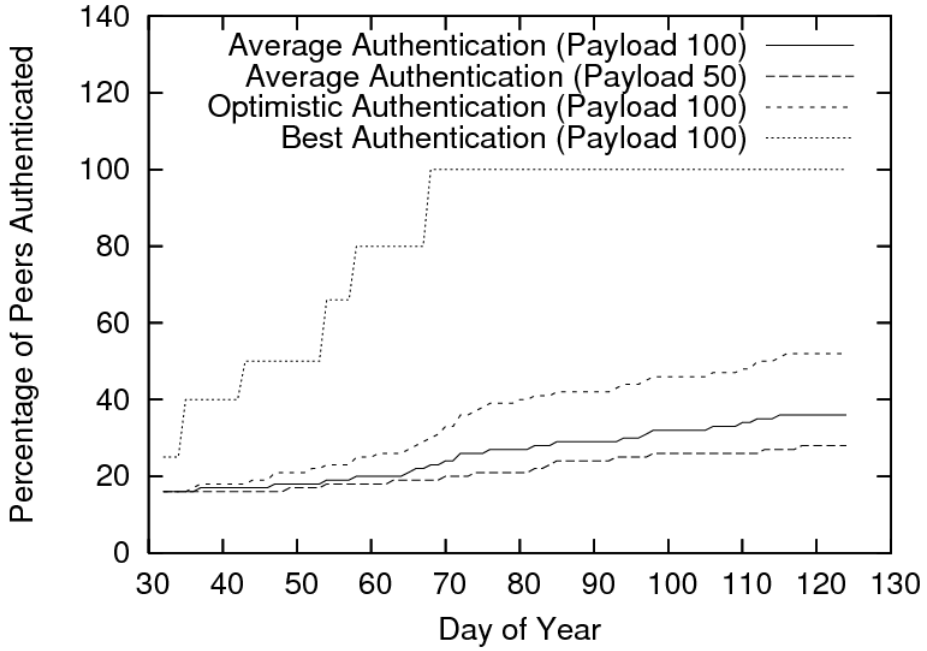
- Recover the designed 10KB overhead

Disk Space Usage



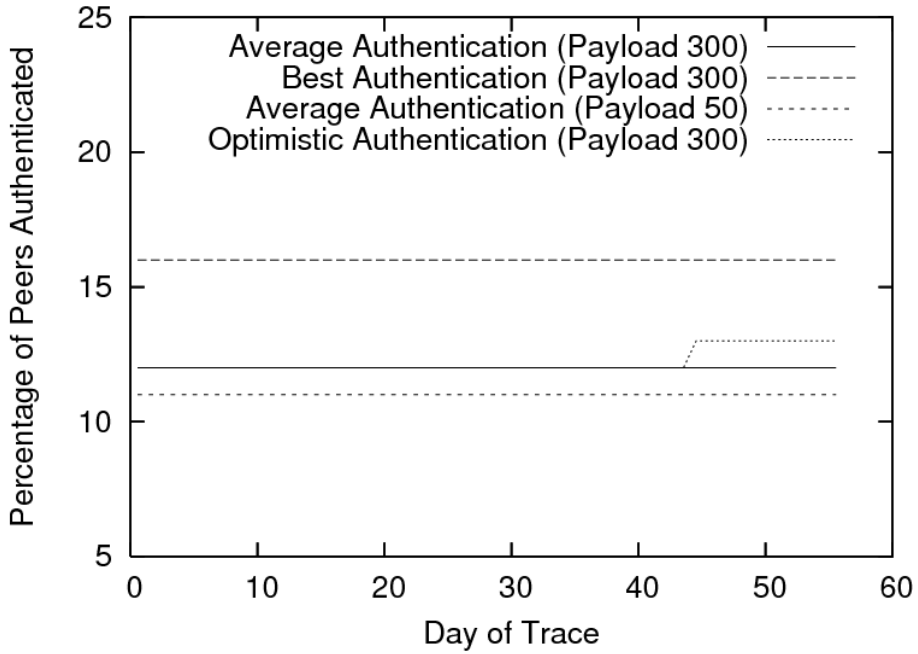
- Epidemic algorithm overhead
  - Trusted group size is 100
  - Overhead about 10MB per peer

Completion of Authentication University Trace

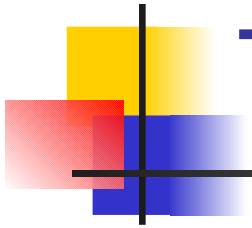


- Partial completion on 92 day trace
  - About 40% of peers authenticated

Completion of Authentication Industry Trace

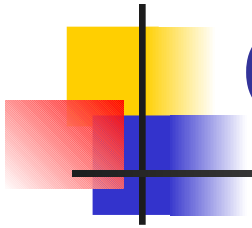


- Reduced progress
  - Trace collected upstream of spam filter
  - Effectiveness of Authentication is near 40%



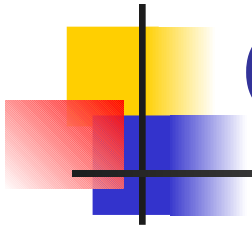
Trace Analysis Study

- Achieve 40% completion on about 3 months of email traffic
  - Using two way bootstrapping group
  - Effectiveness depends on bootstrapping group selection
- Modest cache overhead
- Message overhead is respected as designed

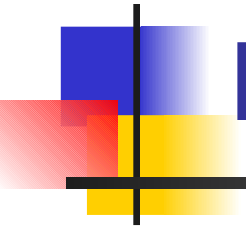


Conclusion

- Implemented and evaluated automatic sender authentication for email
- Future work
  - Data collection from deployment
  - Improve bootstrapping group selection
  - Address authenticity vs. importance



Q&A



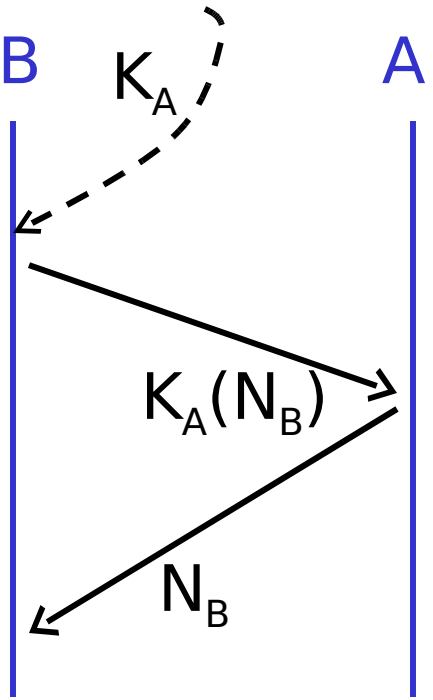
Peer-to-peer Sender Authentication for Email Extra Slides

Extra Slides Outline

- Authentication protocol details
  - Distributed Authentication
  - Byzantine Agreement
  - Trust Groups
  - Public Key Infection
- Simulation results
  - Group size
  - Malicious peers

Authentication Model

- Challenge-response protocol
  - No active attacks
- Man in the middle attack
  - Limited number of attacks

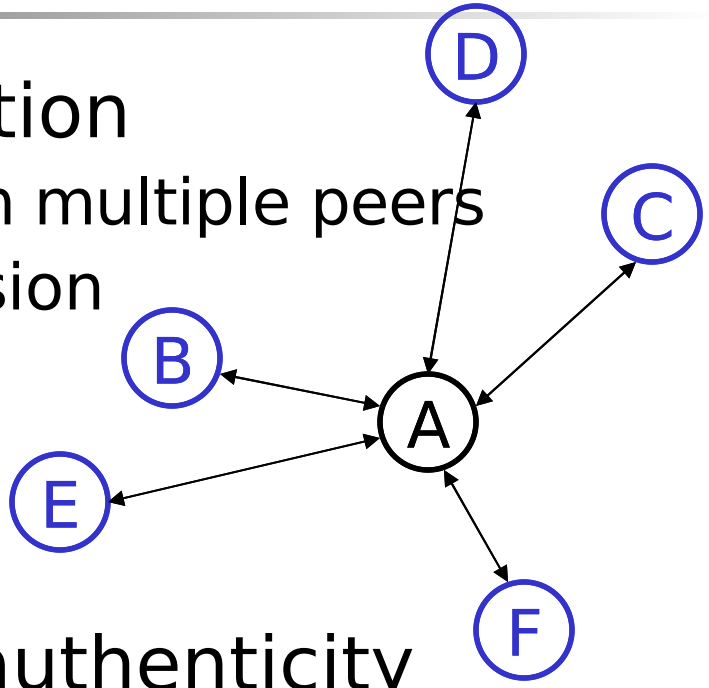


- Proof of possession of K_a

$\{b,a,Challenge,K_a(r)\}_b$, $\{a,b,Response,r\}_a$

Authentication Model

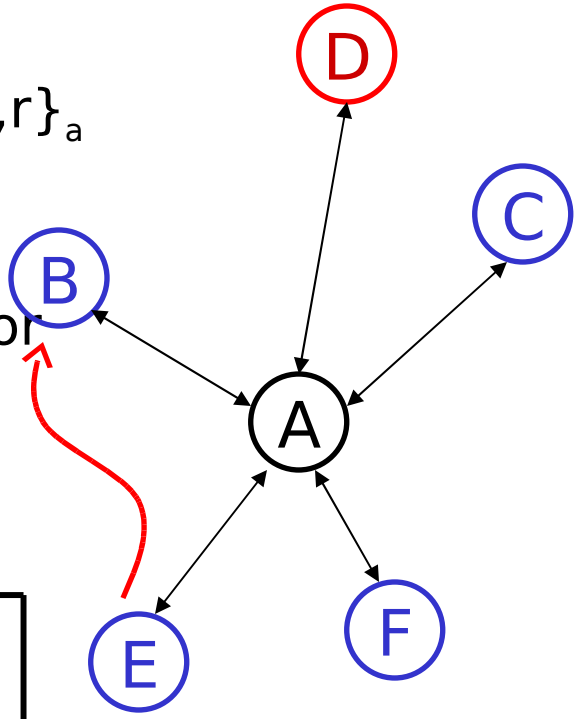
- Distributed Authentication
  - Challenge response from multiple peers
  - Gather proofs of possession



- Lack of consensus on authenticity
  - Malicious peers
  - Man-in-the-middle attack

Authentication Correctness

- Validity of proofs of possession
  - $\{e,a,Challenge,K_a(r)\}_e$, $\{a,e,Response,r\}_a$
- All messages are signed
  - Required for proving malicious behavior
  - Recent proofs stored by the peers



From peers	P_B	P_C	P_D	P_E	P_F
From A	P_B	P_C	P_D	P_E	P_F

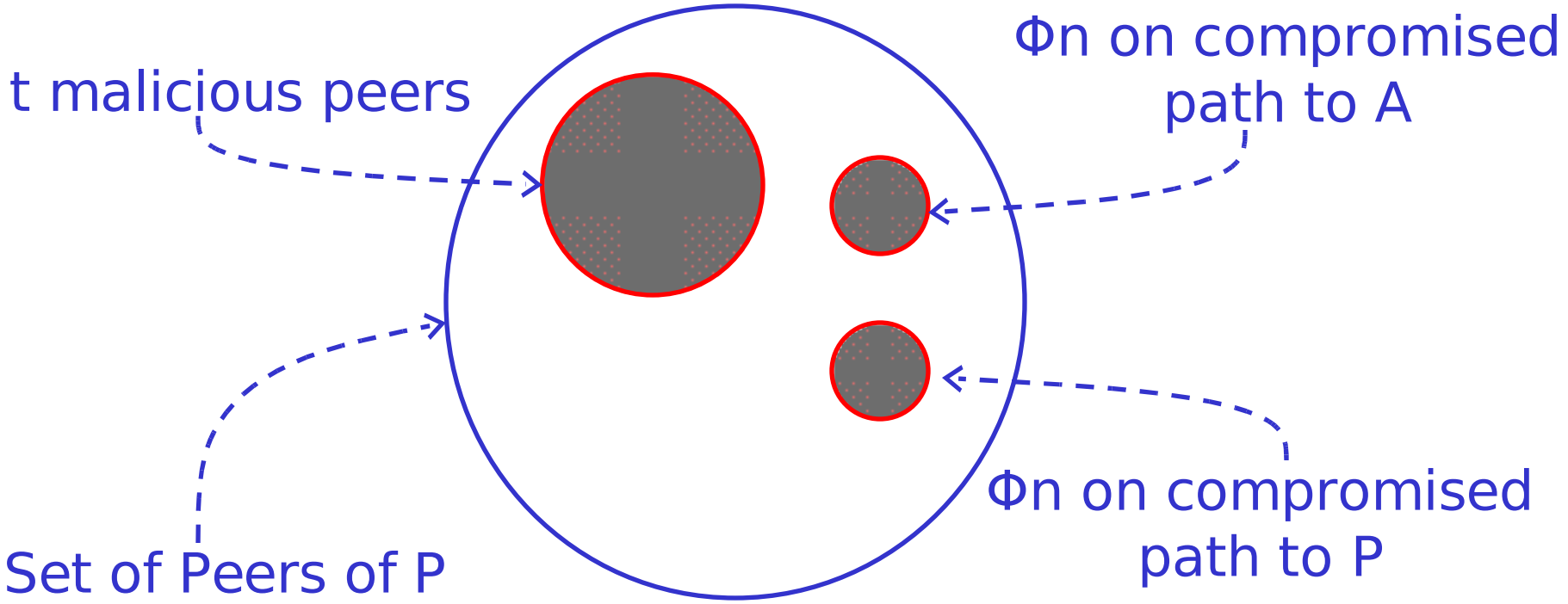
Byzantine Agreement Overview

- Publicize lack of consensus
  - Authenticating peer sends proofs of possession to peers
- Each peer tries to authenticate A
  - Sends its proof-of-possession vector to every peer
  - Byzantine agreement on authenticity of K_A
- Majority decision at every peer
  - Identify malicious peers
  - Complete authentication

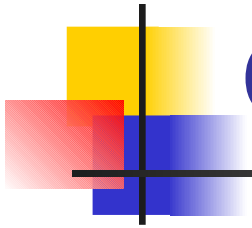
From B	1	1	0	1	1
From C	1	1	1	1	1
From D	1	1	1	1	1
From E	1	1	0	1	1
From F	1	1	0	1	1

Byzantine Agreement Correctness Overview

- Consider proofs received at a peer P



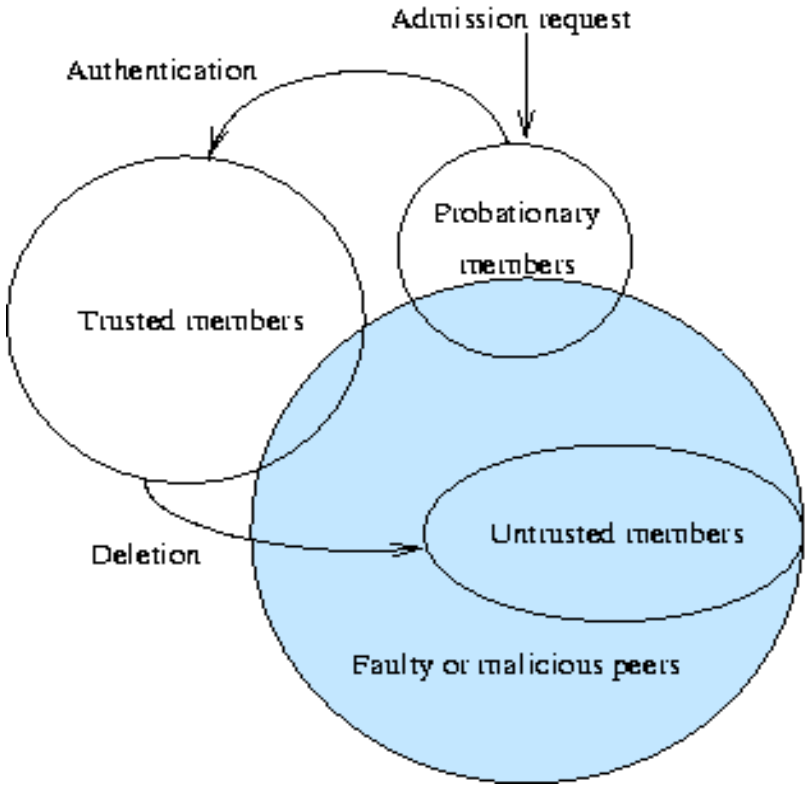
Byzantine Agreement Correctness Overview



- t + 2Øn may not arrive
  - P receives at least n-t-2Øn proofs
- t + 2Øn may be faulty
  - P receives at least n-2t-4Øn correct agreeing proofs
  - P decides correctly by majority if n-2t-4Øn > t + 2Øn
- Agreement is correct if $t < {}^{1-6Ø}/_{3}\, n$

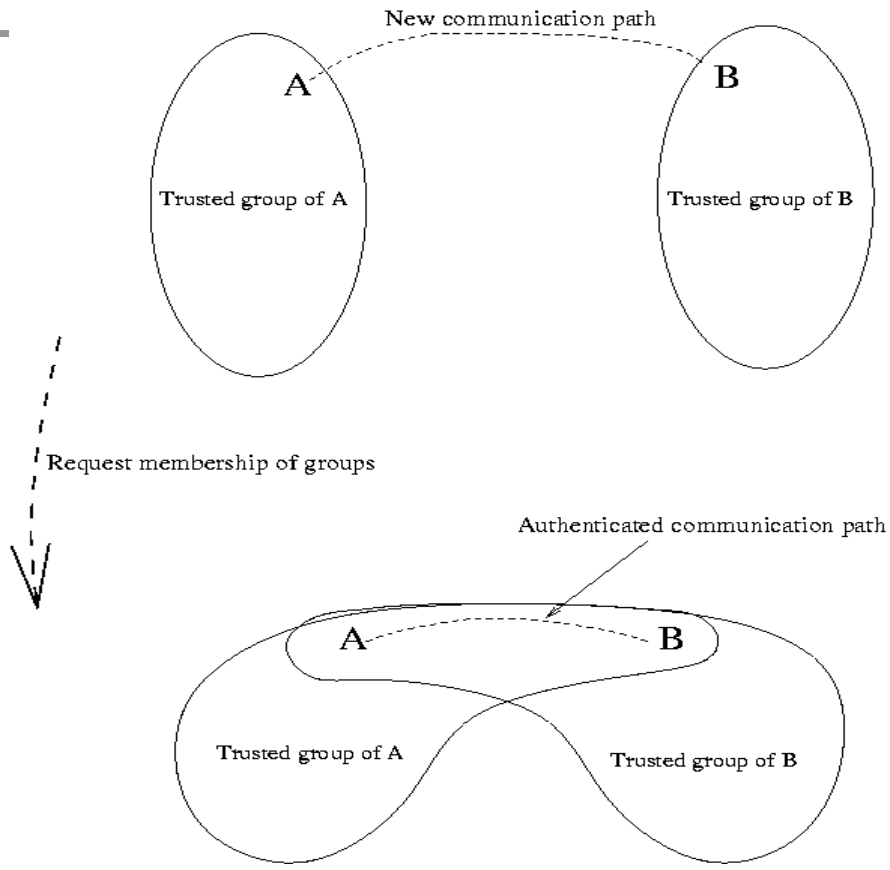
Trust Groups

- Execute Authentication on smaller Trust groups
  - Quadratic messaging cost
  - Peer interest
- Trusted group
  - Authenticated public keys
  - Not (overtly) malicious
- Probationary group
- Un-trusted group
  - Known to be malicious

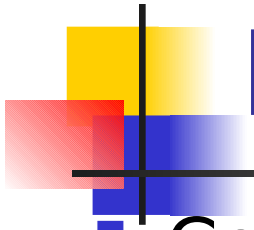


Growth of Trust Groups

- Governed by communication patterns
- Discovery of new peers
  - Authentication of discovered peers
  - Addition to trusted set
- Discovery of un-trusted peers



Evolution of Trust Groups



- Covertly malicious peers
  - May wait until honest majority is violated
  - Lead to incorrect authentication
- Periodic pruning of trusted group
  - Unresponsive peers
  - Remove older trusted peers from trust group
    - Reduce messaging cost
    - Randomize trusted group membership
  - Group migration event
- Probability of violating honest majority

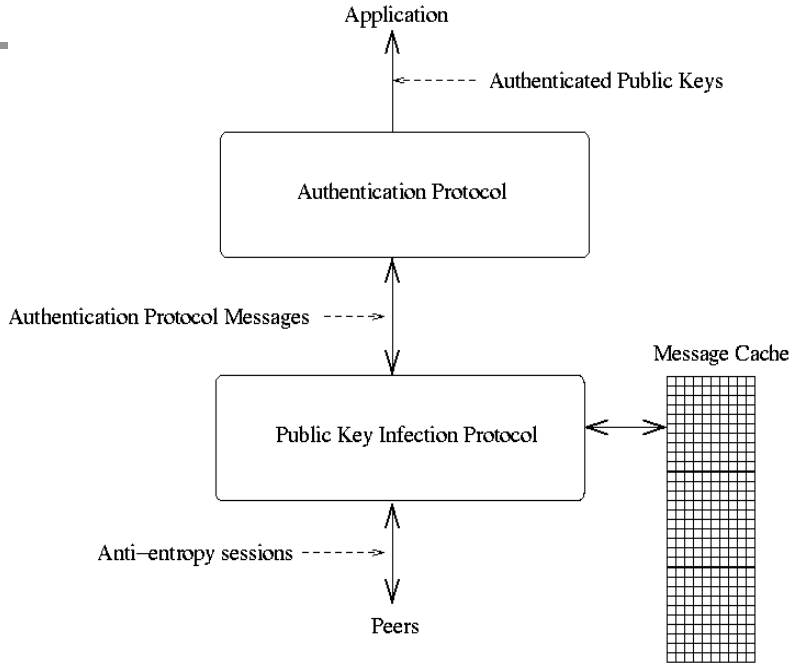
Bootstrapping Trust Group

- Authentication needs an honest trust group
  - Initialize a Bootstrapping trust group
  - Needed for cold start
  - Authenticate each bootstrapping peer
- Size of bootstrapping trust group
  - Recover from trusting a malicious peer

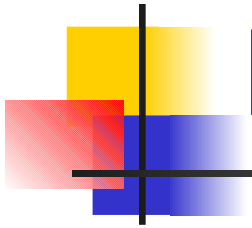
$$n > {}^{3}/_{1-6\emptyset}$$

Public Key Infection

- Optimistic trust
  - Lazy authentication
  - Reduced messaging cost



- Cache of undelivered messages
  - Use peers for epidemic propagation of messages
  - Anti-entropy sessions eventually deliver messages
  - Infect peers with new undelivered messages



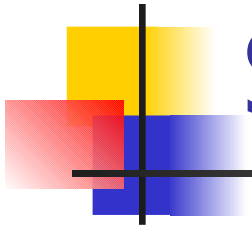
Public Key Infection

- Use logical and vector timestamps
  - Determine messages to exchange for anti-entropy
  - Detect message delivery
- Double exponential drop in number of uninfected peers with time
- Number of cached messages is in O(nlogn)

Extra Slides Outline

- Authentication protocol details
  - Distributed Authentication
  - Byzantine Agreement
  - Trust Groups
  - Public Key Infection

- Simulation results
  - Group size
  - Malicious peers

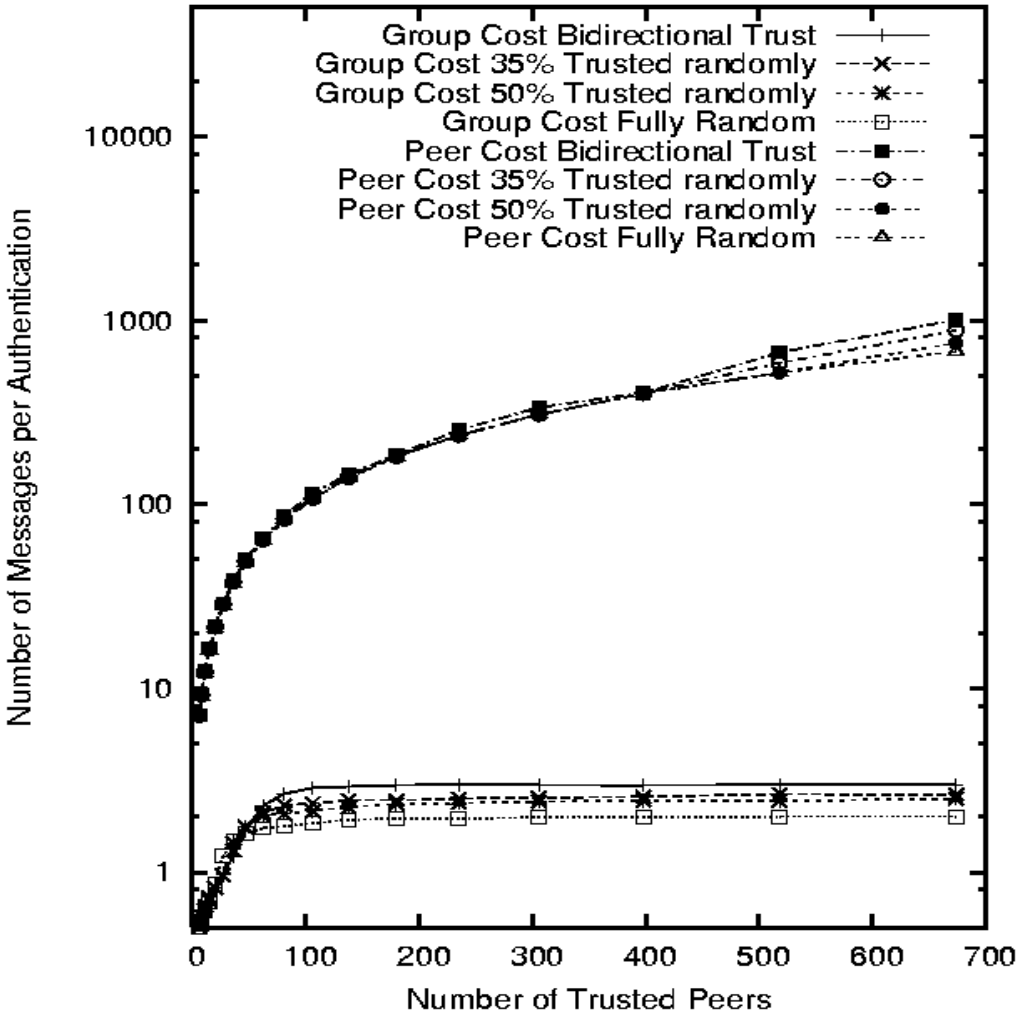


Simulation

- Implemented Byzantine Fault Tolerant Authentication as a C++ library
- Simulation program
  - Make library calls and keeps counters
  - Study effects of
    - Group size
    - Malicious peers

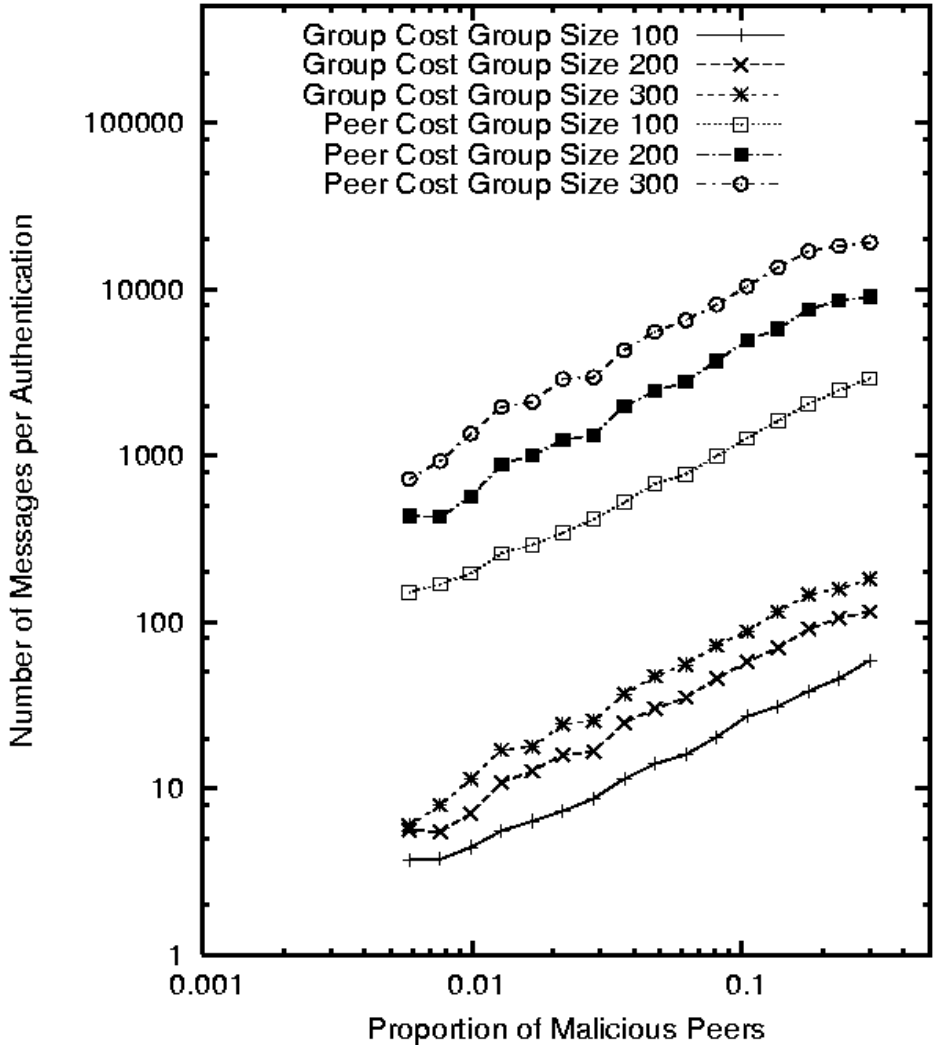
Effects of Group Size

- Constant Cost for trusted peers
- Probationary peers process $O(n^2)$ messages
- Trust graph does not affect the cost
  - Randomized trusted sets from Bi-directional trust

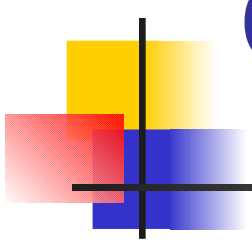


Effects of Malicious Peers

- Rapid increase of messaging cost
  - With group size
  - With proportion of malicious peers
- Byzantine agreement has quadratic messaging cost



Conclusion



- Autonomous authentication without trusted third party
  - Incremental approach to security
  - Suited for low value peer-to-peer systems
- Tolerate malicious peers
  - Suited for applications spanning multiple administrative domains
- Scalable to large peer-to-peer systems
- Eliminate total trust and single point of failure
- Made feasible by using stronger network assumptions
  - Network adversary is not all powerful