An Integrated System Solution for Secure P2P Content Distribution Based on Network Coding

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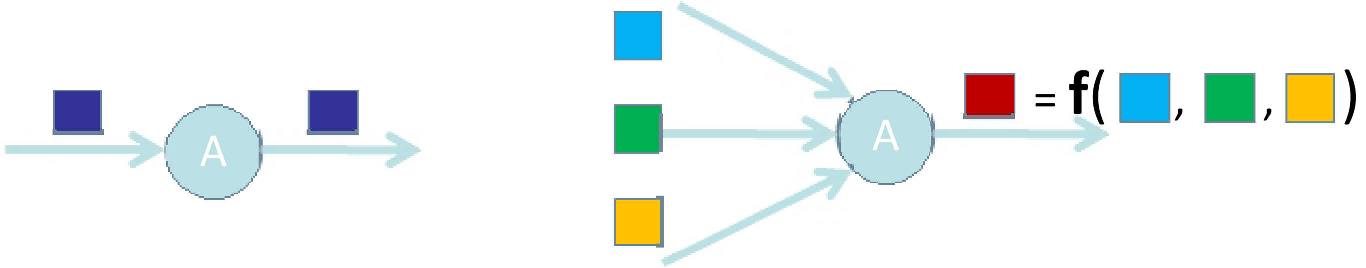
Introduction

Network Coding

- New paradigm of routing:
  - Packet mixing at intermediate nodes



Traditional routing : store-and-forward

Network coding

- Benefits:
  - Maximum throughput, robustness to link failure, energy efficiency …
- Applications:
  - Multicast/broadcast, P2P file distribution, P2P streaming, wireless unicast …

Network coding in P2P content distribution

- Benefits of network coding in P2P content distribution

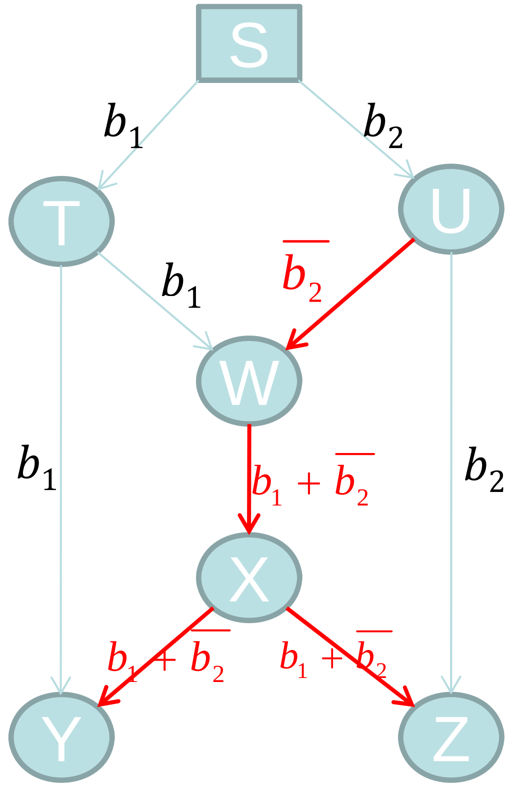
  Better resilience to peer dynamics

  leading to less downloading time

- Drawbacks

  Network coding is vulnerable to pollution attacks

The traditional signatures and hashes can not protect encoded blocks!



Related work

To thwart pollution attacks in network coding:

corruption detection

References [Infocom 08, 09]
- expensive for P2P system
- vulnerable to collusion attack

error correction

References [Koetter, IEEE TIT]
- not applicable for P2P system

- Attacker identification is a more efficient approach in P2P system
- It has received much less attention

attacker identification

References [Wang, Infocom 2010]
- significant identification overhead in dynamic P2P network
- vulnerable to collusion attack
- low security level

Solution

ISNC: An Integrated system solution for Secure P2P content distribution based on Network Coding

Objective

- Detect corrupted blocks on-the-fly
- Identify malicious peers effectively
- Maintain high throughput
- Be applicable for P2P system

Contributions

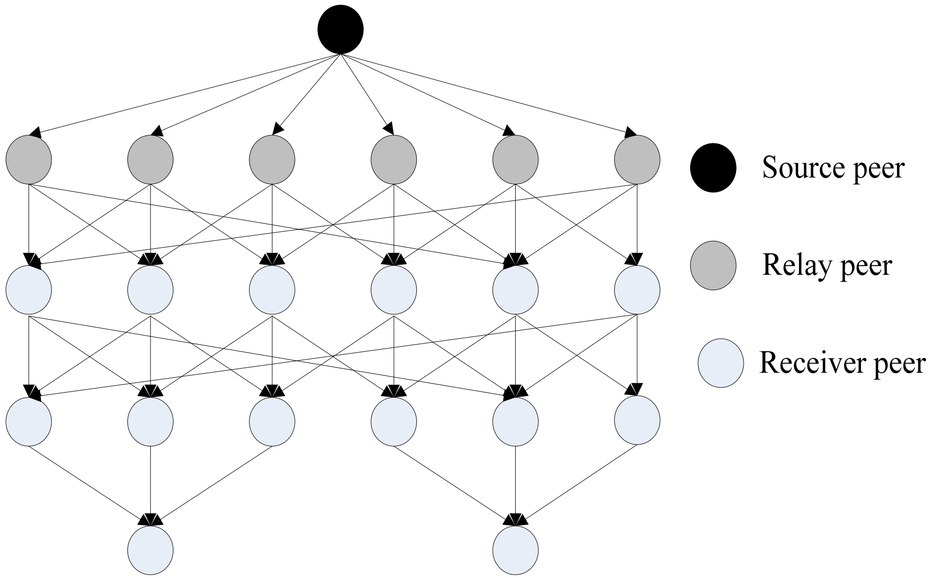
- The system architecture based on extended uniform bipartite network
- A secure network coding signature scheme
- An identity-based malicious peer identification scheme

Outline

- The system architecture
- A secure network coding signature scheme
- An identity-based malicious peer identification scheme
- Performance evaluation
- Conclusion

The system architecture

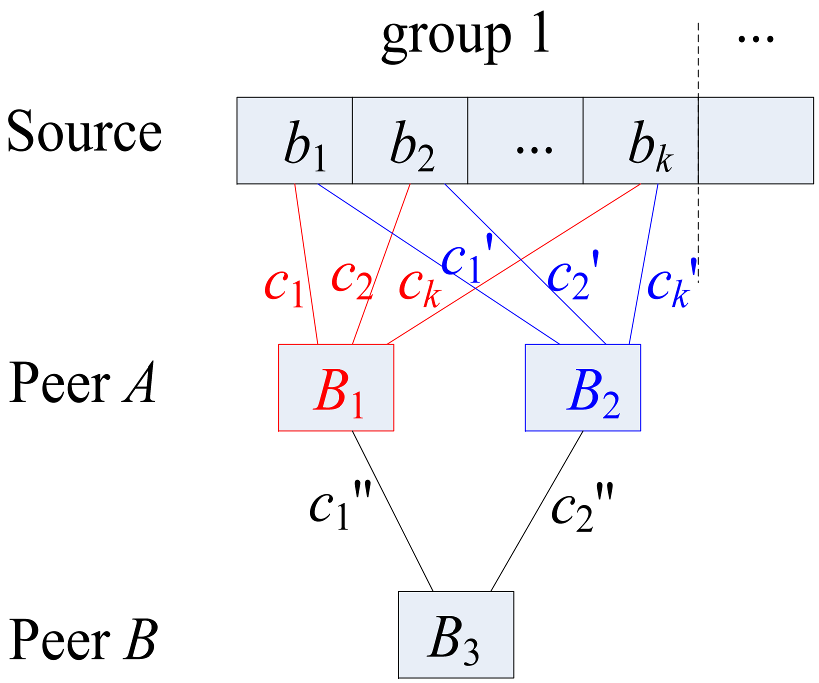
- Extend the uniform bipartite network as system topology, achieving high throughput with network coding.



- The above three layers constitute a uniform bipartite network C_n^k (n=6, k=3);
- Peers in the 4th layer and below connect with k peers in the upper layers.

Content distribution with network coding

- Utilize linear network coding to encode every group of the file, to reduce coding complexity.



$B_1 = \sum_{i=1}^{k} c_i \cdot b_i$, Coding vector $(c_1, c_2, \ldots, c_k)$

$B_3 = c_1'' B_1 + c_2'' B_2$,

Coding vector $(c_1''c_1 + c_2''c_1',\ c_1''c_2 + c_2''c_2',\ \ldots)$

A peer reconstructs original blocks when receiving k independent coded blocks.

A secure network coding signature scheme

- A secure network coding signature scheme, based on homomorphic hash function, achieving high security and applicability of P2P systems.

- Given a file identifier id_f, a group identifier id_g, k original blocks b_i (i=1, ..., k), the source computes the signatures as:

- Algorithm 1
  - Compute the homomorphic hash for each block $b_i = (b_{i1}, ..., b_{ir})$ as $\sigma_i = \prod_{j=1}^{r} g_j^{b_{ij}} \bmod p$, for i = 1, ..., k.
  - Compute the signature for the hashes as θ = Sign(SK, (id_f, id_g, $\sigma_1, ..., \sigma_k$)), where Sign is a standard signature algorithm.
  - Generate the signature of the group $\varphi = (\sigma_1, ..., \sigma_k, \theta)$.

A secure network coding signature scheme

- Peers download the signatures from its upstream peers. The peer checks the validity of block $B = \sum_{i=1}^{k} c_i \cdot b_i$ as:

- Algorithm 2
  - Check the validity of φ by standard signature verification algorithm. If φ is invalid, algorithm2 aborts. The peer must contact its upstream peers to regain φ.
  - Compute the homomorphic hash of $B = (B_1, \ldots, B_r)$ as $\sigma = \prod_{j=1}^{r} g_j^{B_j}$ mod p.
  - Compute the hash of B as $\sigma' = \prod_{i=1}^{k} \sigma_i^{c_i}$ mod p.
  - If $\sigma = \sigma'$, the receiving peer accepts B; otherwise, it discards corrupted B.

An identity-based malicious peer identification scheme

- Blocks not be checked are kept in an insecure window

Computation of homomorphic hashes may be expensive for some peers

- Peers check blocks probabilistically
- Blocks are checked using batching method

- When detecting corrupted blocks using batching, an identity-based malicious peer identification scheme is triggered

- Prevent corrupted blocks from propagating
- Identify malicious peers

An identity-based malicious peer identification scheme

- The scheme is based on the uniform bipartite network topology

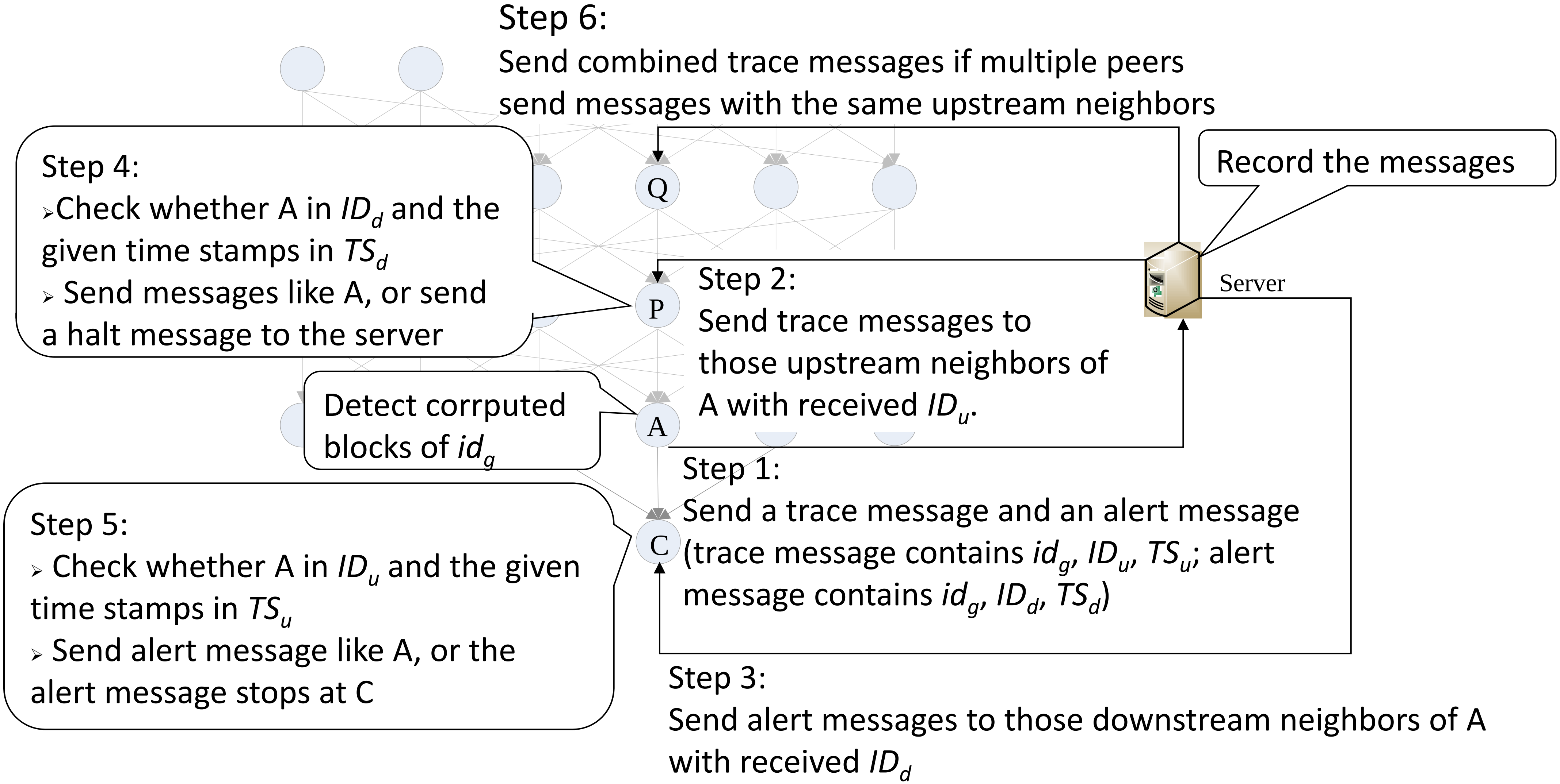
- Every peer maintains a table containing:

  1) the identities of its upstream neighbors that sent blocks inside its insecure window ID_u, the time stamps of these blocks TS_u

  2) the identities of its downstream neighbors that received blocks encoded with insecure window blocks ID_d, the time stamps of the encoded blocks TS_d

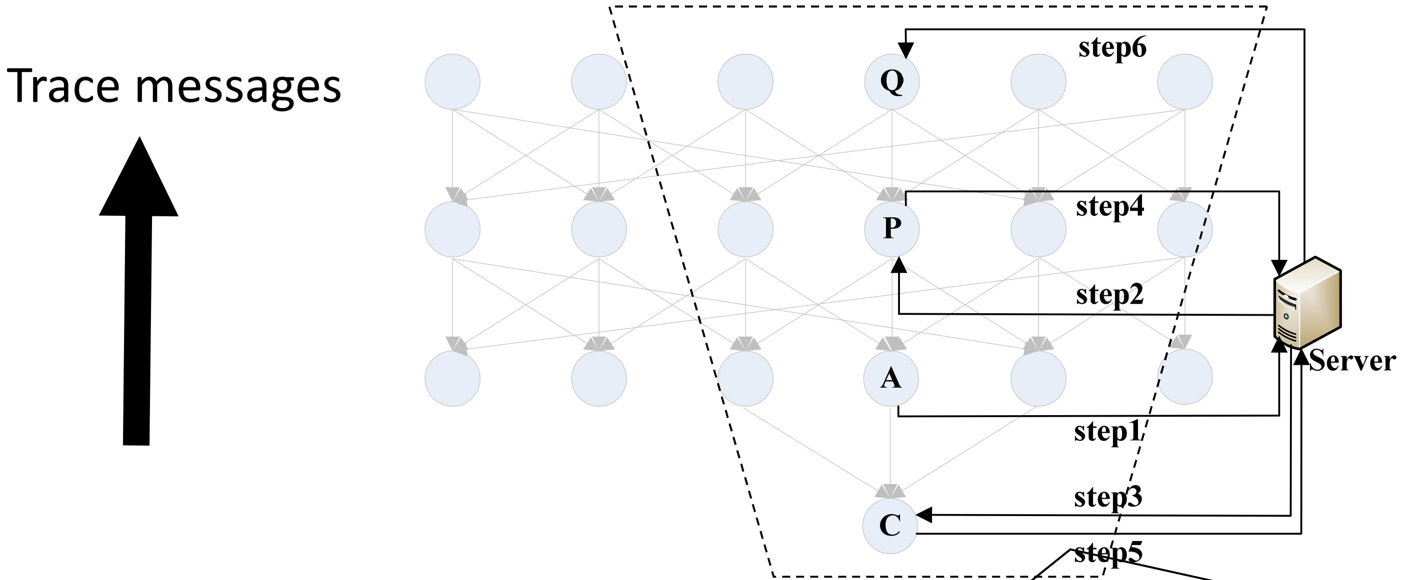
An identity-based malicious peer identification scheme

- A Bottom-up Approach for Identification Scope Restriction



An identity-based malicious peer identification scheme

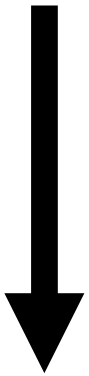
- A Bottom-up Approach for Identification Scope Restriction



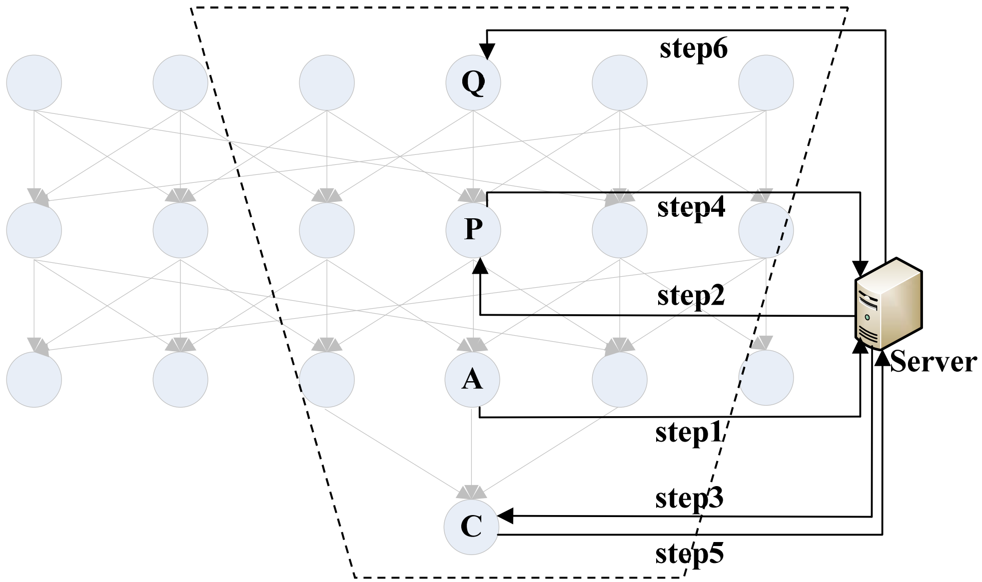
- the identification scope restricted as the area that trace messages cover
- peers in the scope start to check blocks concurrently after sending messages

An identity-based malicious peer identification scheme

- A Top–down Approach for Malicious Peer Identification



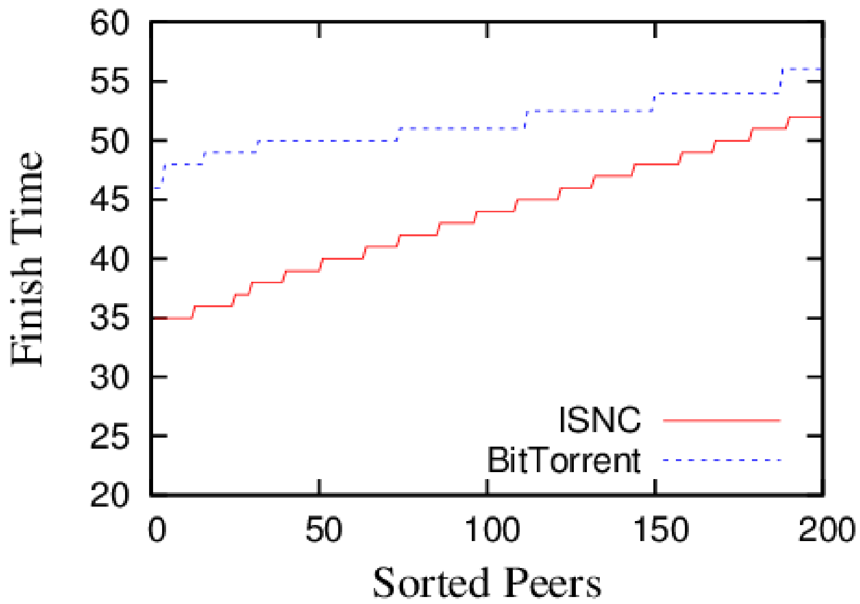
identification messages



- The server identifies malicious peers from the highest to the lowest layer
- E.g. to check Q, downstream neighbors return results to the server
- The peer doesn't need to be checked if its upstream neighbor is malicious

Performance evaluation

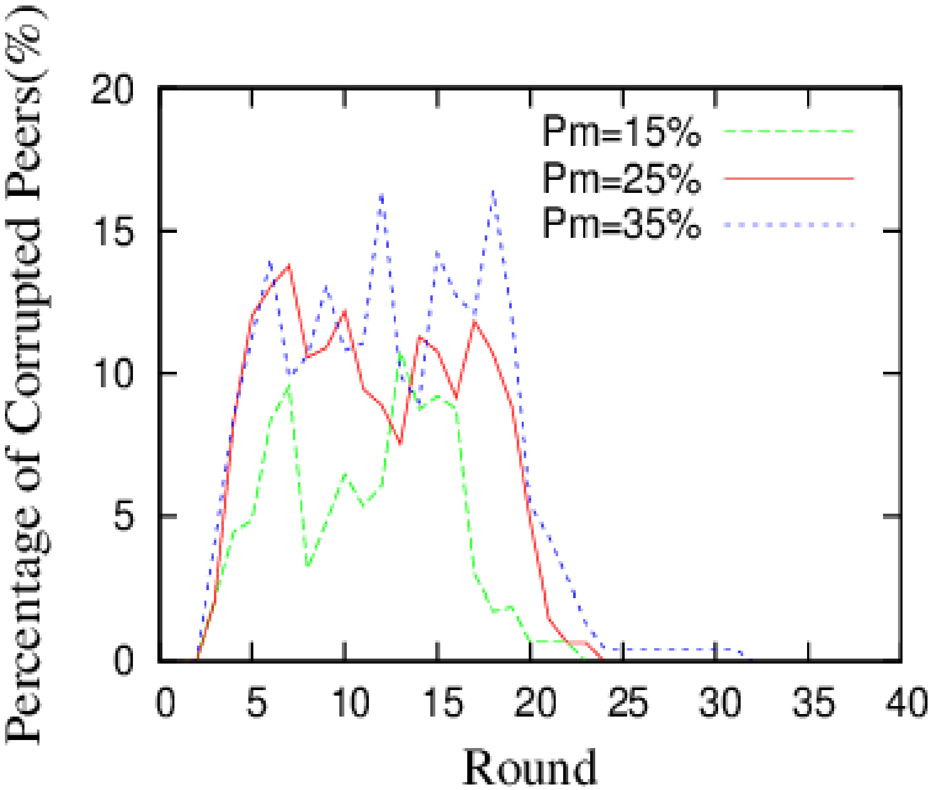
- Throughput Evaluation (through simulations)
  - network size: 200 peers; file size: 100 blocks; group size: 6 blocks
  - source & relay peers: 6 blocks/round; other peers: 3 blocks/round
  - topology, C_{12}^{6} extended uniform bipartite network



- Average finish time of our scheme is 15% less than BitTorrent
- Our system brings better throughput

Performance evaluation

- Corruption Evaluation
  - malicious peer proportions: 15%, 25%, 35% in 3 circumstances
  - probability of checking: 5%



- The scheme proposed in [Infocom 06]:

Pm	15%	25%	35%
Percentage of corrupted peers	20%	24%	26%

- All malicious peers are identified by ISNC
- Percentage of corrupted peers is smaller in ISNC

Performance evaluation

- System Overhead
  - signature size: only 0.05% of file size
  - peers download signatures only once, no signature added to transmitted blocks
  - Current existing schemes repeatedly distribute verification information and append signature to every block, which brings significant overheads

Conclusion

- We propose a novel and integrated system solution for secure P2P content distribution based on network coding (ISNC) against pollution attacks.
- ISNC can not only detect corrupted blocks effectively, but also identify all the malicious peers, even when they collude to launch attacks.
- ISNC is especially applicable for P2P content distribution, and can achieve both high security and overall efficiency.

THANK YOU!

Q/A?