Universally Verifiable Efficient Re-encryption Mixnet

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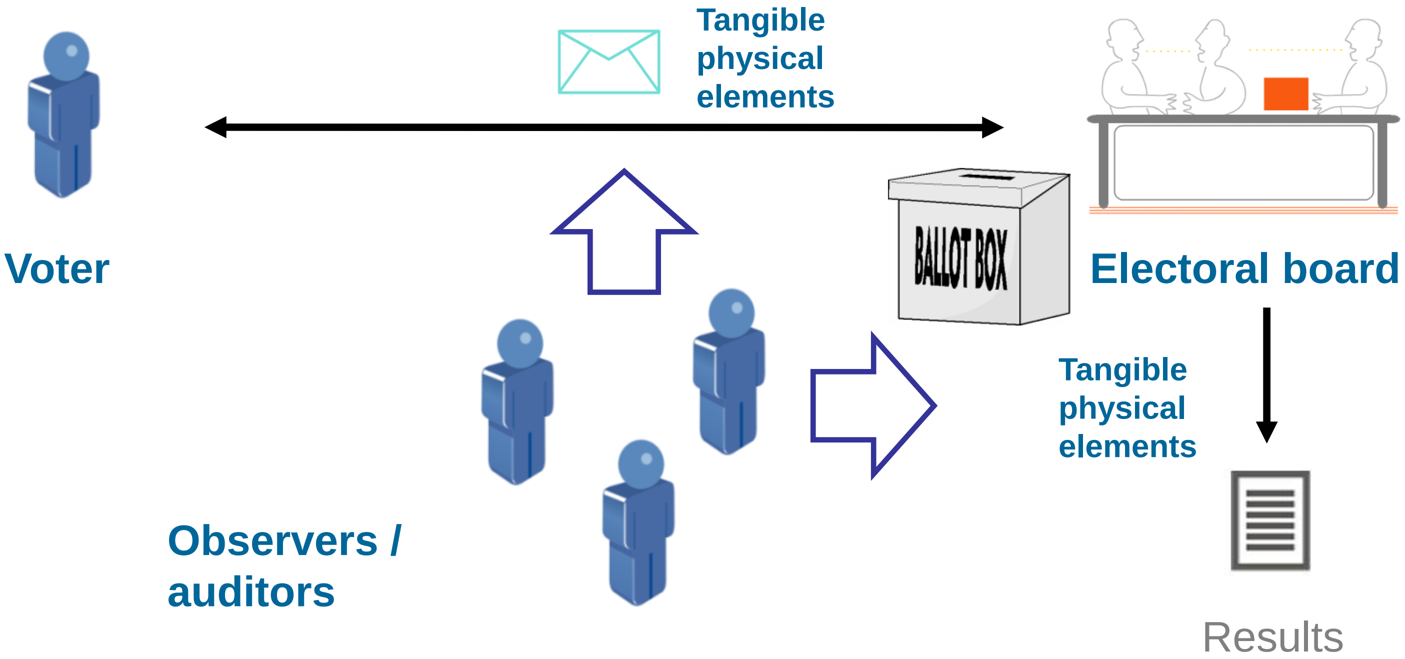
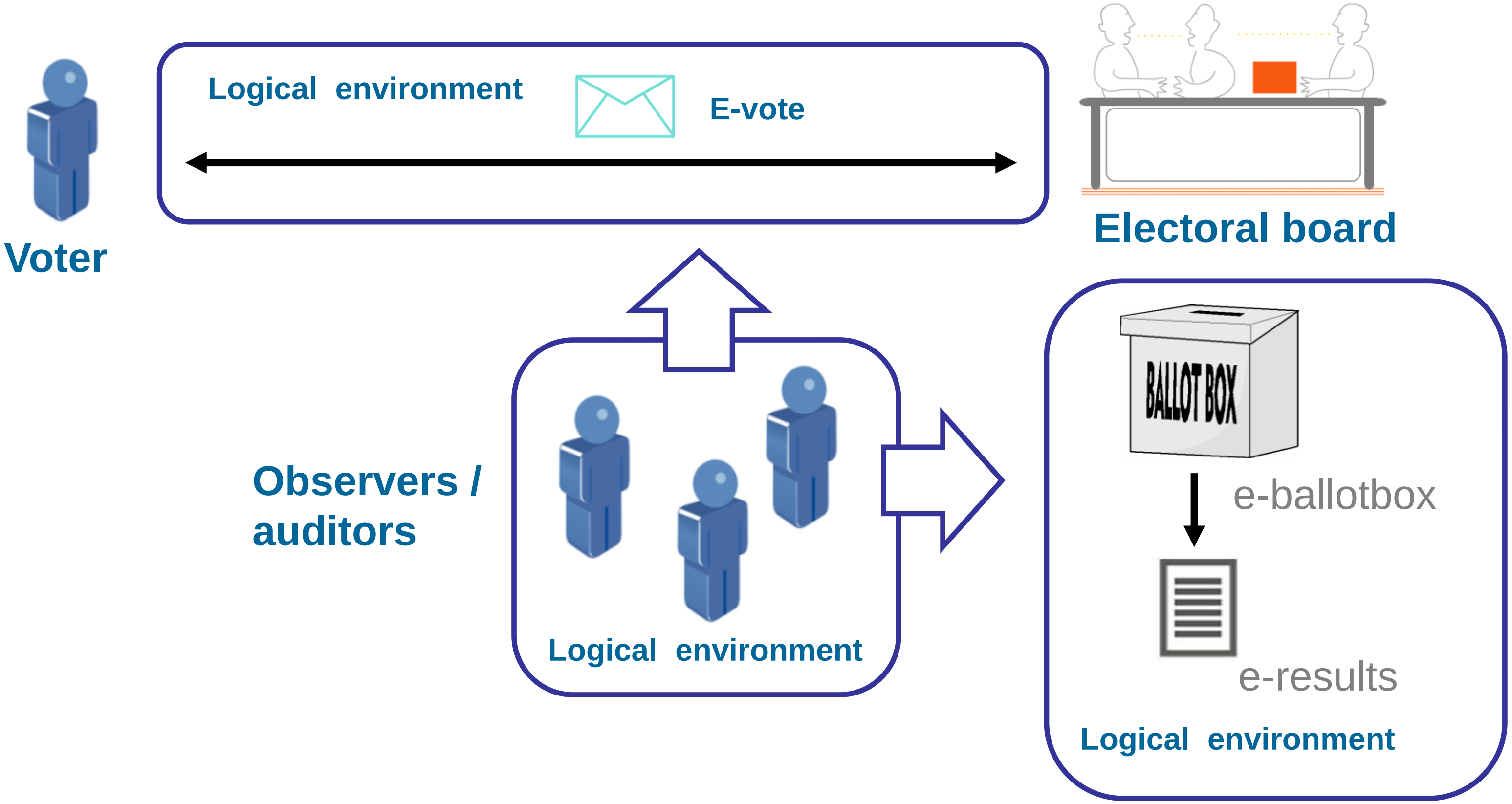
Auditability in traditional voting



- Votes and processes (e.g., counting) are based on tangible elements
  - Audit can be done by observers and independents auditors by human means when the processes are carried out
  - Observers can monitor the behavior of other observers to detect any fraud practices



- Votes and processes are happening in a logical dimension
  - Audit cannot be done by human means
  - Difficult to monitor the behavior of other observers

Audit processes in e-voting

- Source code review/certification
  - Audit process done in advance
  - Does not allow to verify what is exactly happening when the voting platform is executed
- Audit logs
  - Allows to trace what is happening during the execution of the voting platform
  - Could be tampered with by the voting platform during the execution of the voting process
- Monitoring processes
  - Allows to monitor the behavior of the voting platform
  - Intrusive: Who monitors this processes? (Who watches the watchers?)

Is there any way to verify the behavior of the counting process when it is executed without being intrusive?

Solution: Universal verifiable cryptographic protocols

Universal verifiable cryptographic protocols

- Objective
  - Audit process based on the input and output data of the counting process
    - Inputs:
      - Encrypted votes
    - Outputs
      - Decrypted votes
      - Cryptographic proofs of correct behavior of the cryptographic processes (e.g., Zero Knowledge Proofs)
  - Audit process shall preserve the privacy of voters and integrity of the election

- Universal verifiable protocols
  - Homomorphic tally
    - Flexibility problems: does not support alls kinds of vote formats
    - Scalability problems: the amount of cryptographic operations depends on the number of candidates
  - Universal verifiable Mix-nets
    - Does not have limitations on the format of the vote
    - More efficient for large candidate lists

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Universal verifiable Mix-nets

- Objectives
  - Correctness
    - Probability of detecting a bad behavior in the Mixing process
  - Voter privacy
    - Prevents the correlation between encrypted votes and decrypted ones
  - Efficiency
    - Reduces the amount of cryptographic operations required to generate and verify the cryptographic proofs
- Current proposals
  - Sako and Kilian [SK95], Furukawa and Sako [FS01], and Neff [Ne01]
    - High correctness and preserve voter privacy
    - Low efficiency for large elections
  - Random Partial Checking [JJR02]
    - Trade-offs correctness and some voter privacy to improve efficiency
  - Optimistic Mixing [Go02]
    - Preserves voter privacy by sacrificing some correctness to improve efficiency.
- Our proposal tries to solve the handicaps of Random Partial Checking and Optimistic Mixing proposals.

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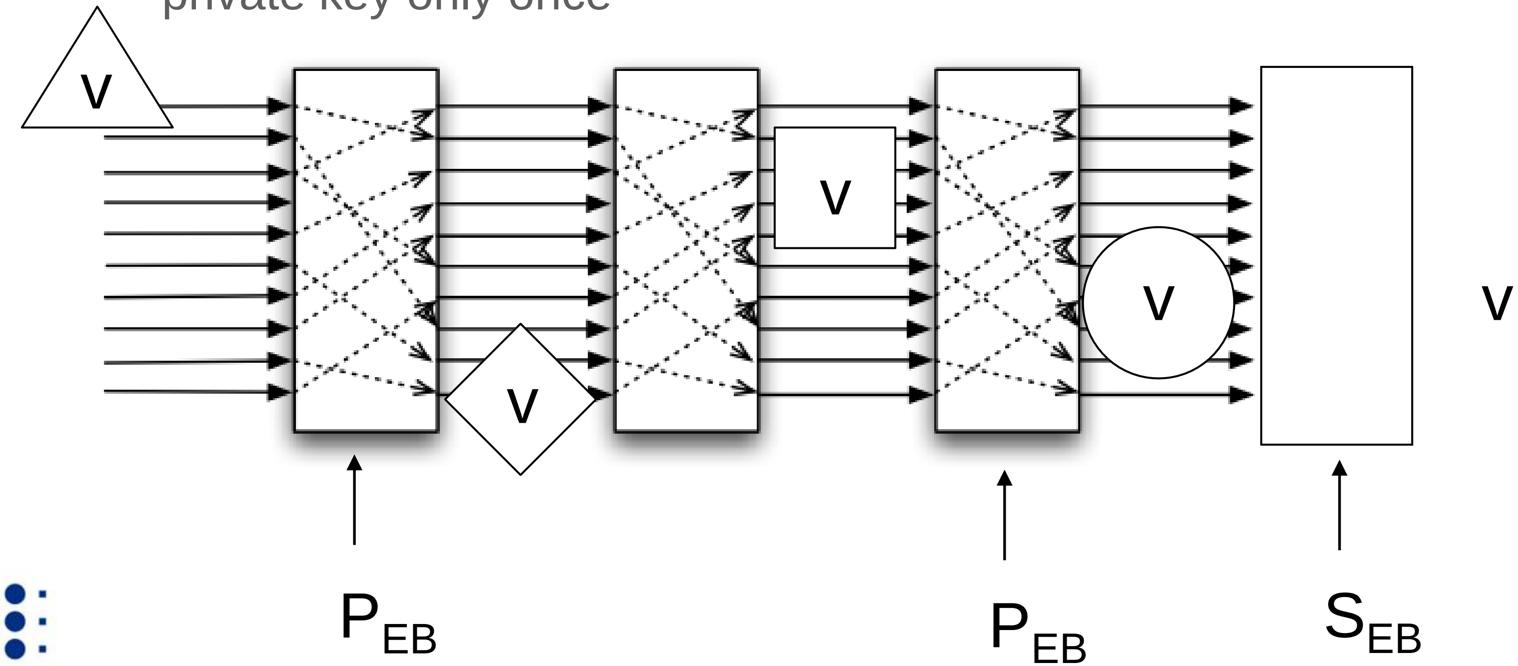
Building blocks from our proposal

- Re-encryption Mixnet
  - Preserves voter privacy in the decryption process
- Homomorphic operation of the votes
  - Allows to generate integrity proofs of sets of encrypted votes without knowing the contents
- Zero Knowledge proofs of:
  - Re-encryption
    - Allows to verify that the result of the re-encryption preserves the original encrypted vote without disclosing it.
  - Correct decryption
    - Allows to verify that a decrypted votes correspond to an encrypted one without disclosing the private key and randomization factor

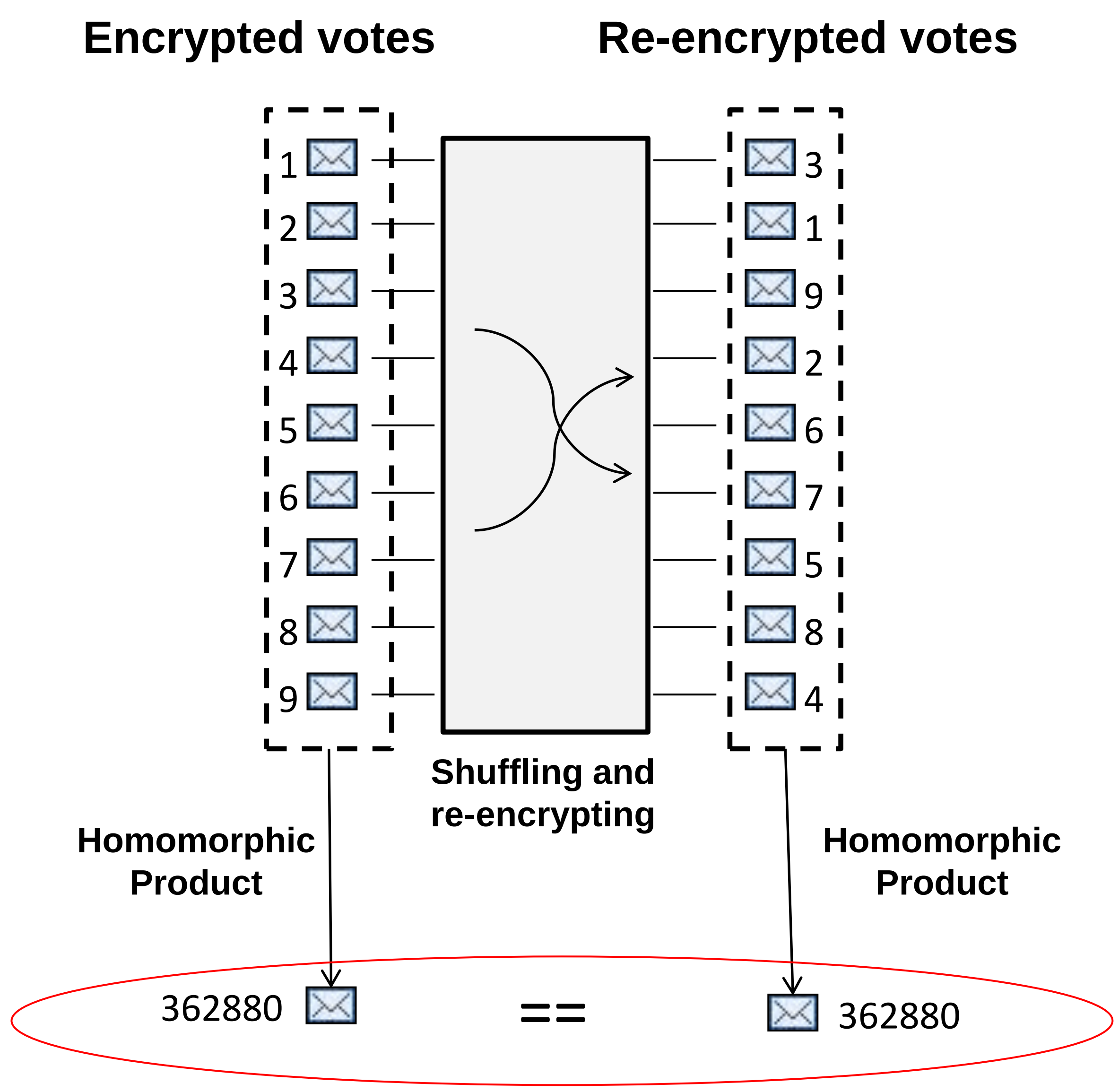
- Re-encryption Mixing:
  - It uses the homomorphic and probabilistic properties of some algorithms: re-encrypting one vote with the same public key does not require multiple decryptions of the vote with the private key, only one.

    $$c = c'. (1. h^{w''}, g^{w''}) = (m'.h^{w'}, g^{w'}) . (1. h^{w''}, g^{w''}) = (m'. h^{w'+w''}, g^{w'+w''})$$

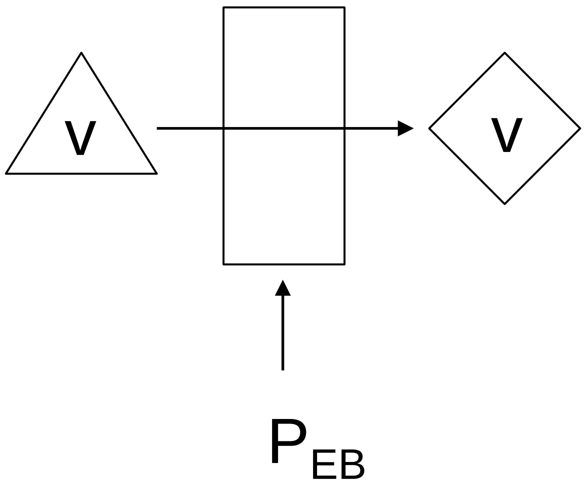
  - Votes are initially encrypted by voters using the Electoral Board public key
  - Each Mix-net node re-encrypts and shuffles the encrypted votes using the same Electoral Board private key
  - At the end of the Mix-net, the Electoral Board decrypts the votes using the private key only once



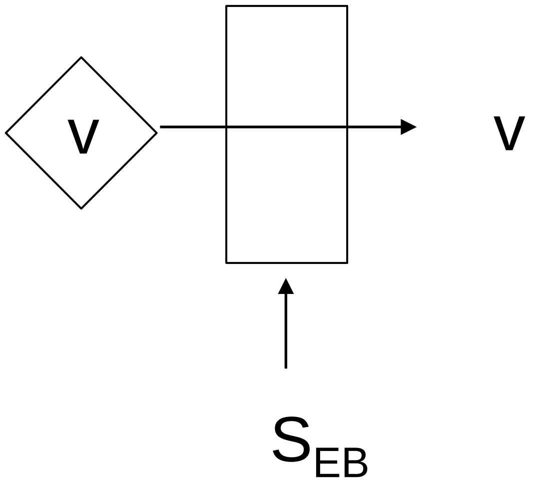
Homomorphic Operation



- Zero Knowledge proof of re-encryption
  - Proofs that the Mix-node knows the re-encryption factor without disclosing it.
  - Based on Schnorr Identification Protocol



- Zero Knowledge proof of correct decryption
  - Proofs that the Mix-node knows the decryption factor without disclosing this factor or the private key.
  - Based on Schnorr Identification Protocol



Steps of our proposal

- Re-encryption of the votes
  - Encrypted votes are re-encrypted and shuffled using a re-encryption Mix-net

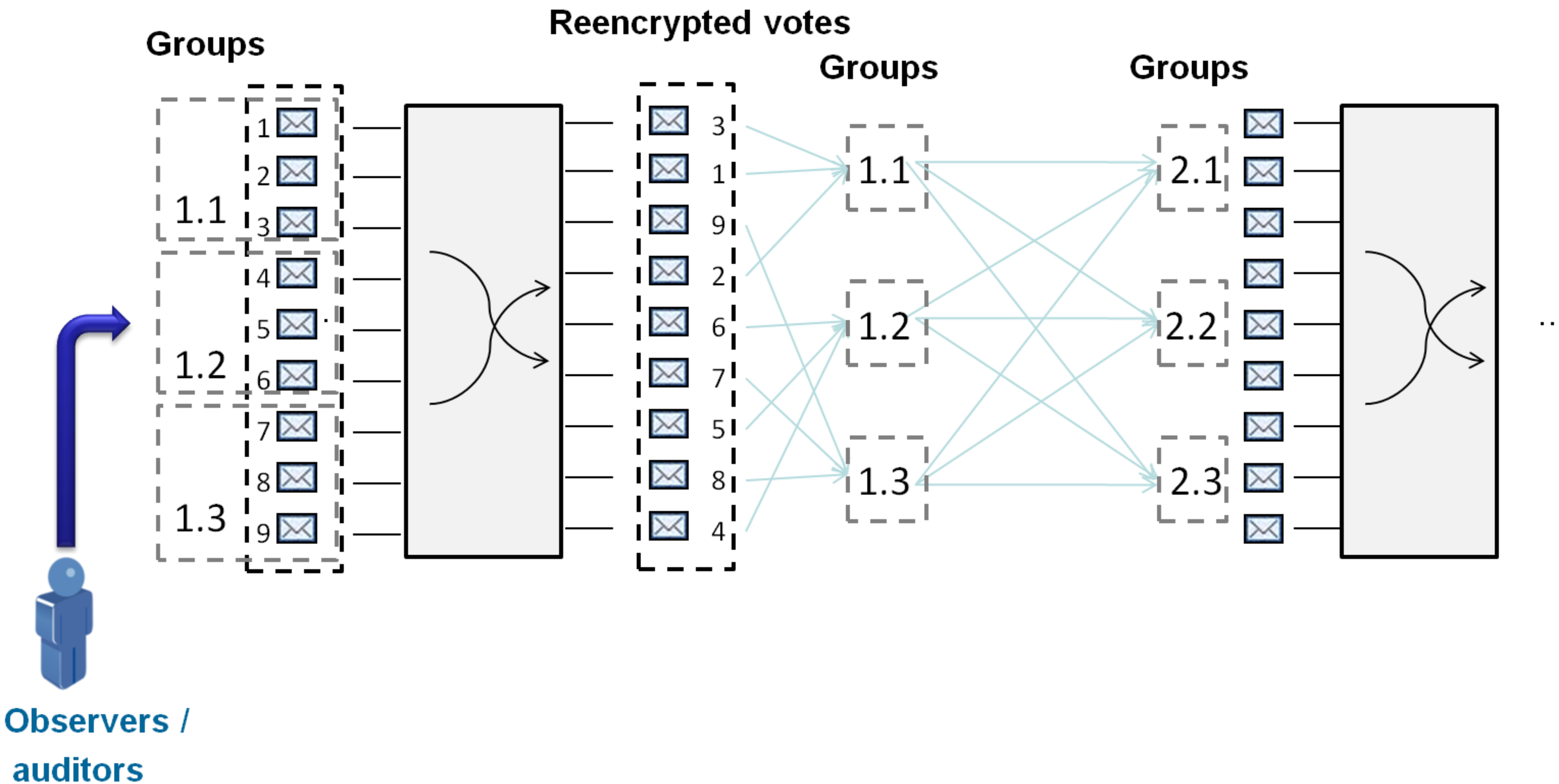
- Auditor/observer challenges the Mix-net
  - Auditor challenges the Mix-net defining a random vote grouping initialization vector
  - Mix-net nodes generates integrity proofs of votes groups

- Verification of the Integrity proofs
  - Integrity proofs are verified before proceeding with vote decryption

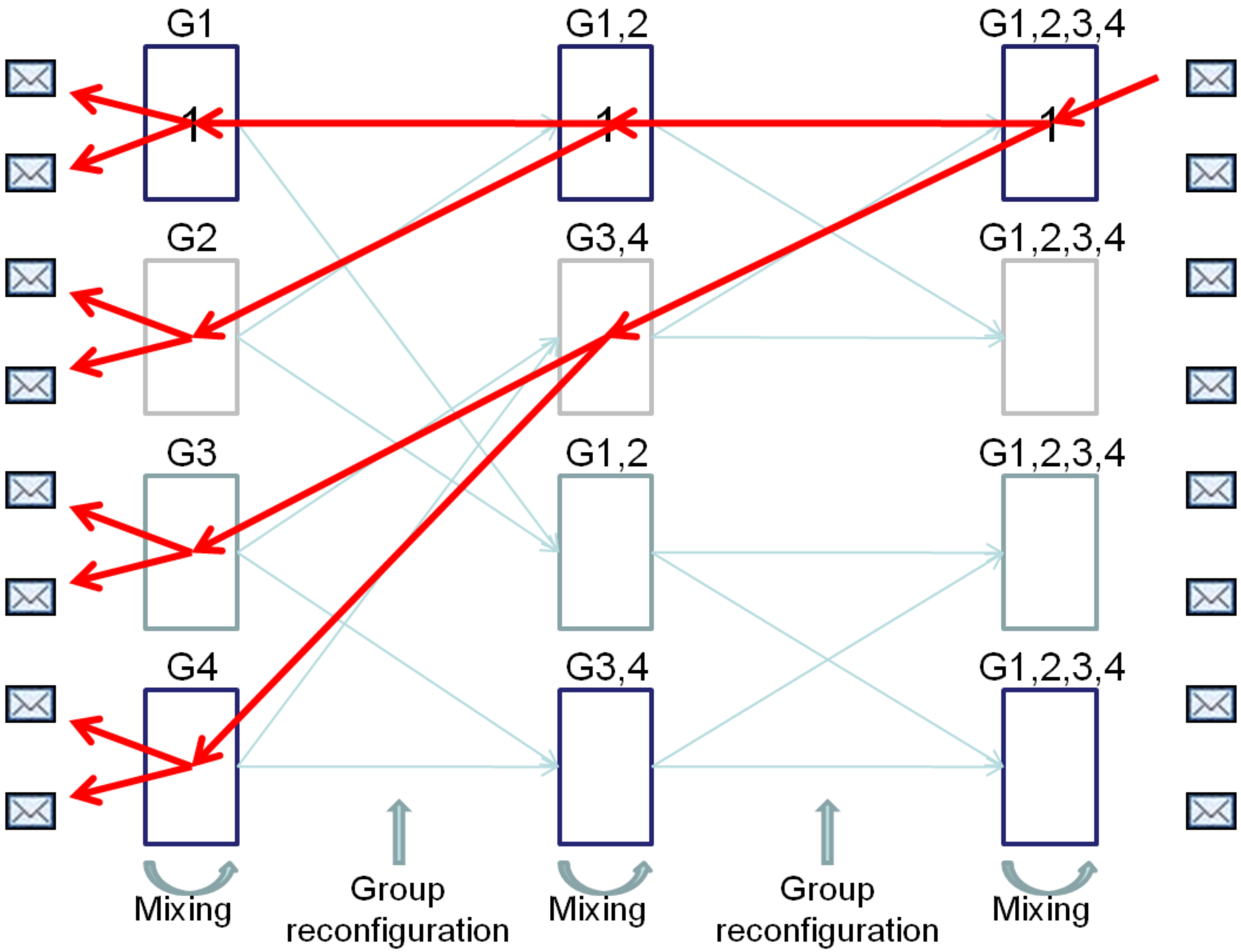
- Decryption of the votes
  - Proofs are verified before proceeding with vote decryption
  - Decryption process generates proofs of correct decryption

- Further audits
  - Input/output Mix-node information (encrypted votes) and integrity proofs can be securely stored to allow further audits

Grouping mechanism



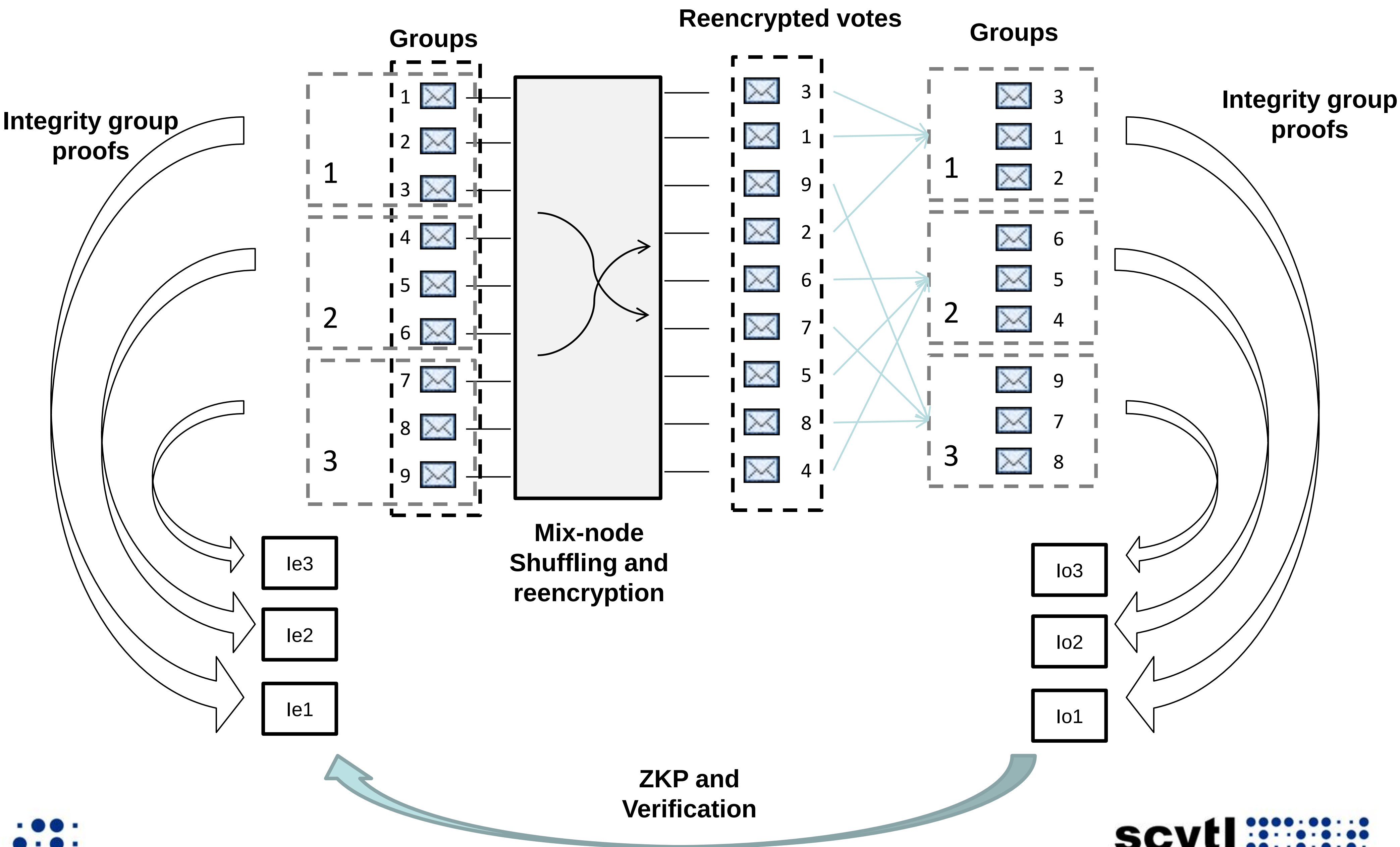
Grouping rationale



$$n = \sqrt[t]{m}$$

t is number Mix-net nodes and m is the total number of votes

Integrity proofs



scytl Secure Electronic Voting

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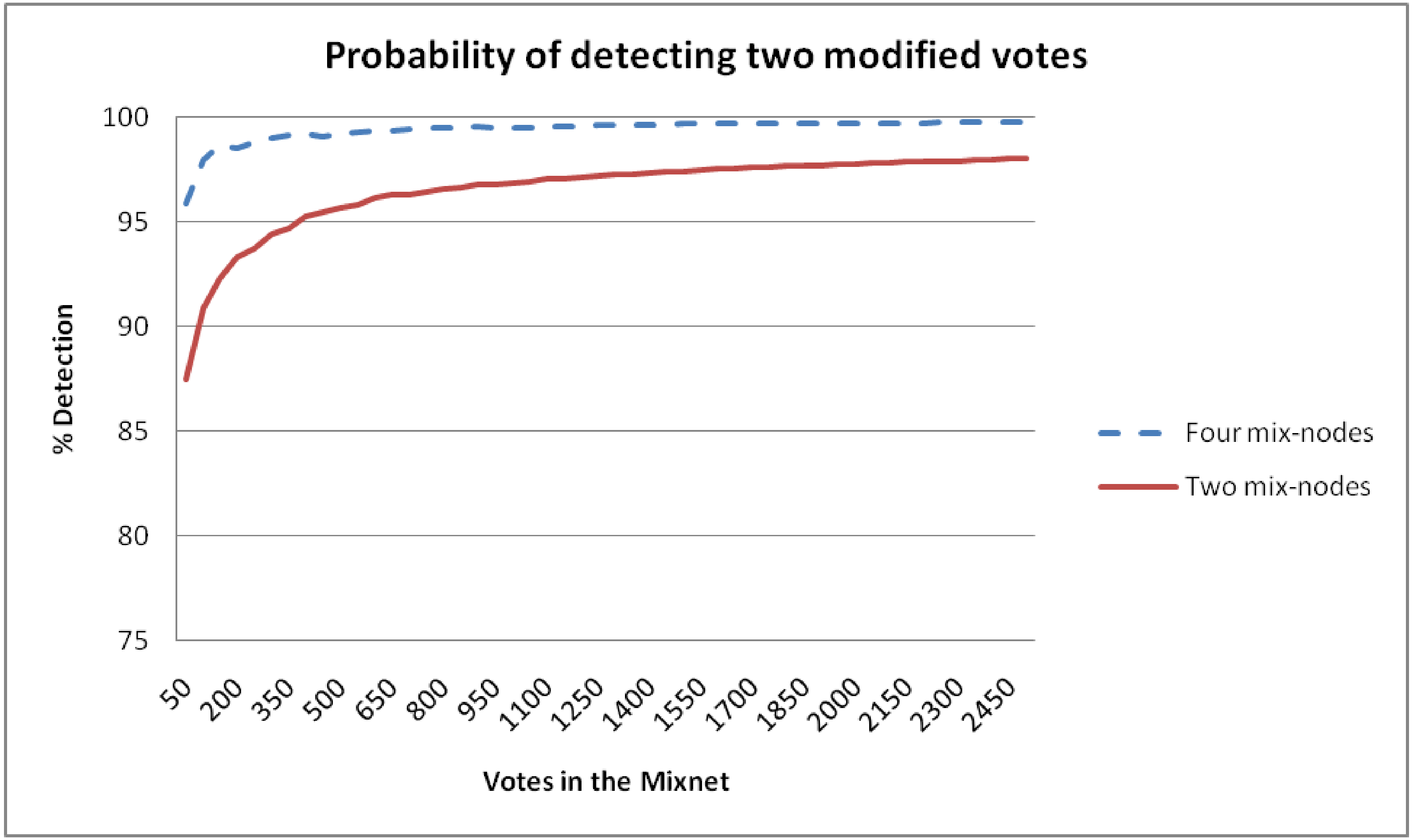
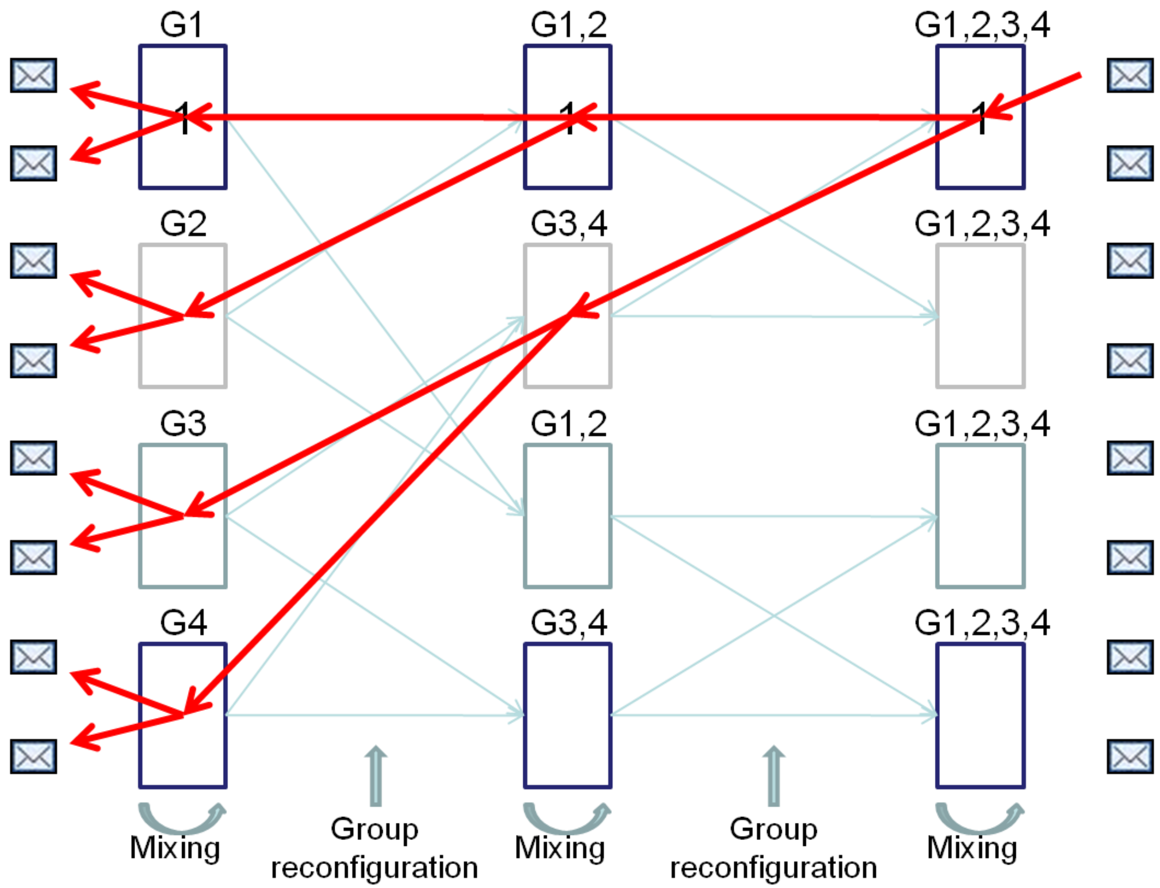


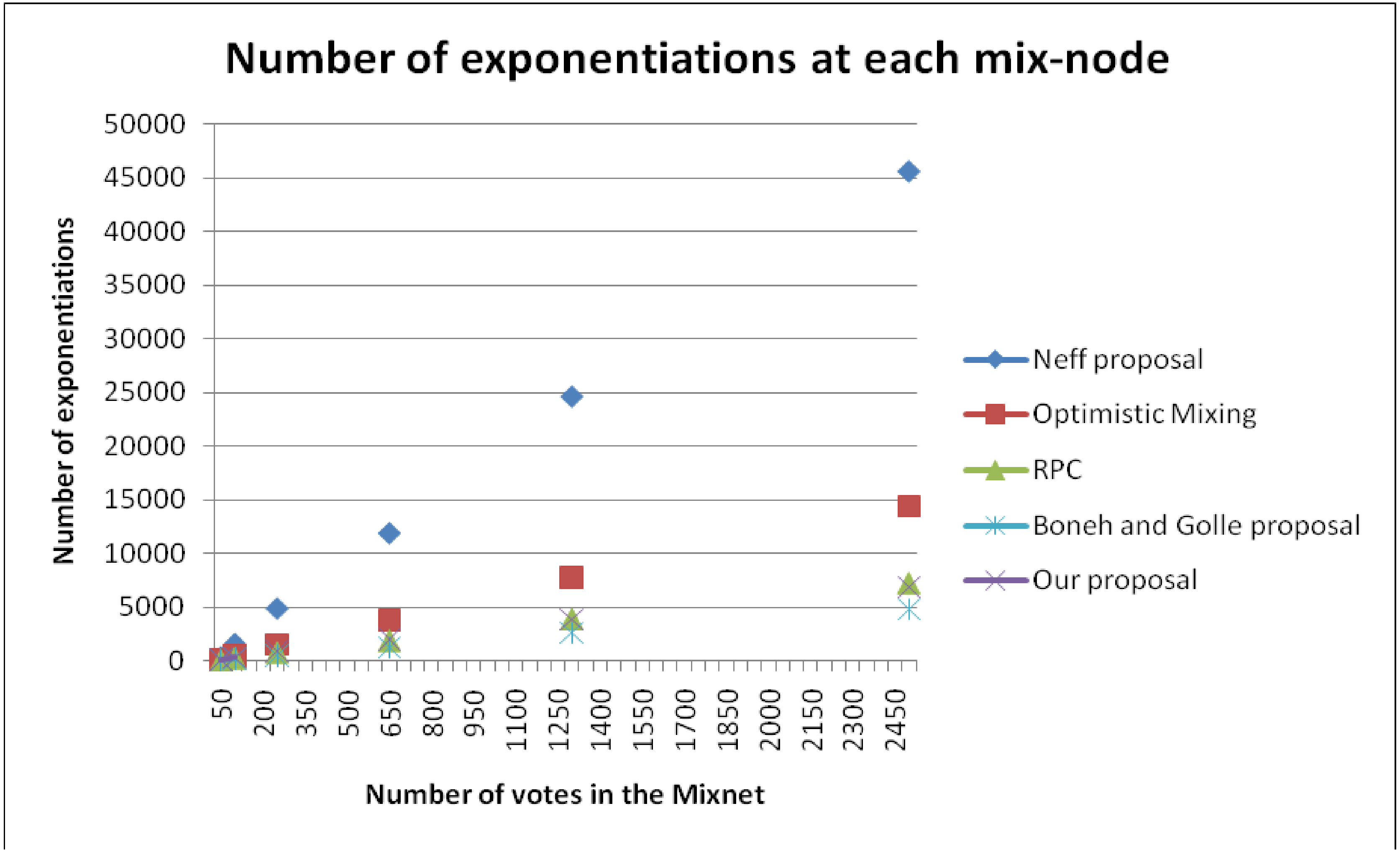
$$P_{success} = 1 - \frac{n-1}{m-1}$$

m is total number of votes and n is the number of votes in each group



- Proofs are based on groups of votes
- Grouping mechanism prevents correlation between input and output Mix-net votes

Efficiency



Number of exponentiations at each mix-node
Number of exponentiations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
50
200
350
500
650
800
950
1100
1250
1400
1550
1700
1850
2000
2150
2300
2450
Number of votes in the Mixnet
Neff proposal
Optimistic Mixing
RPC
Boneh and Golle proposal
Our proposal

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Conclusions

- From the point of view of efficiency, the computation cost of our proposal is close to the fastest one (Boneh and Golle [BG02]) the fastest one, and faster than Random Partial Checking [JJR02] for medium amounts of votes (more than 1500)

- In terms of privacy, it does not pose any privacy concerns as the other efficient methods.

- In terms of accuracy, our proposal achieves a high level of cheating detection compared to the other most efficient methods. This probability is closer to 100% when the number of votes is near 300 votes (99%). The other methods, except [Ne01], have similar or lower accuracy levels.

- In summary, compared with the current verification methods, our solution is the most well-balanced in terms of efficiency, privacy, and accuracy, while providing universal verification properties.

Any questions?

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