Practical Provably Correct Voter Privacy Protecting End to End Voting Employing Split Value Representations of Votes

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RRV (Rabin Rivest Voting) Properties

- Voter Privacy Preserving
- Vote Values Publicly Posted
- Publicly Verifiable Proof of Correctness
- Supports Complicated Voting Forms
- Resistant to Gossipy and Failing Servers
- Highly Efficient
- Not Dependent on Specialized Encryptions Such as Homomorphic Encryptions
- Employs Novel Highly Efficient, Verifiable, Mix-Net Using Just Any Commitment Functions and Split-Value Representation

Structure

- Voter Uses Tablet
- Secure Bulletin Board (SBB) for Posting Concealed Votes, Eventually Clear Vote Values, Proof of Correctness
- Proof Server (PS) Consisting of (For Example) 11 Interconnected Servers
- In Example, Tolerates Up To Two Gossipy Servers, Two Failing Servers
- Correctness Proof, If Accepted, Assures Absolute Correctness of Vote Tally Irrespective of Server Misbehavior

Split-Value Representations [Rabin et al., 2007], [Rabin et al., 2009]

- Let M be an integer, $0 \leq x < M$ a value. A Split-Value (SV) representation of x is $X = (u,v)$ where

$$\text{Val}(X) = (u+v) \bmod M = x$$

- Random SV representation is obtained by $u \leftarrow_R [0, M-1]$, and
$v = (x-u) \bmod M$
- Let COM$(,)$ be a commitment function so that a value u is committed by choosing key K and setting COM(u) = COM(K, u)

Split-Value Representations Continued

- Opening / Decommitting COM(u) done by revealing K, u. Checking correctness by computing COM(K, u) and verifying equality with COM(u).
- COMSV(X) (COM Split-Value X) for $X = (u, v)$ obtained by choosing random keys K_1, K_2 and setting COMSV$(X) = ($COM$(K_1, u),$ COM$(K_2, v))$

Proving Correctness of Equality and of Addition of Concealed Values

- Let $X=(u_1, v_1), Y=(u_2, v_2)$. Assume COMSV$(X)$, COMSV($Y$) posted. Prover who knows to open commitments, claims to Verifier that Val(X)=Val(Y)
- Note: Val(X)=Val(Y) iff exists $t \in [0, M-1]$ s.t. $X = Y + (t, -t)$ i.e. $(u_1, v_1) = (u_2 + t, v_2 - t)$ (all ops. $mod\ M$)
- Proof: Prover posts t

Proving Correctness of Equality and of Addition of Concealed Values (Continued)

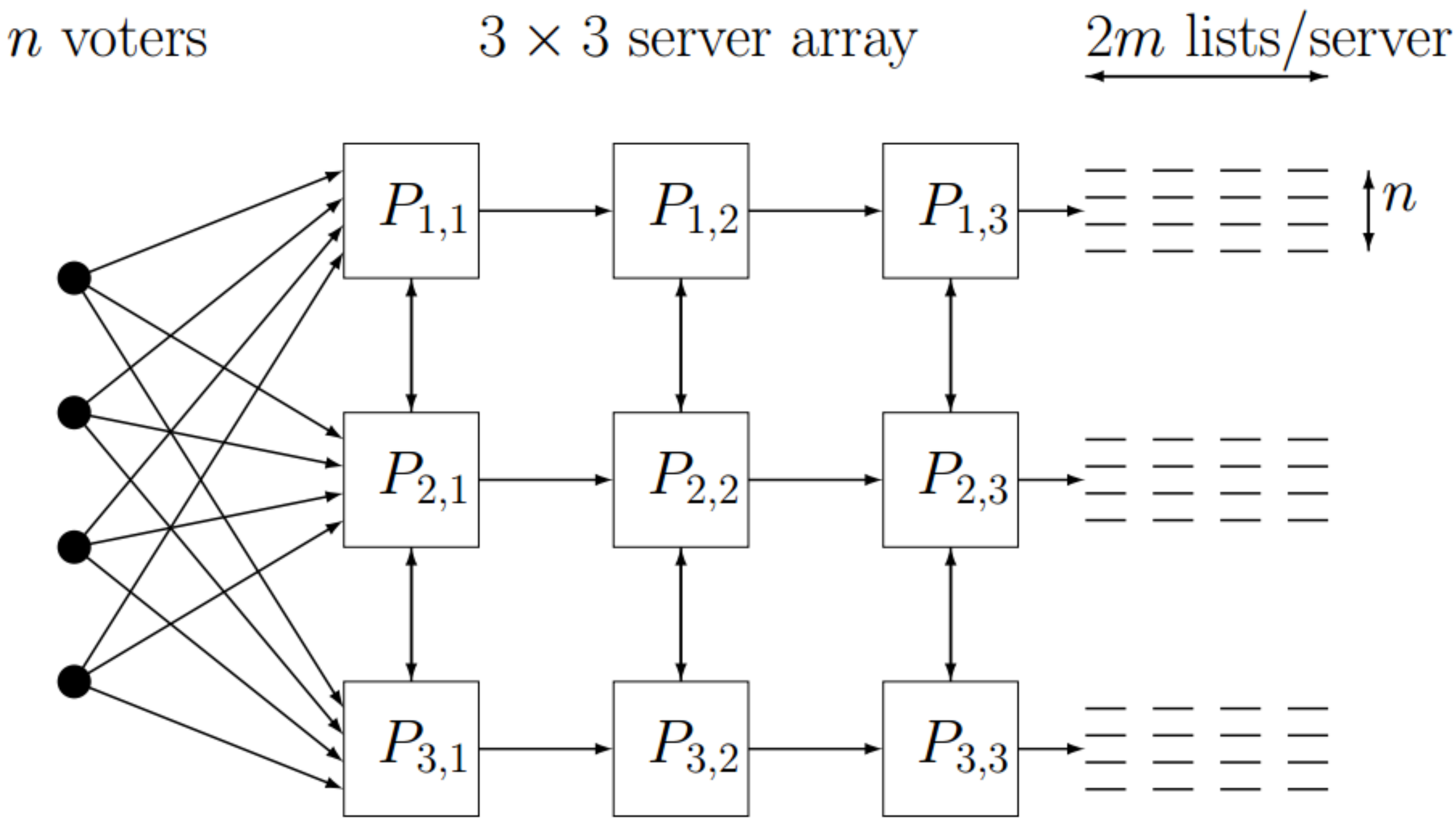
- Verifier randomly chooses $c \in \{1, 2\}$
- If $c=1$, Prover reveals u_1, u_2. Verifier checks $u_1 = u_2 + t$
- If $c=2$, Prover reveals v_1, v_2. Verifier checks $v_1 = v_2 - t$
- PROB(Verifier Accepts False Claim of Val(X) = Val(Y)) ≤ ½
- Assume COMSV(X), COMSV(Y), COMSV(Z) posted. Prover who knows to open commitments claims to Verifier that Val(X)+Val(Y) = Val(Z)

Proving Correctness of Addition (Continued)

- Again, addition holds iff exists $t \in [0, M-1]$, s.t. $X + Y = Z + (t, -t)$. I.e. $(u_1, v_1) + (u_2, v_2) = (u_3 + t, v_3 - t)$
- Again Verifier randomly chooses $c \in \{1, 2\}$.
- If $c = 1$, Prover reveals u_1, u_2, u_3.
- Verifier accepts claim if $u_1 + u_2 = u_3 + t$
- Similarly if $c = 2$
- PROB(Verifier accepts false claim)$\leq 1/2$
- Note that these proofs REVEAL NOTHING about Val(X), Val(Y), Val(Z)!!

Structure of System

- Proof Server comprises 9 servers arranged in 3 rows and 3 columns



Structure of System (Continued)

- System employs standard PKE, say RSA. Three instances EN_1, EN_2, EN_3 with public encryption keys en_1, en_2, en_3 and private / secret decryption keys dc_1, dc_2, dc_3 are used.
- Every Voter Tablet has all public encryption keys en_1, en_2, en_3
- In Proof Server PS first server $P_{1,1}$ in first column gets decryption key dc_1, second server $P_{2,1}$ in first column gets dc_2, third server $P_{3,1}$ in first column gets dc_3.

Voting

- Voter gets a Voter Tablet. Vote represented by some values

  $w \in [0, M-1]$. M, say, $= 2^{32}$
- Tablet randomly breaks voter vote value w into components $w = x + y + z \ (Mod\ M)$
- Tablet creates random split-value representations X, Y, Z for x, y, z. Tablet selects random keys $K_1, K_2, \ldots, K_5, K_6$. Creates COMSV($X$), COMSV($Y$), COMSV($Z$)
- Voter is assigned vote id vid. Voter Ballot is $vid, COMSV(X), COMSV(Y), COMSV(Z)$

Voting (Continued)

- Not mandatory. Voter gets receipt $R = vid,$ Hash of his Ballot
- Tablet collects all ballots, orders by voter ids and posts on SBB

Voter Tablet: Randomly chooses AES key $ktab$

AES($ktab$, list of all X comp. of its vote values) —send→ $P_{1,1}$

AES($ktab$, list of all commitment keys K_1, K_2 of COMSV(X)) —send→ $P_{1,1}$

$EN_1(en_1, ktab)$ —send→ $P_{1,1}$

- Similarly for $P_{2,1}$ and $P_{3,1}$ with Y and Z

Creation of Proof

- Proof Server chooses $2m$ (say $2m=24$)
- Proof Server repeats $2m$ times a net-mixing of cast votes
- Mixing done along the three rows of PS, see diagram
- In each PS column, Proof Servers jointly agree on a permutation of vote values to next column
- Proof Servers in column agree on obfuscation of vote value components, see paper for obfuscation

Creation of Proof (Continued)

- Proof Server $P_{1,3}$ of rightmost column creates COMSV(X) of its obfuscated components. Posts in the permuted order. Similarly, for $P_{2,3}$ creating COMSV(Y) and $P_{3,3}$ creating COMSV(Z)
- Now there are posted $2m$ permutations of commitments to obfuscated components of all the vote values
- Cut-And-Choose: Using strong source of randomness, m permuted lists are chosen and PS rearranges by vote ids and using Split-Value proves equality to posted concealed votes

Creation of Proof (Continued)

- Remaining m permuted lists of commitments to components of votes are opened in permuted form
- Vote values are computed by addition of components
- Assuming fewer than three gossipy servers, voter votes remain private
- Dealing with failures requires two additional servers. Details in full paper.
- Further work deals with fully malicious servers

Probability of Accepting False Proof

- Theorem: The probability that the revealed arrays of vote values are permutations of same values but differ from actually cast value by more than k locations and accepting the tally as correct is at most

$$1/C(2m,m)+(1/2)^k \approx \sqrt{(3.14m)}/2^{2m}+(1/2)^k$$

- Speed. Tallying and posting proof of correctness for one million votes requires less than ten minutes!

Extra slides below

Illustration of the Method

- Addition
  - M=17
  - x=7, y=7, x+y=z=14
  - X=(3,4), Y=(15,9), Z=(8,6)
  - CLAIM: val(X)+val(Y) = val(Z)

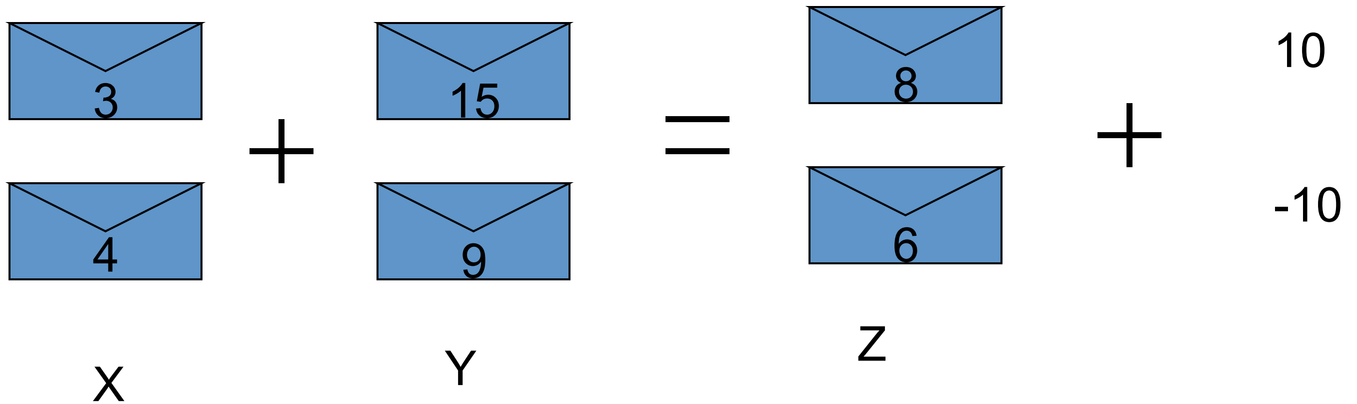


Illustration of the Method

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Prover posts (10,-10). Verifier: $c \xleftarrow{R} \{1,2\}$