Design of a Privacy-Preserving and Anonymously Verifiable E-Voting Protocol using Linkable Ring Signatures, Paillier Homomorphic Encryption, and NIZK-Proven Binary Vote Correctness Enforcement

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***Abstract*—This work proposes a novel electronic voting protocol that achieves both voter privacy and end-to-end verifiability. This scheme leverages *linkable ring signatures* to ensure voter anonymity while preventing double-voting, combined with *Paillier homomorphic encryption* to preserve vote secrecy during tallying. Crucially, this work enforces that each ciphertext encodes a valid binary vote via a non-interactive zero-knowledge (NIZK) proof. This work describes the NIZK proof both mathematically and via explicit Python code. The combination of these components yields a receipt-free voting system in which any observer can verify the correctness of the published tally without learning individual votes. In a comparative analysis, this work contrasts this protocol with Benaloh–Tuinstra [4] and Tsang–Wei [7], demonstrating that this scheme uniquely integrates anonymous authentication with homomorphic tallying and strong ballot correctness proofs. Security arguments and efficiency evaluation indicate that this protocol is practical and provides rigorous privacy and verifiability guarantees.**

***Keywords*—Non-Interactive Zero Knowledge Proofs; Linkable Ring Signature; Secure & Anonymous E-Voting**

1 Introduction

Secure electronic voting must reconcile conflicting goals: preserving voter privacy while allowing public verifiability of election outcomes. Traditional schemes based on mix-nets or homomorphic encryption achieve privacy, but often at the expense of either complex infrastructure or insufficient voter anonymity. For example, Chaumian mix-nets obscure the link between ballots and voters but require trusted mix servers, whereas homomorphic schemes (e.g. based on Paillier encryption) allow tallying without decrypting individual votes[2]. However, simple homomorphic voting protocols are vulnerable to voters revealing secret randomness (creating a *receipt*) and may not provide strong anonymity. The notion of *receipt-freeness* was introduced by Benaloh and Tuinstra [4], who designed a multi-authority voting protocol intended to prevent vote-buying, although subsequent analysis found it to be vulnerable [5]. More recently, linkable ring signatures have been proposed to provide anonymous credentialing: Tsang and Wei [7] introduced a short linkable ring signature (LRS) scheme and built an e-voting system with it, achieving efficient tallying and public verifiability even in worst-case vote distributions.

This work combines the advantages of these techniques. This protocol uses a linkable ring signature scheme to allow a voter to sign a ballot anonymously on behalf of the entire electorate, while ensuring that two votes by the same voter can be detected (through the linking tag) and hence disallowed. Each vote is encrypted under a Paillier public key, taking advantage of its additive homomorphism for tallying. To guarantee that a voter cannot cheat by encrypting an invalid value (e.g. a vote for multiple candidates), this work employs a NIZK proof that the ciphertext encodes either 0 or 1. This proof is constructed via a standard sigma-protocol made non-interactive by the Fiat–Shamir transform [9]. The combination yields a voting protocol that is privacy-preserving (votes are ciphertexts and signers are anonymous) and verifiable (anyone can check the ring signatures and NIZKs, then homomorphically tally and decrypt).

This main contributions are summarized as follows:

- **Protocol Design:** This work designs a complete e-voting protocol incorporating *linkable ring signatures* for anonymous eligibility and double-vote prevention, *Paillier encryption* for privacy-preserving tallying, and a *binary vote correctness NIZK proof* to enforce well-formed ballots.
- **NIZK Construction:** This work formally describes and

mathematically derives the non-interactive zero-knowledge proof for a ciphertext encoding 0 or 1. This work includes explicit equations and step-by-step derivation, as well as a fully annotated Python implementation of the proof generation and verification.

- **Security Analysis:** This work analyzes the protocol's security properties (privacy, authenticity, verifiability) and provides a comparison table contrasting this design with the Benaloh–Tuinstra scheme [4] and the Tsang–Wei scheme [7]. This work shows that the protocol enhances both privacy (through ring anonymity) and correctness enforcement (through NIZK proofs) relative to those prior works.

- **Evaluation:** This work estimates the computational and communication costs of this protocol, discussing the practicality of key operations (Paillier encryption/decryption, ring signature generation/verification, and NIZK proof) for realistic parameter sizes.

The remainder of this paper is organized as follows. Section 2 reviews cryptographic primitives used. Section 3 surveys related e-voting protocols. Section 4 details this proposed scheme, including mathematical description of the NIZK proof and its Python realization. Section 5 analyzes security, with a comparative table. Section 6 evaluates performance. This work concludes in Section 7.

2 Preliminaries

This work reviews the essential building blocks of the protocol: the Paillier cryptosystem, linkable ring signatures, and non-interactive zero-knowledge proofs.

2.1 Paillier Cryptosystem

The Paillier public-key cryptosystem [2] operates over an RSA modulus $N = pq$, where p, q are large primes. The public key is (N, g) (often $g = N + 1$) and the private key is $\lambda = \mathrm{lcm}(p-1, q-1)$. Encryption of a message $m \in \{0, 1, \ldots, N-1\}$ with randomness $r \in \mathbb{Z}_N^*$ yields ciphertext

$$C = g^m \, r^N \bmod N^2.$$

Decryption recovers m by computing $C^\lambda \bmod N^2$ and scaling. Paillier encryption has the additive homomorphic property: the product of ciphertexts decrypts to the sum of the plaintexts. In particular, if $C_1 = g^{m_1} r_1^N$ and $C_2 = g^{m_2} r_2^N$, then $C_1 \cdot C_2 \equiv g^{m_1+m_2}(r_1 r_2)^N \pmod{N^2}$, which decrypts to $m_1 + m_2 \bmod N$. This allows votes to be tallied without revealing individual ballots. The security of Paillier relies on the decisional composite residuosity assumption [2].

2.2 Linkable Ring Signatures

A *linkable ring signature* (LRS) [7] allows a signer to anonymously sign on behalf of a set (ring) of public keys. The signature does not reveal which member signed, providing anonymity akin to a group signature without a group manager. Additionally, linkability means that if the same secret key signs two different messages (or the same message twice), the two signatures are publicly linkable via a common tag. This property deters double-signing without identifying the signer by name. Formally, an LRS scheme consists of algorithms $(\text{LRS-KeyGen}, \text{LRS-Sign}, \text{LRS-Verify}, \text{LRS-Link})$, where LRS-Link outputs YES if two signatures are by the same signer (same key) in the same ring.

In this protocol, each voter has a public/private key pair. The ring is taken as the collection of all eligible voters' public keys. When a voter signs a ballot, they produce a linkable ring signature σ on the ballot and accompanying ciphertext. Any observer verifies σ against the full set of keys, confirming membership of the signer without knowing which key. If a voter signs twice, the LRS-Link algorithm will detect the reuse of the same secret key, and the second ballot can be rejected. This work adopts the short LRS construction of Tsang & Wei [7], which yields signatures of constant size (independent of ring size) and security under the Link-DSA assumption.

Each user selects a private key $x \in \mathbb{Z}_q$ at random and computes the public key $P = xG$, where G is a generator of an elliptic curve group of order q. The key image is defined as

$$I = x \cdot H_p(P),$$

where $H_p : \{0,1\}^* \to \mathscr{G}$ is a hash-to-curve function. The key image I binds signatures from the same key without revealing the key itself.

To sign a message m with anonymity among a ring of n public keys $\{P_0, \ldots, P_{n-1}\}$, suppose the signer's secret key corresponds to index s. The signer picks $u \in_R \mathbb{Z}_q$ uniformly at random and computes

$$L_s = uG, \qquad R_s = u H_p(P_s).$$

Let $H : \{0,1\}^* \to \mathbb{Z}_q$ be a cryptographic hash function (modeled as a random oracle) used for challenge generation. The signer initializes the challenge chain by computing

$$c_{(s+1) \bmod n} = H\big(m \,\|\, L_s\big).$$

Then for each $i = s+1, s+2, \ldots, s-1$ (indices taken mod n), the signer chooses a random $r_i \in_R \mathbb{Z}_q$ and computes

$$L_i = r_i G + c_i P_i, \qquad R_i = r_i H_p(P_i) + c_i I,$$

and updates

$$c_{i+1} = H\big(m \,\|\, L_i\big).$$

After completing the loop back to index s, the signer sets

$$r_s = u - c_s x \pmod{q}.$$

The signature consists of the key image I, the initial challenge $c_{(s+1) \bmod n}$, and the responses r_i for $i = 0, \ldots, n-1$.

To verify a signature on m, the verifier recomputes for each $i = 0, \ldots, n-1$:

$$L_i' = r_i G + c_i P_i, \qquad R_i' = r_i H_p(P_i) + c_i I,$$

and sets $c_{i+1} = H(m \| L_i')$. The signature is accepted if and only if the final challenge equals the initial one (i.e., the challenge loop closes, so $c_n = c_0$ when indices are considered modulo n).

2.3 Zero-Knowledge Proofs

Zero-knowledge proofs allow a prover to convince a verifier of a statement without revealing any additional information beyond the validity of the statement. In particular, this work uses a *non-interactive* zero-knowledge (NIZK) proof in the Random Oracle Model via the Fiat–Shamir heuristic [9]. Concretely, to prove knowledge of a secret satisfying some relation, the prover simulates a three-move Σ-protocol by choosing random commitments, computing a challenge as the hash of these commitments (and the statement), and then responding accordingly. The verifier checks that the commitments and responses satisfy the relation given the challenge. By the Fiat–Shamir transform, this yields a proof that anyone can verify by recomputing the hash as the challenge, without interaction.

In this scheme, we require a proof that a given Paillier ciphertext encrypts either 0 or 1 (a *binary range proof*). This work constructs a specialized OR-proof for the statements "$C = g^0 r^N$" or "$C = g^1 r^N$", detailed in Section 4. This enforces vote integrity (no invalid votes) while preserving privacy.

3 Related Work

E-voting protocols with strong privacy and verifiability have been widely studied. Mix-net based schemes [1] achieve unlinkability of ballots, and homomorphic encryption schemes [2, 3] allow public tallying. Benaloh and Tuinstra [4] introduced multi-authority homomorphic voting protocols aiming for *receipt-freeness*, but Hirt and Sako [5] showed that their scheme could still be coerced. Cramer *et al.* [3] provided efficient homomorphic protocols with proofs of well-formed ballots. Other works (e.g. [6, 3]) consider mix-nets or blind signatures to mitigate coercion. However, those approaches either require complex distributed trust or can only partially prevent receipt attacks.

Ring signatures have been applied to e-voting to enhance anonymity. The original ring signature by Rivest *et al.* allows a user to sign anonymously among a chosen group. Linkable variants [8, 7] add double-sign detection. Tsang and Wei [7] explicitly designed a short linkable ring signature scheme and used it to build an e-voting protocol. Their scheme provides efficient tallying and supports write-in votes, but does not by itself include a proof of vote correctness. This protocol can be viewed as building on this idea: this work uses a linkable ring signature to achieve anonymity and double-vote prevention, but additionally incorporates Paillier encryption and an explicit NIZK proof to guarantee vote validity.

In summary, this work synthesizes these advances: like [7], this work achieves anonymous and verifiable voting via ring signatures, and like [2, 3] this work uses homomorphic encryption for tallying. However, this work uniquely enforces vote well-formedness (binary votes) via a NIZK proof, offering stronger correctness assurance without compromising privacy.

4 Proposed Scheme

Assume an election with n eligible voters. Each voter i has a key pair (sk_i, pk_i) for a linkable ring signature scheme [7]. Let the set of all public keys be $\mathscr{R} = \{pk_1, \ldots, pk_n\}$. A central authority generates a Paillier key pair (PK, SK) with public key $PK = (N, g)$ and private key for decryption. These parameters are publicly known.

Voting proceeds as follows. Voter i with secret key sk_i chooses a binary vote $v \in \{0, 1\}$. They perform:

1. **Encrypt:** Pick random $r \in \mathbb{Z}_N^*$. Compute the Paillier ciphertext
$$C = g^v r^N \bmod N^2.$$
This encrypts v under PK.

2. **Prove:** Compute a non-interactive zero-knowledge proof π that C encrypts either 0 or 1. This proof is constructed by an OR-sigma protocol as follows (details below).

3. **Sign:** Form the message $M = (C, \pi)$ and compute a linkable ring signature $\sigma \leftarrow \text{LRS-Sign}(sk_i; \mathscr{R}, M)$. This yields an anonymous signature proving that some member of $\mathscr{R}$ (namely voter i) signed M, with a linkability tag to detect repeats.

4. **Publish:** Send (C, π, σ) to the public bulletin board. All parties (voters and observers) then verify the signature and proof.

After voting, anyone can perform the tally:

1. **Verify Ballots:** For each posted (C, π, σ), check that σ is a valid ring signature on $M = (C, \pi)$ with respect to $\mathscr{R}$, and check that the NIZK proof π verifies (see below). Reject any ballot failing these checks or any second ballot linked (by LRS-Link) to the same secret key.

2. **Aggregate:** Multiply all valid ciphertexts:

$$C_{\text{tot}} = \prod_{\text{valid } C} C \bmod N^2.$$

Due to Paillier's homomorphism, C_{tot} is an encryption of the sum of all votes.

3. **Decrypt:** The authority (or a threshold of authorities) uses Paillier decryption to recover the tally $\sum_i v_i$. Publish the total and a proof of correct decryption if desired.

This completes the protocol. Now focus on the NIZK proof and its implementation.

4.1 NIZK-Proof of Binary Vote

The goal is to prove that the ciphertext $C = g^v r^N$ encrypts a valid vote $v \in \{0,1\}$ without revealing v or r. Equivalently, prove knowledge of r_0 or r_1 such that

$$C = 1 \cdot r_0^N \quad \text{or} \quad C = g \cdot r_1^N.$$

This is a disjunction of two statements. This work constructs a sigma-protocol that proves the OR of these statements, and makes it non-interactive via Fiat–Shamir.

Concretely, the voter does the following for their chosen vote $v \in \{0,1\}$ (with corresponding randomness r):

1. Choose random values. If $v = 0$, let $r_0 = r$ be the true randomness (so $C = r_0^N$) and pick random $u_0 \in \mathbb{Z}_N^*$. Also pick random challenge $e_1 \in \{0,\ldots,N-1\}$ and random response $z_1 \in \mathbb{Z}_N^*$. If $v = 1$, let $r_1 = r$ (so $C = g r_1^N$), pick random $u_1 \in \mathbb{Z}_N^*$, and random e_0, z_0 instead.

2. Form commitments:

$$A_0 = \begin{cases} u_0^N \bmod N^2, & \text{if } v = 0, \\ (g^{z_0})(C)^{-e_0} \bmod N^2, & \text{if } v = 1, \end{cases}$$

$$A_1 = \begin{cases} g^{z_1}(C/g)^{-e_1} \bmod N^2, & \text{if } v = 0, \\ u_1^N \bmod N^2, & \text{if } v = 1. \end{cases}$$

Here $g^{z_1}(C/g)^{-e_1}$ means $g^{z_1} \cdot (C/g)^{-e_1} \bmod N^2$. Note $(C/g) = r_1^N$ when $v = 1$, and $C/1 = r_0^N$ when $v = 0$.

3. Compute the challenge e as the hash $e = H(A_0, A_1, C)$ (modeled as random), and split it: if $v = 0$ set $e_0 = e - e_1 \pmod N$; if $v = 1$ set $e_1 = e - e_0 \pmod N$.

4. Compute responses:

$$z_0 = \begin{cases} u_0 \cdot r_0^{-e_0} \bmod N, & v = 0, \\ z_0, & v = 1 \text{ (simulated)}, \end{cases}$$

$$z_1 = \begin{cases} z_1, & v = 0 \text{ (simulated)}, \\ u_1 \cdot r_1^{-e_1} \bmod N, & v = 1. \end{cases}$$

The proof π consists of the tuple $(A_0, A_1, e_0, e_1, z_0, z_1)$. A verifier checks:

$$e \stackrel{?}{=} e_0 + e_1 \pmod N,$$
$$A_0 C^{e_0} \equiv z_0^N \pmod{N^2},$$
$$A_1 (C/g)^{e_1} \equiv g^{z_1} \pmod{N^2}.$$

These equations ensure that either $C = r_0^N$ or $C = g r_1^N$ was proven without revealing which case is real. This construction yields a non-interactive ZK proof of the binary plaintext. The security follows from the standard OR-proof arguments and the Fiat–Shamir heuristic [9].

4.2 Example Python Implementation

The following Python code illustrates the Paillier encryption and the NIZK proof for a binary vote. (In practice, one would use a cryptographic library and secure hashing for the challenge.) This work presents the full code of proof generation and verification for clarity:

```
import random, math

# Extended GCD for modular inverse
def egcd(a,b):
    if b == 0:
        return (1, 0, a)
    x2, y2, g = egcd(b, a % b)
    return (y2, x2 - (a//b)*y2, g)

def modinv(a, m):
    x, y, g = egcd(a, m)
    if g != 1:
        raise Exception
            ("No modular inverse")
    return x % m

# Example Paillier key (small
# primes for illustration)
p = 61
q = 53
N = p * q
g = N + 1
```

```
N2 = N * N  # modulus N^2

# Paillier encryption
# of bit m (0 or 1)
def encrypt(m):
    r = random.randrange(1, N)
    C = pow(g, m, N2) *
        pow(r, N, N2) % N2
    return C, r

# Generate a NIZK proof that C
# encrypts 0 or 1 under Paillier
def prove_binary(C, m, r):
    if m == 0:
        # Case: real is C = r0^N
        r0 = r
        # Simulate S1 branch by
        # choosing e1,z1 at random
        u0 = random.randrange(1, N)
        A0 = pow(u0, N, N2)
        e1 = random.randrange(0, N)
        z1 = random.randrange(1, N)
        inv_g = modinv(g, N2)
        H = (C * inv_g) % N2  # = r0^N
        # Compute A1 = g^z1 * H^{-e1}
        H_e1 = pow(H, e1, N2)
        A1 = pow(g, z1, N2) *
             modinv(H_e1, N2) % N2
        e = random.randrange(0, N)
        e0 = (e - e1) % N
        inv_r0e0 = modinv(
            pow(r0, e0, N),
            N
        )
        z0 = u0 * inv_r0e0 % N
    else:
        # Case: real is C = g * r1^N
        r1 = r
        # Simulate S0 branch by
        # choosing e0,z0 at random
        e0 = random.randrange(0, N)
        z0 = random.randrange(1, N)
        C_e0 = pow(C, e0, N2)
        A0 = modinv(C_e0, N2)
        # Real S1 branch:
        u1 = random.randrange(1, N)
        A1 = pow(u1, N, N2)
        e = random.randrange(0, N)
        e1 = (e - e0) % N
        inv_r1e1 = modinv(
            pow(r1, e1, N),
            N
        )
        z1 = u1 * inv_r1e1 % N
    return (A0, A1, e0, e1, z0, z1)

# Verify the NIZK proof
def verify_proof(C, proof):
    A0, A1, e0, e1, z0, z1 = proof
    # Check challenges sum correctly
    if (e0 + e1) % N != (e0 + e1):
        return False
    # Check equations
    left0 = A0 * pow(C, e0, N2) % N2
    right0 = pow(z0, N, N2)
    left1 = A1 * pow(
        (C * modinv(g, N2)) % N2,
        e1, N2
    ) % N2
    right1 = pow(g, z1, N2)
    return (left0 == right0)
        and (left1 == right1)

# Example usage:
# Voter encrypts vote m=0 or 1
m = random.choice([0,1])
C, r = encrypt(m)
proof = prove_binary(C, m, r)
assert verify_proof(C, proof),
    "Proof failed!"
```

In the above code, `prove_binary` follows the mathematical description. The verifier checks that the supplied tuple satisfies $A_0 C^{e_0} \equiv z_0^N$ and $A_1 (C/g)^{e_1} \equiv g^{z_1}$ modulo N^2. This ensures C encrypts either 0 or 1.

5 Security Analysis

This protocol satisfies key security properties:

Voter Privacy and Anonymity. Each ballot is signed with a ring signature over the full voter set $\mathscr{R}$, so the voter's identity is hidden among all eligible voters [7]. The linkable tag only reveals if the same secret key voted twice, not the voter's identity. Under the anonymity of the LRS scheme, an adversary cannot distinguish which member signed a given ballot.

Ballot Secrecy. Votes $v \in \{0,1\}$ are encrypted under Paillier, and only the aggregated ciphertext is ever decrypted. No individual vote is revealed. Semantic security of Paillier [2] ensures that ciphertexts do not leak vote values, assuming the authority's secret key remains secret.

Integrity and Non-Malleability. The NIZK proof π binds each ciphertext to the statement "it encrypts 0 or 1." A malicious voter cannot produce a ciphertext for an invalid vote without making the

proof fail. Furthermore, the linkable ring signature σ binds the ciphertext and proof to an eligible voter's key: it is unforgeable under the LRS security assumption (similar to group signature security) [7]. Thus no outsider can forge a valid ballot, and any tampering with (C, π) will invalidate the signature or proof.

Double-Vote Prevention. If a voter attempts to vote twice, the two ballots will yield the same linking tag in their ring signatures. Observers will detect this via LRS-Link and reject the second ballot. Hence each eligible key can produce at most one counted vote, ensuring one-person-one-vote.

Public Verifiability. All ballots (C, π, σ) are posted publicly. Anyone can verify every signature and proof without trusting any authority. The correct tally can be computed by anyone using the homomorphic property, then decrypted by the authority (who must prove honest decryption). This end-to-end verifiability is analogous to other homomorphic schemes [3], with the added benefit of ring-based anonymity.

Table 1 contrasts this protocol with the Benaloh–Tuinstra multi-authority scheme [4] and the Tsang–Wei ring-signature scheme [7]. It highlights differences in encryption, anonymity mechanism, and proof obligations. Notably, only this scheme combines linkable anonymity with a NIZK ballot correctness proof.

Table 1: Comparison of voting schemes: Benaloh–Tuinstra [4], Tsang–Wei [7], and this proposed scheme.

Feature	Benaloh–Tuinstra	Tsang–Wei	Proposed
Homomorphic Tally	Yes (additive)	No	Yes (Paillier)
Signature/Auth.	No	Linkable Ring	Linkable Ring
Vote Privacy	Via mix/secret share	Ring anonymity	Ring anonymity
Double-Vote Check	No	Yes (linking)	Yes (linking)
Ballot Correctness	Assumed	N/A	Proven by NIZK
Receipt-Freeness	Claimed but broken [5]	Not addressed	Yes (no receipts)
Public Verifiability	Partial (multiple authorities)	Yes	Yes
Write-in Support	No	Yes	No (binary only)

Notes: Benaloh–Tuinstra [4] uses secret-sharing among authorities for tally and claimed receipt-freeness, but was later shown not fully receipt-free [5]. Tsang–Wei [7] uses linkable ring signatures for anonymity and write-in votes. This scheme uniquely adds an explicit proof that each ballot encrypts a single valid choice, strengthening integrity without sacrificing privacy.

6 Evaluation

Let's discuss the efficiency and concrete performance considerations of this protocol. Let the number of voters be n. Each voter's ballot consists of one Paillier ciphertext (size $O(\log N^2)$ bits), one linkable ring signature (constant-size in Tsang–Wei's scheme [7]), and the NIZK proof (a few group elements of size $O(\log N)$). Communication per ballot is therefore $O(\log N)$ words.

Computational costs: Paillier encryption requires two exponentiations mod N^2. The NIZK proof generation involves roughly 2 exponentiations for commitments and 2 modular inverses (which are equivalent to exponentiations via extended GCD). The ring signature generation in Tsang–Wei's construction is $O(1)$ exponentiations (independent of ring size). Verification requires similar exponentiations (one per check). Thus overall, a voter performs $O(1)$ exponentiations per ballot, and verification cost per ballot is also $O(1)$. The final tally involves multiplying n ciphertexts and one decryption: multiplication is $O(n)$ multiprecision multiplications, and decryption (modular exponentiation with exponent λ) is moderate cost.

In practice, using 2048-bit RSA groups (so $\log N \approx 2048$ bits), each exponentiation is feasible on modern hardware. For example, Paillier encryption or decryption in a 2048-bit group takes on the order of milliseconds. The ring signature and NIZK exponentiations add only constant overhead. Therefore, this protocol is practical for elections with thousands of voters, especially since proofs can be verified offline after voting concludes. (Using threshold decryption can distribute the final decryption cost if desired.)

7 Conclusion

This work has presented a comprehensive e-voting protocol that integrates linkable ring signatures, homomorphic encryption, and zero-knowledge proofs to achieve voter privacy, ballot integrity, and verifiability. By signing ballots with an LRS scheme, this work ensures that votes remain anonymous yet cannot be double-cast. By encrypting votes with Paillier, this work keeps ballots secret and allows public aggregation. By proving via NIZK that each ciphertext encodes a valid binary vote, this work prevents malformed ballots without revealing voter choices. This protocol thus provides a high level of security: ballots are private, votes are cast only once and counted correctly, and the tally can be audited by anyone.

As future work, one could extend this framework to multi-candidate elections (beyond binary votes) by using range proofs, or improve efficiency via optimized NIZK techniques. Integrating this scheme into real-world voting platforms (e.g. with threshold decryption and authenticated bulletin boards) is another direction. I believe the combination of linkable ring signatures and homomorphic encryption, now with provable vote integrity, offers a strong foundation for next-generation privacy-preserving voting systems.

Source Code at Github

Here is the link of the paper source code on my GitHub: https://github.com/ZKTally/ZKTally.

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Pernyataan

Dengan ini saya menyatakan bahwa makalah yang saya tulis ini adalah tulisan saya sendiri, bukan saduran, atau terjemahan dari makalah orang lain, dan bukan plagiasi.

Bandung, 20 Juni 2024

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