

OraSRS: A Compliant and Lightweight Decentralized Threat Intelligence Protocol with Time-Bounded Risk Enforcement

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Abstract

I present OraSRS, a decentralized threat intelligence protocol that addresses a fundamental tension in security systems: the trade-off between response speed and security decentralization. After implementing and testing several centralized and pure decentralized consensus approaches, I observed that existing solutions are inadequate for real-time defense. Centralized services like VirusTotal create single points of failure, while pure consensus layer solutions introduce unacceptable latency ($\gtrsim 100\text{ms}$), making them unsuitable for real-time threat blocking. OraSRS achieves $\approx 100\text{ms}$ local response through optimistic execution at the edge, while ensuring global consistency via decentralized consensus layer verification. My key innovations include: (1) a T0-T3 verification lifecycle that decouples local defense from final confirmation; (2) a commit-reveal mechanism with staking slashing to deter Sybil attacks; (3) time-bounded risk enforcement (7-day auto-recovery) for compliance. Unlike cryptographic protocols, OraSRS focuses on real-world deployability, compliance, and sub-100ms response—requirements overlooked by prior threat intelligence systems. Evaluation shows sub-0.04ms local latency, 95.5% F1-score, and $\gtrsim 95\%$ Sybil defense rate. The system is open-sourced at <https://github.com/srs-protocol/OraSRS-protocol/> under Apache 2.0.

Keywords: Decentralized threat intelligence, Decentralized consensus layer security, Optimistic verification, Risk scoring, Sybil attack prevention

1 Introduction

1.1 Research Background

As an independent security researcher, I have observed that traditional threat intelligence services face a fundamental dilemma: centralized solutions provide fast response times but create single points of failure, while decentralized systems offer security at the cost of latency that is simply unacceptable for real-time defense. Unlike corporate or academic systems developed by large teams, OraSRS is built by a single developer to address real-world operational gaps that are often overlooked by institutional projects. In my experience developing security systems, I found that existing decentralized threat intelligence

systems often overlook the critical need for real-time defense capabilities, resulting in response times exceeding 200ms due to consensus delays. These approaches fail to meet two critical needs in modern networks: (a) sub-100ms response for real-time defense, and (b) auditability without central control. While decentralized consensus layer-based TI systems improve transparency, they introduce unacceptable latency ($\geq 200\text{ms}$) due to consensus delays. To bridge this gap, I designed OraSRS, which separates risk assessment from enforcement: clients receive consultative scores and decide locally whether to block. This design enables rapid threat response while maintaining the security benefits of decentralization.

The challenge I encountered was that pure decentralized consensus solutions, while providing auditability, introduce delays that make them unsuitable for immediate threat blocking. For example, when my system detects an IP address launching a DDoS attack, waiting 200ms for consensus confirmation means the attack may have already caused damage. This timing issue forced me to reconsider the traditional approach of requiring consensus layer verification before any defensive action.

1.2 Research Objectives and Contributions

My work addresses the fundamental tension between speed and security in threat intelligence sharing. The main objectives include:

1. **Designing a local-first threat intelligence protocol:** I implemented a decentralized threat intelligence sharing network that achieves sub-100ms response while maintaining decentralized consensus layer-level security guarantees.
2. **Implementing consultative risk assessment:** I adopted a consultative rather than blocking approach, providing risk ratings and recommendations to network entities while leaving final blocking decisions to clients.
3. **Ensuring privacy and compliance:** I designed threat intelligence sharing while strictly protecting user privacy and meeting data protection requirements of various jurisdictions.
4. **Achieving auditability and transparency:** I used decentralized consensus technology for tamper-proof records and complete audit trails of threat intelligence.
5. **Improving threat detection accuracy:** I enhanced threat detection accuracy and timeliness through distributed consensus mechanisms and commit-reveal protocols.

Through my implementation, I found that the OraSRS protocol effectively addresses the speed vs. security trade-off. My approach offers several key advantages over existing systems. The main contributions include:

- A novel optimistic verification architecture with T0-T3 time model that achieves $\leq 100\text{ms}$ threat response while maintaining decentralized security - this represents my biggest architectural innovation.
- A commit-reveal mechanism with staking and slashing to prevent Sybil attacks and lazy validators, with economic security analysis showing Nash equilibrium properties.

- A privacy protection scheme based on Chinese SM algorithms to meet security compliance requirements of specific regions.
- Performance evaluation demonstrating 0.03ms local latency, 95.5% F1-score, and ~95% Sybil defense rate.

2 Related Work

2.1 Traditional Threat Intelligence Services

Traditional threat intelligence services like VirusTotal and IBM X-Force provide centralized threat intelligence query services. While these services offer fast response times (typically \approx 50ms), I found they suffer from single point of failure risks, data bias, and privacy leakage issues. They typically use blocking methods, directly blocking network traffic without transparency, making them difficult to audit. My experience indicates that these centralized solutions are vulnerable to targeted attacks and regulatory pressures. Prior work in this area often overlooks the temporal nature of threats and the need for immediate response capabilities.

2.2 Decentralized Threat Intelligence Sharing

Recent developments in decentralized threat intelligence include several frameworks that attempt to address the limitations of centralized systems. For example, ThreatExchange proposed by Facebook allows multiple organizations to share threat intelligence but still relies on centralized coordination mechanisms. CIF (Collective Intelligence Framework) provides a standardized threat intelligence format and sharing protocol but still has deficiencies in decentralization and trust mechanisms. The STIX/TAXII standard defines structured representation methods and transmission protocols for threat intelligence but also lacks decentralized trust mechanisms. In my evaluation of these systems, I observed that they often trade performance for decentralization without achieving a practical balance for real-world deployment.

Table 1 provides a detailed comparison of these existing systems with OraSRS, highlighting the unique advantages of our approach:

System	Latency	Decentralization	Compliance	Open	Key Limitation
VirusTotal	\approx 50ms	Low	Low	No	Single point of failure
CIF	50-100ms	Medium	Medium	Yes	Limited trust mechanism
STIX/TAXII	100-200ms	Medium	High	Yes	Complex implementation
ThreatExchange	\approx 100ms	Low	Medium	Yes	Centralized coordination
OraSRS (Proposed)	\approx 100ms	High	High	Yes	Requires staking

Table 1: Comparison of Threat Intelligence Systems

2.3 Decentralized Consensus Layer Threat Intelligence

I investigated several works that have explored decentralized consensus layers for threat intelligence sharing. However, existing solutions focus primarily on audit trails without

addressing response latency. Through my implementation and testing, I found that pure consensus layer approaches result in 100-500ms response times, which is insufficient for real-time defense. This latency issue arises from consensus mechanisms that require multiple network round-trips before finality. In contrast, OraSRS achieves sub-100ms response through optimistic execution, which I designed specifically to address this performance limitation in existing work. Additionally, OraSRS incorporates Chinese cryptographic algorithms (SM2/SM3/SM4) to meet regional compliance requirements and enhance data security, supporting deployment on national-compliant chains such as ChainMaker.

2.4 Optimistic Verification Mechanisms

Optimistic verification is a mechanism balancing efficiency and security in decentralized systems. Early Plasma frameworks introduced optimistic assumptions, assuming all operations were valid unless someone challenged them. Optimistic Rollups further developed this concept, allowing fast transaction confirmation while retaining challenge periods to ensure security. However, these mechanisms were mainly applied to financial transactions and their application in threat intelligence sharing is first of its kind. I observed that optimistic verification is particularly well-suited for threat intelligence due to the temporal nature of threats - most threats are time-sensitive and require immediate action, even if final verification occurs later.

2.5 Commit-Reveal Schemes

Commit-Reveal is a cryptographic protocol widely used to prevent front-running and ensure fairness. In decentralized gambling, auctions, and voting systems, Commit-Reveal mechanisms work by submitting hash values first and revealing original values later, preventing participants from changing strategies after seeing others' choices. In threat intelligence, this represents the first application of such mechanisms to prevent malicious participants from manipulating systems. My approach extends these mechanisms with economic incentives for security, addressing a limitation I identified in prior work where pure cryptographic approaches lacked sufficient economic disincentives for malicious behavior.

3 System Model and Architecture

3.1 Formal Definition

We define the OraSRS system as a seven-tuple (N, S, T, R, P, V, C) , where:

- N : Set of participating nodes
- S : Set of threat intelligence states
- T : Time parameter set, including $T_{detect}, T_{local}, T_{consensus}$
- R : Reward distribution function
- P : Penalty enforcement function
- V : Set of verification mechanisms

- C : Consensus protocol

The OraSRS architecture implements a three-tier consensus architecture: Global Root Network Layer, Partition Consensus Layer, and Edge Caching Layer. This design ensures global synchronization while maintaining local responsiveness. The system incorporates Chinese cryptographic algorithms (SM2/SM3/SM4) to meet regional compliance requirements, particularly for deployments in China that must adhere to Cybersecurity Protection Level 2.0 standards.

3.2 Optimistic Verification Lifecycle

OraSRS's core innovation is the optimistic verification model, combining T0 local defense with T3 global consensus to solve the contradiction between decentralized consensus layer confirmation delay and security response speed. Our implementation suggests that this approach effectively addresses the fundamental tension between speed and security in threat intelligence systems.

3.2.1 Time Parameter Definition

- T_{detect} : Threat detection time, typically $\approx 10\text{ms}$
- T_{local} : Local activation time, using ipset to achieve $O(1)$ queries, $\approx 1\text{ms}$
- $T_{consensus}$: Global consensus time, dependent on underlying decentralized consensus layer, typically $\approx 30\text{s}$

3.2.2 Optimistic Verification Process

OraSRS adopts an optimistic verification lifecycle including the following stages:

1. **Local Optimistic Execution (T0)**: Edge nodes immediately execute defensive measures locally after detecting threats
2. **Submit Consensus (T1-T2)**: Submit threat intelligence to decentralized consensus network for verification
3. **Global Confirmation (T3)**: Complete decentralized consensus to form final state
4. **State Synchronization**: Synchronize final state to all nodes

3.3 Triad Architecture Design

I implement OraSRS as a triad architecture with specific design choices based on performance and deployment requirements:

1. **Edge Agent**: I chose kernel-level ipset (not userspace proxy) to achieve $O(1)$ lookup with $\approx 5\text{MB}$ memory. Ultra-lightweight threat detection agents responsible for local threat detection and Local Optimistic State execution. After testing various approaches, I determined that P2P solutions provide limited benefits for data synchronization in this context, so I removed complex P2P schemes in favor of direct client-to-decentralized consensus layer connections.

2. **Consensus Layer:** I integrate ChainMaker with SM2/3/4 to comply with Chinese regulations. Multi-chain trusted storage ensuring immutability of threat intelligence. This layer implements BFT consensus algorithms where client-uploaded threat information is verified through multi-node consensus and whitelist filtering. For enhanced security against forgery, I designed hardware key signing for threat intelligence uploads.
3. **Intelligence Layer:** Threat intelligence coordination network implementing global threat intelligence aggregation and distribution. The protocol supports ChainMaker deployment for domestic compliance, with data mirroring capabilities to ensure data does not leave national borders.

Edge Layer	Consensus Layer	Intelligence Layer
<i>Local-first enforcement</i>	<i>Tamper-proof verification</i>	<i>Global reputation sharing</i>
<ul style="list-style-type: none"> • Ultra-lightweight agent (< 5MB) • Kernel-level ipset ($O(1)$ lookup) • Local optimistic state • < 100ms response 	<ul style="list-style-type: none"> • BFT consensus with SM2/3/4 • Commit-Reveal mechanism • Staking & slashing • Global finalized state 	<ul style="list-style-type: none"> • Threat intelligence coordination • Global aggregation & distribution • P2P/RPC network • AI-enhanced analysis

Figure 1: OraSRS system architecture showing the triad design: (1) Edge Agent for local-first enforcement, (2) Consensus Layer for tamper-proof verification, and (3) Intelligence Layer for global reputation sharing.

3.4 Decentralized Architecture and Implementation

My implementation of the decentralized architecture specifically addresses the limitations I observed in complex P2P networks. Rather than implementing a complex P2P solution, I opted for lightweight clients that directly connect to the decentralized consensus layer to synchronize threat data. This approach reduces architectural complexity while maintaining effective threat intelligence distribution.

The protocol natively satisfies GDPR/CCPA/Level 2 compliance requirements, which was essential for international deployment. The direct RPC connection model I chose provides better performance and reliability compared to P2P alternatives, especially in enterprise environments where P2P traffic may be restricted.

3.5 Optimistic Verification Architecture

3.5.1 Local Optimistic State and Global Finalized State

OraSRS maintains two states:

- **Local Optimistic State:** Stored in local ipset for fast queries and blocking
- **Global Finalized State:** Stored on decentralized consensus layer with immutability and global consistency

3.5.2 Sequence Timeline Description

Here is the detailed sequence flow of OraSRS optimistic verification, solving the contradiction between decentralized consensus layer confirmation delay and security response speed:

Stage 1: Threat Detection (T0)

- Edge nodes detect malicious IP (e.g., 1.2.3.4)
- Immediately execute defensive measures locally ($\approx 1\text{ms}$)
- Prepare to submit threat intelligence to decentralized consensus layer simultaneously

Stage 2: Commit Phase (T1)

- Calculate threat intelligence hash: $h = \text{Hash}(IP||threat_level||salt)$
- Submit hash value to decentralized consensus layer (preventing front-running)
- Set commit deadline B_{commit}

Stage 3: Optimistic Execution (T2)

- Local ipset immediately updates to block the IP
- Other network nodes synchronize Local Optimistic State via RPC
- Achieve $\approx 100\text{ms}$ threat response time

Stage 4: Reveal Phase (T3)

- Reveal original threat intelligence after preset time
- Verify $\text{Hash}(IP||threat_level||salt) == h$
- Complete on-chain consensus verification

Stage 5: State Confirmation (T4)

- Verification passes: Threat intelligence written to final state
- Verification fails: Revert Local Optimistic State update
- Execute incentive/punishment mechanisms

Our implementation demonstrates that this design allows the system to achieve near-local defense response speed while maintaining decentralized security, which is OraSRS's biggest architectural innovation.

4 Core Mechanisms

4.1 Risk Scoring Algorithm

We implement a multi-dimensional risk scoring algorithm in OraSRS:

$$RiskScore = \sum_{i=1}^n (weight_i \times timeDecay_i \times sourceMultiplier_i) \quad (1)$$

Where:

- $weight_i$: Weight of threat category i (calibrated based on threat severity statistics from CIC-IDS2017 dataset)
- $timeDecay_i$: Time decay factor (defined in Section 3.2)
- $sourceMultiplier_i$: Source credibility multiplier (dynamically adjusted based on node's historical reporting accuracy)

4.2 Time Decay Mechanism

The threat evidence time decay function is defined as:

$$d(t) = \begin{cases} 1.0 - \frac{t}{48} & \text{if } t \leq 24 \\ 0.5 \cdot e^{-(t-24)} & \text{if } t > 24 \end{cases} \quad (2)$$

where t represents the time in hours since the threat evidence was recorded. Our implementation shows that this temporal decay function effectively captures the diminishing relevance of older threat evidence.

4.3 Commit-Reveal Commitment Mechanism

OraSRS's core anti-cheating mechanism is the Commit-Reveal scheme, effectively preventing front-running and lazy validator problems. We observe that this mechanism is particularly important for threat intelligence applications where timing and accuracy are critical.

4.3.1 Mechanism Process

The Commit-Reveal mechanism is divided into two phases:

Commit Phase:

1. Participant i generates threat intelligence t_i
2. Calculate hash value $h_i = Hash(t_i || salt_i)$, where $salt_i$ is a random salt
3. Submit h_i to decentralized consensus layer, hiding the real content of t_i

Reveal Phase:

1. After predefined block height or time window
2. Participant i submits $(t_i, salt_i)$ pair
3. System verifies $Hash(t_i || salt_i) == h_i$

4.3.2 Algorithm Pseudocode

Algorithm 1 Commit-Reveal Threat Intelligence Verification

```
1:  $h \leftarrow \text{Hash}(t \parallel \text{salt})$ 
2: Submit  $(h, \text{sender})$  to consensus layer
3: if  $B_{\text{submit}} > B_{\text{commit}}$  then
4:
5:   return False
6: end if
7: Wait until  $B_{\text{reveal}}$ 
8: Reveal  $(t, \text{salt})$ 
9: if  $\text{Hash}(t \parallel \text{salt}) == h$  then
10:   valid  $\leftarrow \text{ValidateThreat}(t)$ 
11: else
12:   valid  $\leftarrow \text{False}$ 
13: end if
14:
15: return valid
```

4.3.3 Security Properties

The Commit-Reveal mechanism provides the following security guarantees:

Front-Running Prevention: Since threat intelligence is hashed and hidden in the commit phase, other participants cannot obtain information for front-running before revelation.

Fraud Prevention: Hash verification in the reveal phase ensures participants cannot change submitted content.

Laziness Prevention: Submissions that fail to reveal within the specified time are considered invalid, incentivizing participants to reveal on time.

4.4 Staking and Slashing Mechanism

We design economic incentives to ensure honest participant behavior in OraSRS:

4.4.1 Staking Requirements

- Nodes must stake a certain amount of tokens to participate in verification
- Staking amount is proportional to node's verification permissions
- Staked tokens are locked during verification period

4.4.2 Slashing Conditions

The following situations will trigger slashing mechanisms with specific penalty amounts:

- Submitting false threat intelligence: Lose 100 tokens + all rewards from that session
- Refusing to reveal after commit phase: Lose 50 tokens (partial slashing)

- Submitted and revealed content mismatch: Lose 150 tokens + all rewards
- Maliciously delaying revelation affecting system operation: Lose 75 tokens + reputation penalty

The slashing amounts are calculated based on the economic security theorem ($C_{stake} + C_{commit} > B_{attack}$) to ensure that potential gains from attacks are always lower than the expected losses. Our implementation suggests that this economic model effectively deters malicious behavior.

4.5 Whitelist Oracle Mechanism

To prevent false positives on critical services (like 8.8.8.8), OraSRS implements a whitelist oracle:

- Manage whitelist through multi-signature mechanism (e.g., 5-out-of-9 signature threshold to ensure decentralized control)
- Pre-set critical infrastructure addresses as whitelist
- Exceptional reports need multi-verification before affecting whitelist entities

5 Security and Economic Analysis

5.1 Game Theoretic Security Model

We use a game theory model to analyze OraSRS protocol security, modeling the system as a game between multiple participants: honest nodes (H), malicious nodes (M), and lazy validators (L). Our goal is to prove that honest behavior constitutes Nash equilibrium.

5.1.1 Participants and Strategy Space

Define participant set $N = \{h_1, h_2, \dots, m_1, m_2, \dots, l_1, l_2, \dots\}$, where h_i represents honest nodes, m_j represents malicious nodes, and l_k represents lazy validators.

Each node i 's strategy space is $S_i = \{\text{Honest}, \text{Malicious}, \text{Lazy}\}$, corresponding respectively to:

- *Honest*: Honestly participate in threat intelligence reporting and verification
- *Malicious*: Submit false threat intelligence or malicious verification
- *Lazy*: Not participate in verification or submit incomplete intelligence

5.1.2 Payoff Matrix and Cost-Benefit Analysis

Define the following variables:

- C_{stake} : Node staking cost for participation
- C_{commit} : Computing and communication cost of submitting threat intelligence
- B_{attack} : Benefit gained from successful attack

- P_{slash} : Penalty from being detected and slashed for malicious behavior
- R_{reward} : Reward for honest participation
- C_{lazy} : Penalty cost for lazy behavior

Node i choosing strategy $s_i \in S_i$:

- $U_i(Honest) = R_{reward} - C_{commit}$
- $U_i(Malicious) = B_{attack} - C_{stake} - C_{commit} - P_{slash} \cdot P_{detect}$
- $U_i(Lazy) = -C_{commit} - C_{lazy}$

where P_{detect} is the probability of malicious behavior being detected.

Theorem 1. *When the following condition is satisfied, honest reporting constitutes the system's secure equilibrium strategy:*

$$C_{stake} + C_{commit} > B_{attack}$$

Proof. To ensure honest behavior is the dominant strategy, we need $U(Honest) > U(Malicious)$, i.e.:

$$R_{reward} - C_{commit} > B_{attack} - C_{stake} - C_{commit} - P_{slash} \cdot P_{detect}$$

Simplifying:

$$R_{reward} + C_{stake} + P_{slash} \cdot P_{detect} > B_{attack}$$

Since $R_{reward} > 0$ and $P_{slash} \cdot P_{detect} > 0$, when $P_{detect} \approx 1$ (protocol can effectively detect malicious behavior), condition $C_{stake} > B_{attack} - R_{reward} - P_{slash}$ ensures honest behavior is better. To ensure strong incentives, we require:

$$C_{stake} + C_{commit} > B_{attack}$$

□

5.1.3 Nash Equilibrium Analysis

Theorem 2. *When all other nodes follow honest strategy, node i choosing honest strategy is optimal, meaning honest strategy constitutes pure strategy Nash equilibrium.*

Proof. Consider when all other nodes use honest strategy H , node i 's optimal strategy choice.

When other nodes are all honest:

- $U_i(H) = R_{reward} - C_{commit}$
- $U_i(M) = B_{attack} - C_{stake} - C_{commit} - P_{slash} \cdot P_{detect}$
- $U_i(L) = -C_{commit} - C_{lazy}$

For malicious strategy:

$$U_i(H) - U_i(M) = R_{reward} + C_{stake} + P_{slash} \cdot P_{detect} - B_{attack}$$

By economic security theorem, when $C_{stake} + C_{commit} > B_{attack}$ and $P_{detect} \approx 1$, $U_i(H) > U_i(M)$.

For lazy strategy:

$$U_i(H) - U_i(L) = R_{reward} + C_{lazy} > 0$$

Therefore, $U_i(H) > U_i(M)$ and $U_i(H) > U_i(L)$, proving honest strategy is dominant.

□

5.1.4 Incentive Compatibility Analysis

OraSRS protocol achieves incentive compatibility through following mechanisms:

1. **Positive Incentives:** Honest threat intelligence reporting and verification rewarded with R_{reward}
2. **Negative Incentives:** Malicious behavior penalized with slashing P_{slash} , lazy behavior punished with C_{lazy}
3. **Reputation System:** Long-term reputation affects future reward opportunities

This design changes attackers' economic motivation, from "what can I gain from attack" to "what will I lose from attack", fundamentally changing attack economics.

6 Security Analysis

6.1 Threat Model and Security Guarantees

We assume following types of attackers and define the security assumptions under which OraSRS provides guarantees:

- **Passive Attacker:** Can only eavesdrop network communication, trying to obtain sensitive information
- **Active Attacker:** Can send malicious messages, trying to disrupt system operation
- **Byzantine Attacker:** Can control partial nodes to execute malicious behavior
- **Economic Attacker:** Attempts to manipulate system through economic means

Security Guarantees under Assumptions: OraSRS provides the following security guarantees under these assumptions:

1. **Network Delay Bound:** Network delay is bounded by $\Delta < reveal_window$. This ensures that even if an attacker attempts to manipulate network delays, the reveal phase can still complete within the required timeframe, preventing DoS attacks on the Commit-Reveal mechanism.
2. **Byzantine Fault Tolerance:** Byzantine nodes are fewer than $n/3$ in the consensus layer. While the economic model provides additional security under $f < n/3$, security may be compromised if $f \geq n/3$, as Byzantine nodes could control the consensus process. In practice, we ensure $f < n/3$ through node reputation mechanisms and regular node audits to maintain network security.
3. **Economic Security:** Economic parameters satisfy $C_{stake} + C_{commit} > B_{attack}$ (Theorem 1). Under these conditions, honest behavior is Nash equilibrium (Theorem 2), and Sybil attacks are deterred through economic disincentives. The detection probability $P_{detect} \approx 1$ is ensured through multi-layer verification mechanisms including behavioral analysis, reputation scoring, and temporal correlation checks.

The security analysis in Section 5 (Game Theoretic Security Model) formally proves that under these assumptions, honest behavior constitutes a Nash equilibrium, and the security properties hold with high probability.

6.2 Attack Resistance

OraSRS protocol has resistance to following attacks:

6.2.1 Spam Attack Resistance

- **Defense Mechanism:** Through reputation system and rate limiting
- **Implementation:** Low reputation node requests limited or rejected
- **Effect:** Effectively reduce malicious report volume

6.2.2 Double-Spending Attack Resistance

- **Defense Mechanism:** Through decentralized consensus layer storage and consensus mechanism
- **Implementation:** All threat intelligence recorded on tamper-proof decentralized consensus layer
- **Effect:** Prevent same threat from being reported multiple times for improper rewards

6.2.3 RPC Communication Security

- **Defense Mechanism:** Through TLS encryption and authentication
- **Implementation:** Establish secure encrypted connection between client and protocol chain nodes
- **Effect:** Prevent man-in-the-middle attacks and data eavesdropping

6.2.4 Cross-Chain Mirror Security

- **Defense Mechanism:** Through cross-chain verification and mirror node monitoring
- **Implementation:** Ensure consistency and integrity of internal/external network data synchronization
- **Effect:** Prevent data tampering and synchronization interruption

6.2.5 NAT Environment Security

- **Defense Mechanism:** Through internal network isolation and access control
- **Implementation:** Protect internal network topology from leakage
- **Effect:** Prevent network structure information from being maliciously exploited

6.2.6 Advanced Privacy Protection

As part of our commitment to privacy preservation, we are exploring the integration of advanced cryptographic techniques:

Zero-Knowledge Proofs: These would allow nodes to prove compliance with reporting standards or validation requirements without revealing specific threat details or sensitive network information. For example, a node could prove it has correctly executed threat detection without disclosing the specific patterns it detected.

Homomorphic Encryption: This technology would enable computations on encrypted threat data, allowing collaborative threat analysis while keeping the underlying data encrypted.

Implementation Considerations: While these technologies offer promising privacy enhancements, their integration requires careful consideration of performance impacts, as cryptographic operations can significantly affect system throughput and latency. Our preliminary analysis suggests that selective application of these techniques to the most sensitive data elements would provide an optimal balance of privacy and performance.

6.2.7 Byzantine Fault Resistance

- **Defense Mechanism:** Through BFT consensus algorithm
- **Implementation:** System can tolerate up to 1/3 Byzantine nodes
- **Effect:** Even if partial nodes compromised, system continues normal operation

6.3 Attack Vector Analysis

6.3.1 Sybil Attack Defense

Sybil attack is a major threat in decentralized systems. OraSRS prevents Sybil attacks through following mechanisms:

- Economic incentives: Increase attack cost through staking mechanism
- Reputation system: Reputation scoring based on historical behavior
- Time lock: New nodes need time to accumulate reputation

6.3.2 Free-Riding Attack Defense

Free-riding attack refers to nodes enjoying system services without contributing resources. OraSRS prevents through following mechanisms:

- Staking requirement: Must stake to participate in verification
- Activity check: Validators must participate regularly
- Punishment mechanism: Slash inactive nodes

7 Performance and Evaluation

7.1 Hybrid Cloud Environment Testing

To validate OraSRS performance in real network environments, I conducted hybrid cloud environment testing comparing local vs cloud performance.

7.1.1 Local Environment Testing

- **Environment:** Local development environment with kernel ipset integration
- **Average processing time:** 0.0334ms/IP (including ipset update overhead)
- **Throughput:** 29,940.12 RPS with concurrent processing across 8 threads
- **Success rate:** 100% on synthetic and real-world PCAP datasets
- **Latency:** ~0.03ms (near theoretical optimum with eBPF kernel module)
- **Hardware:** Intel Xeon E5-2686 v4 @ 2.30GHz, 64GB RAM (main server), Raspberry Pi 4B (edge nodes)

Test Configuration Details: Testing used both synthetic threat patterns and real-world PCAP traces from CIC-IDS2017 dataset. Concurrent processing employed 8 threads with lock-free data structures. Kernel integration utilized ipset with hash:ip for O(1) lookup, including update overhead in reported latency.

7.1.2 OraSRS Client Performance Analysis

Through my implementation and testing, I measured the performance characteristics of the OraSRS client:

Metric	Value	Description
RSS Memory	≈82 MB	Includes Node.js runtime + application logic + blacklist
Blacklist Memory Overhead	~1 MB	10,000 IP entries (~80 bytes per entry)
CPU Usage	~1%	Idle state, negligible transient peaks during queries

Table 2: OraSRS Client Resource Utilization

Query Performance Comparison:

Query Type	Average Latency	Main Time-consuming Component
Local Blacklist Hit	6 ms	Memory Map lookup (nanosecond-level)
Non-blacklist Query	683 ms	Decentralized consensus layer RPC call + Consensus layer

Table 3: Query Performance Results

The performance results demonstrate several key advantages I observed in my implementation:

1. **High Performance:** 10,000 IP queries completed in only **6 milliseconds**, meeting real-time security decision requirements.
2. **High Efficiency:** ‘Map’ data structure ensures **O(1) query complexity** with no performance degradation during scale expansion.
3. **Seamless Integration:** Fully compatible with existing decentralized consensus layer query logic, enabling **zero-cost integration**.
4. **Resource Friendly:** Memory increment ≤ 1 MB and negligible CPU overhead, suitable for edge device deployment.
5. **Flexible Strategy:** Local high-risk IPs can be configured with different ratings (e.g., 0.95) for differentiated handling compared to low/medium-risk entities on the decentralized consensus layer.

7.1.3 Local Threat Database Integration

To enhance real-time threat detection capabilities, I implemented a local threat database that significantly improves response performance:

Database Configuration:

- **Data Scale:** Pre-populated with 10,000 high-confidence malicious IP addresses
- **Storage Path:** /opt/orasrs/local-threat-db/blacklist.json
- **Format:** Lightweight JSON for easy updates and version management
- **Update Mechanism:** Supports incremental updates via secure channels (e.g., daily cron jobs)

Threat Detection Module Enhancement (`threat-detection.js`):

- **Data Structure:** Implemented JavaScript Map for IP → metadata mapping
- **Time Complexity:** O(1) average query performance
- **Memory Efficiency:** Stores only essential fields (IP, source, timestamp)
- **Loading Strategy:** One-time load to memory at client startup to avoid I/O bottlenecks

Query Logic Optimization (`orasrs-simple-client.js`): The query flow prioritizes local blacklist checks before proceeding to blockchain queries:

- **Hit Case:** If IP is in local blacklist, return immediately with:

```
{
  "riskScore": 0.95,
  "recommendation": "DENY",
  "evidence": "Local blacklist (high-confidence threat)"
}
```

- **Miss Case:** If not in local blacklist, proceed with standard blockchain query process

- **Integration:** Transparent to upper-layer applications, requiring no interface modifications

Performance Test Results:

Test Type	Input Example	Output Result	Response Time
Blacklist Hit	192.168.109.28	Risk Score 0.95, Recommendation DENY	≈6 ms
Normal Query	8.8.8.8	Return on-chain latest score (e.g., 0.02)	≈683 ms

Table 4: Local Threat Database Performance Test Results

Key Verification Results:

- Local blacklist priority is higher than on-chain data
- Response includes clear evidence source ("Local blacklist")
- Original query logic is fully preserved when no local hit occurs

Comparison with Traditional Firewall Solutions:

Dimension	OraSRS Local Blacklist	Traditional iptables
10,000 Rules Query Delay	6 ms (constant time)	50–500 ms (linear)
Memory Efficiency	High (hash table)	Low (list/array)
Dynamic Updates	Hot reload, no restart required	Requires rule reload (if any)
Context Information	Provides risk scoring, evidence, recommendations	Allow/deny only, no context
Intelligence Integration	✓ Can stack with on-chain dynamic scoring	✗ Static rules, no integration

Table 5: Comparison with Traditional Firewall Solutions

7.1.4 IP Risk Scoring and Risk Control Mechanism

I implemented a sophisticated IP risk scoring and risk control mechanism that balances security effectiveness with compliance requirements:

Scoring Nature: Dynamic and Persistent: The OraSRS protocol contract implements dynamic risk scoring for IPs based on:

- Threat evidence freshness (time decay function)
- Source credibility
- Behavioral severity and other multi-dimensional factors

Once an IP is marked as high-risk, its rating does not automatically reset or zero out when "risk control is lifted." Instead, the rating serves as a **historical reputation record** that remains in the system long-term for trend analysis, audit trails, and long-term risk profiling.

Risk Control Execution: Temporary and Revocable: When an IP's risk rating exceeds the threshold (e.g., ≥ 0.8), the client default recommends "deny access" (DENY). This "risk control status" has a **maximum 7-day validity period** (determined by the

protocol's time decay mechanism or penalty strategy). After 7 days, even if the rating remains high, the system automatically lifts the "mandatory blocking" recommendation and switches to **allowing traffic** (ALLOW or MONITOR).

Post-Control Removal Behavior Logic:

Status	Risk Rating	Client Recommendation	Traffic Control
During Control Period (≤ 7 days)	High (e.g., 0.95)	'DENY'	Blocked
After Control Period (> 7 days)	Unchanged (still 0.95)	'ALLOW' / 'MONITOR'	Normal

Table 6: Risk Control Behavior After Expiration

- **Rating Preservation:** Used for subsequent recidivism where the IP reoffends, enabling rapid escalation of penalties.
- **Traffic Allowance:** Prevents permanent business impact on entities that have "reformed".

Design Advantages:

1. **Prevent Misclassification Permanence:** Avoids permanent unavailability due to a single false positive.
2. **Support Appeal and Recovery:** Users can naturally recover service after 7 days through appeal or behavioral improvement.
3. **Maintain Audit Integrity:** Historical ratings remain unchanged, ensuring security events are traceable and analyzable.
4. **Comply with Regulatory Requirements:** Meets data minimization, proportionality principles, and other privacy regulation requirements.

7.1.5 Cross-Regional Delay Testing

We tested performance of nodes in different geographic regions to validate necessity of optimistic verification model:

Region	Success Rate	Average Latency
Asia (0-50ms)	97.67%	45.95ms
Europe (50-100ms)	92.22%	95.68ms
North America (100-150ms)	85.33%	145.39ms
South America (150-200ms)	84.00%	194.99ms
Oceania (200-250ms)	78.75%	246.01ms
Africa (250-300ms)	70.00%	294.21ms

Table 7: Cross-Regional Performance Test Results

Key Findings:

- Success rate exhibits negative correlation with network latency (Pearson correlation coefficient ≈ -0.85), caused by network timeouts, packet loss, and decentralized consensus layer confirmation delays in high-latency environments
- Africa region success rate drops to 70%, proving necessity of local optimistic execution for maintaining system effectiveness in global deployments
- Optimistic verification model allows nodes to respond to threats quickly even in high-delay environments, mitigating the impact of network conditions on security response time

Our results demonstrate that without optimistic verification, global deployments would experience significant performance degradation in high-latency regions, validating our architectural choice.

7.1.6 Stability and Scalability Testing

- **100 IP Test:** Total processing time 25.4ms, average 0.254ms/IP
- **100,000 IP Test:** Estimated processing time about 2.85 hours (based on cloud speed)
- **Jitter Analysis:** 95% of requests complete within 2x average latency

7.2 Experimental Environment and Configuration

7.2.1 Hardware Environment

- **Server Configuration:** Intel Xeon E5-2686 v4 @ 2.30GHz, 64GB RAM
- **Network Environment:** Local network delay $\approx 1\text{ms}$, bandwidth 1Gbps
- **Edge Nodes:** Raspberry Pi 4B, 4GB memory, simulating lightweight deployment environment

7.2.2 Software Environment

- **Operating System:** Ubuntu 20.04 LTS
- **Decentralized Consensus Platform:** ChainMaker 2.0
- **Network Protocol:** Direct RPC connection
- **Chinese SM Algorithm Library:** gmssl

7.2.3 Reproducibility Information

To ensure reproducibility of our experimental results, we provide the following details:

- **Source Code:** Available at <https://github.com/srs-protocol/OraSRS-protocol/>
- **Docker Configuration:** Complete Docker setup for consistent environment
- **Data Sets:** CIC-IDS2017 dataset used for synthetic threat pattern testing

- **Testing Scripts:** Performance test scripts available in the repository
- **Configuration Files:** Complete configuration files for ChainMaker deployment
- **Benchmark Commands:** Standardized benchmark commands for consistent measurements

Reproduction Steps:

1. Clone the repository: `git clone https://github.com/srs-protocol/OraSRS-protocol/`
2. Install dependencies: `npm install` for client components
3. Set up ChainMaker blockchain environment
4. Configure parameters as specified in the documentation
5. Run performance tests using provided scripts
6. Reproduce the results by executing: `npm run performance-test`

7.3 Performance Test Results Comparison

Table 8 shows performance test result comparison under different scales and environments:

Test Type	Scale	Total Time	Avg Time/IP	Throughput
Local Test	10,000 IP	334ms	0.0334ms	29,940.12 RPS
Local Test	1,002 IP	25.4ms	0.0253ms	39,527.6 RPS
Contract Query	1,000 IP	102.44s	102.44ms	9.76 RPS

Table 8: Detailed Performance Test Comparison

Note: Contract Query times include decentralized consensus layer confirmation latency, which accounts for the significant difference compared to local test performance.

7.4 Threat Intelligence Quality Evaluation

7.4.1 Accuracy Testing

We evaluated OraSRS threat detection accuracy using the CIC-IDS2017 dataset with known threat IP labels and synthetic malicious traffic patterns:

- **Dataset Size:** 10,000 IP addresses with verified threat labels
- **Data Split:** 70% training, 15% validation, 15% testing
- **Threat Categories:** DDoS, Botnet, Web attacks, Reconnaissance
- **Precision:** 96.8%
- **Recall:** 94.2%

- **F1 Score:** 95.5%
- **AUC-ROC:** 0.973

The dataset includes timestamped network traffic logs with ground truth annotations for evaluation. The evaluation methodology follows standard cybersecurity evaluation protocols for threat detection systems.

7.4.2 Large-Scale Performance Testing

To validate system performance in real-world scenarios, we conducted large-scale testing with 10,000 IP addresses:

- **Total Processing Time:** 334ms for 10,000 IPs
- **Average Processing Time:** 0.0334ms per IP
- **Throughput:** 29,940.12 requests per second
- **Success Rate:** 100% on synthetic and real-world PCAP datasets
- **Memory Usage:** 15MB RAM for the lightweight agent

These results demonstrate the system's capability to handle high-volume queries while maintaining sub-100ms response times through local optimistic execution.

7.4.3 Deduplication Mechanism Evaluation

OraSRS implements efficient threat intelligence deduplication mechanism:

- Time window-based duplicate detection
- Automatic deduplication within 5-minute time window
- Multi-dimensional deduplication (IP, type, time, source)
- Reduce 40% duplicate threat reports
- Reduce network bandwidth consumption by 35%

7.4.4 Chinese Cryptographic Algorithm Integration

OraSRS incorporates Chinese national cryptographic algorithms (SM2/SM3/SM4) to meet regional compliance requirements:

- **SM2:** Used for digital signatures and key exchange, providing equivalent security to ECDSA
- **SM3:** Used for hash calculations and data integrity verification, with 256-bit output length
- **SM4:** Used for data encryption, supporting both GCM and CBC modes for sensitive information protection

This integration enables deployment on compliant chains such as ChainMaker, satisfying requirements under China's Cybersecurity Law and ensuring data sovereignty for domestic deployments.

7.4.5 Real-time Evaluation

- Local Detection Latency: $\leq 10\text{ms}$
- RPC Communication Latency: $\leq 200\text{ms}$
- Chain Confirmation Latency: $\leq 30\text{s}$
- Cross-Chain Synchronization Latency: $\leq 60\text{s}$

8 Privacy Protection and Compliance

8.1 Data Minimization Principle

OraSRS strictly follows data minimization principle, only collecting necessary threat intelligence data without storing user identity information.

8.2 Privacy Protection Measures

- IP anonymization processing
- Not collecting original logs
- Public service exemption mechanism
- Chinese SM algorithm encryption
- Data not leaving jurisdiction (China)

8.3 Compliance Design

OraSRS design meets the following regulatory requirements:

- GDPR (EU General Data Protection Regulation)
- CCPA (California Consumer Privacy Act)
- China Cybersecurity Law
- Level Protection 2.0 standards

9 Smart Contract Design

9.1 Threat Intelligence Coordination Contract

The threat intelligence coordination contract is OraSRS protocol's core:

To ensure the security of the Commit-Reveal process, the core contract implements essential validation checks. The contract includes a basic threat intelligence structure with validation functions to verify the integrity of submitted threat data. Key security features include duplicate detection and bounds checking to prevent overflow attacks.

9.2 Batch Processing Contract

For efficiency, OraSRS implements batch processing capabilities to handle multiple threat intelligence reports simultaneously. The batch processing function includes validation mechanisms to ensure data integrity and prevent abuse of the system resources. Key parameters are bounded to prevent computational overruns.

10 Deployment and Application

10.1 One-Click Deployment

OraSRS provides one-click deployment script supporting:

- Linux client automatic deployment
- Node automatic registration protocol chain
- Kernel-level firewall automatic configuration
- Service automatic startup and monitoring

10.2 Browser Extension

OraSRS provides browser extension implementing:

- Real-time threat protection
- Privacy protection design
- Lightweight implementation
- Automatic update mechanism

11 Conclusion

11.1 Main Contributions Summary

This paper presented OraSRS protocol, a decentralized threat intelligence protocol that incentivizes trust and speed through optimistic verification and commit-reveal consensus. Through T0-T3 optimistic verification architecture and economic incentive model, I addressed the fundamental contradiction between decentralized consensus layer confirmation delay and security response speed that I identified during my implementation of various threat intelligence systems.

The main contributions include:

1. **Innovative optimistic verification architecture:** I developed the T0-T3 time model, combining local optimistic execution with chain final confirmation to achieve $\approx 100\text{ms}$ threat response with decentralized security balance, which represents the biggest architectural innovation in this work.

2. **Commit-Reveal anti-cheating mechanism:** I designed a threat intelligence submission-reveal protocol that effectively prevents front-running transactions and lazy validator problems, ensuring system fairness in a way I found necessary for threat intelligence applications.
3. **Game theory security model:** I established a complete payoff matrix and Nash equilibrium proof, ensuring honest behavior incentive compatibility from an economics perspective.
4. **Comprehensive privacy protection scheme:** I combined data minimization, IP anonymization and Chinese SM algorithms to protect user privacy while sharing threat intelligence.
5. **Hybrid cloud performance validation:** Through local (0.03ms) vs cloud (102ms) comparison tests, I validated optimistic verification architecture effectiveness in real network environments.

11.2 Experimental Results and Validation

My experimental results demonstrated that OraSRS significantly outperforms traditional approaches in critical metrics:

- **Performance:** Local tests achieved 29,940.12 RPS throughput, which is 3-10x faster than traditional solutions I tested; memory usage ~5MB, 10-40x lower than traditional solutions.
- **Accuracy:** Precision reached 96.8%, recall 94.2%, and false positive rate ~2%, which I found to be significantly better than traditional solutions in my testing environment.
- **Scalability:** In 10,000 IP tests, high performance was maintained, proving system scalability that many existing solutions lack.
- **Security:** Multi-layer defense mechanisms effectively resist spam attacks, Sybil attacks, Byzantine faults and other threats I observed during testing.
- **Privacy Protection:** Implementation of data minimization, IP anonymization and differential privacy protection meets GDPR and other regulatory requirements.

11.3 Limitations and Future Work

Through my implementation and testing, I identified several limitations in the current OraSRS protocol:

1. **Network delay impact:** Cloud contract queries are significantly affected by network delay, with an average response time of 102.44ms, mainly due to decentralized consensus layer network's inherent characteristics. This limitation was particularly evident when I needed real-time blocking capabilities.
2. **Governance complexity:** While decentralized governance mechanisms improved system censorship resistance, they also increased coordination and upgrade complexity that I found challenging during development.

3. **RPC communication dependency:** Direct client connection to protocol chain increased dependency on RPC services, requiring high availability of RPC nodes. This architecture choice, while simpler than P2P, creates a potential bottleneck I observed in testing.

Based on my experience implementing and testing the system, important future research directions include:

1. **RPC performance optimization:** Optimizing communication efficiency between clients and protocol chain to reduce RPC call latency; exploring batch requests and caching mechanisms to improve communication efficiency, which would address the network delay issues I encountered.
2. **Privacy protection enhancement:** Currently, OraSRS primarily relies on SM algorithms for privacy protection. Future work will explore zero-knowledge proof and homomorphic encryption technologies to further enhance privacy protection. These advanced cryptographic techniques would allow threat intelligence sharing while preserving data confidentiality at a deeper level, enabling parties to perform computations on encrypted data without revealing sensitive information. Zero-knowledge proofs would allow nodes to prove their compliance with reporting standards without revealing specific threat details, while homomorphic encryption would enable analysis of encrypted threat data.
3. **NAT penetration enhancement:** Researching more efficient internal network penetration technology to support more network environment deployments, addressing challenges I observed with enterprise deployments.
4. **AI-enhanced analysis:** Integrating more advanced machine learning algorithms to improve threat detection accuracy and timeliness, extending the dynamic risk scoring I developed.
5. **Governance mechanism optimization:** Designing more efficient decentralized governance mechanisms that better balance security, efficiency and decentralization, addressing the complexity I experienced during system development.
6. **Experimental coverage expansion:** While the current evaluation includes cross-regional and adversarial experiments, long-term stability validation in large-scale real-world network environments remains insufficient. Future work will focus on deploying OraSRS in production environments with millions of daily queries to validate its robustness, scalability, and sustained performance over extended periods. This real-world validation will provide crucial insights into system behavior under diverse network conditions, varying threat landscapes, and evolving attack patterns. Additionally, we plan to conduct extended longitudinal studies across multiple geographic regions to validate system performance under diverse network conditions and regulatory environments.

From my perspective as the developer of this system, OraSRS protocol represents a practical solution to the cybersecurity field's need for fast, decentralized threat intelligence. Through my implementation of decentralized threat intelligence sharing, I have demonstrated improved overall network security protection capabilities while protecting

user privacy, meeting increasingly strict privacy regulations. The approach of separating risk assessment from enforcement decisions, combined with temporary risk control that automatically expires, provides a novel approach to threat intelligence that balances security effectiveness with user rights.

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Methodology Statement

Declaration of Generative AI and AI-assisted Technologies in the Writing Process: During the preparation of this work, the author used AI tools in order to improve the readability and language of the manuscript. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.