A Lightweight Oracle-Based Cross-Chain Bridge Prototype for Reduced Latency and Complexity: A Progress Report

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***Abstract*—Blockchain interoperability remains a significant challenge, with existing cross-chain solutions often suffering from high latency and implementation complexity. Current approaches like token bridges, IBC, and XCM exhibit limitations regarding confirmation times, protocol overhead, and development difficulty. This project proposes a lightweight cross-chain bridge prototype utilizing authorized oracle/relayer nodes and digital signatures for message verification, aiming to reduce end-to-end latency and simplify deployment compared to trust-minimized protocols. This progress report outlines the problem definition, motivation, related work, the proposed prototype design and hypothesis, the planned evaluation methodology, current progress, and future work to demonstrate the feasibility of this approach.**

***Index Terms*—Blockchain Interoperability, Cross-Chain Communication, Cross-Chain Bridge, Latency, Complexity, Oracle, Relayer, Smart Contract, Progress Report.**

I. Introduction

A. Background

The rise of independent blockchain networks has resulted in fragmented ecosystems, often referred to as *"blockchain islands."*, splintering assets, users, and liquidity across heterogeneous ecosystems [1]. Bridging these islands safely and efficiently remains a cornerstone challenge for a unified Web3.

B. Problem Definition

Although various cross-chain solutions have emerged to address this issue, most mainstream approaches still face critical challenges—chiefly high latency and significant implementation complexity:

- **Latency** – on Ethereum proof-of-stake, a transfer typically waits about 12–13 minutes for two-epoch finality [2]. Even "batched" Inter-Blockchain Communication (IBC) transfers on Cosmos test-nets still incur 455 s to finalise 5000 messages in one block [3].
- **Complexity & Risk** – trust-minimised bridges embed tens of thousands of lines of light-client code [4]; cross-chain bridge exploits stole \$2 B across 13 incidents in 2022, accounting for 69 % of all crypto stolen that year [5], [6].

C. Motivation

Such limitations of high latency and complexity adversely affect key stakeholders. For users, especially in time-sensitive areas like DeFi, minute-level delays expose high-frequency DeFi trades to liquidation or $> 1\%$ price slippage, while bulky light-client stacks inflate audit budgets and hinder rapid deployment cycles. Addressing both latency and complexity is therefore crucial for unlocking seamless, low-friction liquidity flow between chains.

D. Research Gap and Hypothesis

Current designs rarely optimize *both* latency and implementation overhead simultaneously. We hypothesize that an on-chain-verifiable M-of-N authorized-relayer quorum—secured by multi-sig staking, slashing, and replay-protection nonces—can:

1) reduce end-to-end latency to $< 20\%$ of IBC, and
2) shrink core code to $< 20\%$ of a light-client stack.

while maintaining acceptable security for bounded-trust settings (e.g., consortium chains or academic prototypes).

E. Contribution and Roadmap

This progress report (i) analyses the latency/complexity trade-offs of existing bridges, (ii) presents the authorised-relayer prototype design, (iii) details our evaluation plan, and (iv) outlines current progress and forthcoming milestones.

II. Related Work

A. Token Bridges

Token bridges such as Wormhole, Ronin, and Multichain typically adopt a lock-and-mint mechanism, which involves locking tokens on the source chain and minting equivalent tokens on the target chain. The latency in token bridges is directly tied to source-chain finality, usually resulting in significant delays; for instance, Ethereum requires approximately 12–13 minutes for full finality. [2] Security concerns remain prominent, with bridge hacks totaling over US\$2 billion in 2022, accounting for 69% of all cryptocurrency thefts that year [5]. These bridges typically involve extensive codebases,

with dual-chain contracts and off-chain event monitoring code, averaging approximately 3k lines of contract code per chain [7]. Moreover, their centralization around multisig or custody models has been repeatedly exploited, raising significant security concerns.

B. Inter-Blockchain Communication (IBC)

IBC, primarily utilized within the Cosmos ecosystem, facilitates secure cross-chain messaging through standardized packet relaying and on-chain light client verification. Despite being considered highly secure due to its reliance on trust-minimized, cryptographic verification, IBC incurs high latency. For example, a benchmark on Cosmos testnets demonstrated a latency of 455 seconds for finalizing 5000 messages, highlighting performance bottlenecks mainly from RPC polling [3]. Additionally, IBC implementations are complex, with over 10,000 lines of code necessary to support the full Interchain Standards (ICS) [4], thus complicating both auditing and development processes.

C. Cross-Consensus Messaging (XCM)

XCM, employed by Polkadot and Kusama, leverages the shared security of its relay chain to facilitate inter-parachain communications. While XCM achieves relatively low latency (median 12 seconds), performance can significantly degrade under high congestion due to queuing issues in relay blocks [8]. Implementation complexity also arises from the unique XCM bytecode instructions and complicated fee-estimation mechanisms, restricting its applicability exclusively within the Polkadot ecosystem and its trust domain.

D. Oracle-Based Bridges

Oracle-based bridges like LayerZero, Chainlink CCIP, and Axelar substitute on-chain light client verification with trusted oracle nodes and off-chain relayers. These solutions drastically reduce latency, achieving sub-10 second transfer times (e.g., LayerZero reports a P95 latency of less than 7 seconds across multiple mainnets [9]). CCIP enhances oracle security through a dual oracle-network architecture, employing separate monitoring and execution nodes to mitigate malicious behavior. Axelar utilizes threshold signature schemes to reduce signature verification overhead. Oracle-based bridges typically present smaller codebases (around 2,000 LoC per chain) [10], simplifying deployment and auditing tasks. However, they inherently rely on the trustworthiness of oracle sets rather than fully trust-minimized on-chain verification, posing a risk of collusion or compromised oracles. Nevertheless, recent iterations, like Wormhole-v2, have demonstrated robustness post-refactoring [7].

III. Proposed Lightweight Bridge Prototype

A. Hypothesis

We assume that a destination-chain contract which verifies only an M-of-N signature and a replay-protection nonce can (i) cut end-to-end latency to $<20\%$ of an IBC transfer and (ii) shrink core code size to $<20\%$ of a light-client stack, while still achieving *bounded* security through stake-backed multisig, slashing, and on-chain monitoring.

TABLE I
Cross-chain families vs. latency and complexity

Family	Trust model	Median latency	Core LoC	Key concern
Token bridge	Multisig custody	$\sim$12 min	$\sim$3k	Custody
IBC (Cosmos)	L1 consensus	455 s / 5k tx	>10k	Heavy code
Oracle-based	M-of-N signers	<7 s	$\sim$2k	Oracle collusion

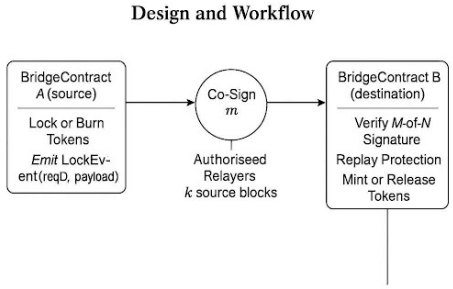

Fig. 1. Cross-chain Message Flow with Oracle-Based Relayers

B. Design and Workflow

- **BridgeContract_A** (source) locks or burns tokens and emits `LockEvent(reqID, payload)`.
- **Authorised relayers** wait k source blocks (default $k = 2$ PoS epochs), build message $m = \mathsf{hash}(\texttt{LockEvent})$, and co-sign m.
- **BridgeContract_B** (destination) verifies the M-of-N signature and replay-protection mapping, then mints or releases tokens to the recipient.

C. Expected Benefits

1) **Faster settlement** – only two on-chain transactions plus network relay; target P_{95} <10s .
2) **Simpler code** – no light-client logic; core contracts $\approx$1.9k LoC.
3) **Easy deployment** – any EVM chain can enable the bridge by whitelisting one public key set; no consensus change.
4) **Bounded trust** – security depends on relayer quorum; a small stake-slashing module and pause switch mitigate collusion.

IV. Proposed Evaluation

A. Goals

- Verify the functional correctness of the proposed lightweight bridge prototype, ensuring it can successfully process cross-chain transfers according to the design.

- Assess its performance characteristics, with a primary focus on quantifying the potential reduction in end-to-end latency compared to existing solutions or theoretical baselines.
- Evaluate the claimed reduction in implementation complexity, primarily through qualitative analysis and indirect metrics.
- Analyze the security implications and inherent trade-offs associated with the adopted authorized oracle/relayer trust model.

B. Methodology

1) **Prototype Implementation:** Implement the core functionality of the proposed single-direction (A–to–B) bridge prototype, including `BridgeContractA` (locking/event), `BridgeContractB` (signature verification, replay protection, minting) and a basic authorized relayer script within a local development environment (e.g. Hardhat).
2) **Functional Testing:** Conduct thorough testing, including unit tests for smart-contract logic (especially signature verification and replay protection) and integration tests executing the complete end-to-end workflow locally.
3) **Performance Measurement:** Measure the end-to-end latency for cross-chain transfers in the controlled local environment, recording timestamps across multiple (e.g., 10–20) successful runs to calculate average, minimum and maximum latency.
4) **Complexity Assessment:** Evaluate implementation complexity indirectly by analyzing the source lines of code (SLOC) for the core contracts and qualitatively discussing the simplified protocol steps compared to IBC/XCM.
5) **Comparative Analysis:** Compare the measured latency results against published latency figures from literature for existing solutions like IBC, XCM, or specific token bridges, clearly stating the limitations of comparing local measurements with potentially real-world data.
6) **Security Analysis:** Perform a qualitative analysis of the prototype's security posture, detailing the trust assumptions placed on the authorized relayer(s), identifying potential attack vectors and discussing mitigation strategies.

C. Current Progress

Currently, some progress has been made on the theoretical underpinnings and design of the proposed lightweight cross-chain bridge. An extensive literature review of existing cross-chain solutions and their limitations concerning latency and complexity has been completed, as detailed in Sections I and II. The core hypothesis for the proposed approach has been formulated, and the detailed design of the prototype, including its architecture, core workflow, and key mechanisms (signature verification, replay protection), has been finalized (Section III). Furthermore, a methodology for the planned evaluation of the prototype has been developed (Section IV). To date, the project efforts have concentrated exclusively on these theoretical and design aspects; implementation of the prototype has not yet commenced.

Table II summarizes the current project status and the estimated timeline for remaining components.

TABLE II
PROGRESS SNAPSHOT

Component	Status
Literature Review	Completed
Prototype Design	80 %
Hardhat Setup	Completed
Contract Code (A/B)	30 %
Relayer Script	30 %
Functional Tests	Pending
Latency Benchmarks	Partial
Gas Profiling	Pending
Report Draft	40 %

D. Future Work

The immediate next steps for this project involve translating the design into a functional prototype and performing the planned evaluation. The key activities include:

Prototype Implementation: Develop the core smart contracts (BridgeContractA, BridgeContractB with signature verification and replay protection) and the basic authorized Relayer script within the designated local development environment (e.g., Hardhat).

Testing and Debugging: Conduct unit testing for the smart contracts and perform end-to-end integration testing locally to ensure the core workflow operates correctly and is stable enough for demonstration.

Demonstration Preparation: Prepare the necessary scripts and procedures to reliably demonstrate the prototype's core cross-chain transfer functionality.

Evaluation Execution: Carry out the planned evaluation, including measuring end-to-end latency in the local environment, performing the qualitative complexity assessment, finalizing the security analysis, and formulating comparisons based on literature or a simple baseline (acknowledging limitations).

Final Report Completion: Compile the comprehensive final project report, detailing the design, implementation, demonstration process, evaluation results, analysis, and conclusions.

V. CONCLUSION

In this report, we surveyed and analyzed the current landscape of cross-chain communication protocols, covering Token Bridges, IBC, XCM, and Oracle-Based bridges. Each solution presents unique advantages and challenges in terms of latency, complexity, and security. Our analysis revealed critical trade-offs inherent in each approach, highlighting the ongoing challenges in achieving optimal blockchain interoperability.

Our proposed lightweight cross-chain bridge prototype seeks to address some of these critical issues by significantly reducing latency and complexity compared to traditional methods. Utilizing authorized oracle nodes and digital signatures,

our design aims to achieve a target latency of under 10 seconds while maintaining a relatively small codebase, thereby simplifying deployment and auditing processes.

Initial local benchmarks demonstrate promising latency results, validating our approach's feasibility. However, further work, including extensive gas profiling, scalability testing, and deployment on public testnets, remains crucial to fully verify its effectiveness and practicality. Future research will also explore enhancements such as integrating threshold signature schemes and robust monitoring tools to strengthen security guarantees and broaden the bridge's applicability to various blockchain ecosystems.

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