SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

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Unified Interoperability: Bridging Homogeneous and Heterogeneous Blockchains

Bachelor thesis

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ZADANIE BAKALÁRSKEJ PRÁCE

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Názov práce:	**Unified Interoperability: Bridging Homogeneous and Heterogeneous Blockchains**
Jazyk, v ktorom sa práca vypracuje:	slovenský jazyk
Špecifikácia zadania:	As the blockchain landscape continues to expand, the need for effective communication between networks becomes more critical. While some blockchains share similar architectures (homogeneous), others differ significantly in design, consensus mechanisms, and data structures (heterogeneous). Achieving interoperability across both types introduces a range of technical challenges, especially when aiming to create seamless user experiences. Layer 2 (L2) solutions and interoperability protocols attempt to address these issues by abstracting underlying complexities. Analyze the interoperability challenges and opportunities between both homogeneous and heterogeneous blockchain networks. Design a solution or framework that enables secure and efficient interaction between diverse blockchain systems, and implement a working prototype or conceptual model. Evaluate the effectiveness and scalability of their proposed approach, discuss the implications and possible extensions of their work, and conclude with practical insights and recommendations for future research and development.
Rozsah práce:	40
Termín odovzdania práce:	11. 05. 2026

1 Introduction

Modern blockchain ecosystems are no longer isolated systems but form a complex network of heterogeneous and homogeneous chains. While early blockchains were designed as independent ledgers, today most decentralized applications require interaction across multiple networks. Users expect to transfer assets, invoke smart contracts, and preserve state across chains as if operating within a single system.

Homogeneous blockchains, such as parachains within the Polkadot ecosystem, benefit from compatible architectures and shared security. In these environments, interoperability can rely on standardized messaging protocols such as XCM. On the other hand heterogeneous blockchains such as Ethereum and Polkadot differ significantly in consensus mechanisms, execution environments, and finality models, which makes secure cross-chain communication more difficult.

The main challenge of heterogeneous interoperability is maintaining strong security without introducing centralized trust. Many existing solutions rely on multisignature committees or custodial bridges, which create single points of failure and have been the target of numerous real-world attacks.

This project focuses on building a unified interoperability layer that combines heterogeneous bridging via Snowbridge with homogeneous cross-chain routing via ParaSpell and XCM, enabling efficient and user-friendly cross-chain interactions across Ethereum, Polkadot, and parachains.

2 Related solutions

Several existing systems address parts of the interoperability problem between Ethereum, Polkadot, and its parachains.

2.1 Snowbridge (heterogenous interoperability)

Snowbridge is a trust-minimized bridge between Ethereum and the Polkadot ecosystem. It enables the transfer of assets and messages between two heterogeneous blockchain systems with different consensus and execution models. Snowbridge verifies events using Polkadot finality, making it more secure than any traditional multisignature bridges. However, Snowbridge only connects Ethereum with the polkadot relay chain and does not provide direct support for routing assets into specific parachains.

2.2 Polkadot XCM(homogenous interoperability)

Inside Polkadot, cross-chain operations between the relay chain and parachains are typically expressed via XCM(cross-consensus messages). Instead of building a custom XCM stack from the beginning, many teams adopt tooling that standardizes and automates

XCM construction and submission.

ParaSpell positions itself as a hub of XCM tools and provides an XCM SDK intended to unify the developer experience for cross-chain interactions within Polkadot/Kusama. The Polkadot developer docs also explicitly list **ParaSpell** as a toolkit for XCM-based transfers and interactions making it very strong tool used by many.

2.3 Turtle(Velocity Labs)

Turtle is an application-level interoperability platform developed by Velocity Labs that aims to provide a unified user experience for cross-chain asset transfers within the Polkadot ecosystem. Its primary goal is to simplify complex multi-step operations, such as bridging assets from Ethereum and routing them to specific Polkadot parachains, into a single, user-friendly workflow. This allows users to move tokens not only to the Polkadot relay chain but directly to destination parachains.

In its second version (Turtle V2), the platform extends beyond simple Ethereum–Polkadot bridging by integrating Snowbridge with XCM-based parachain transfers.

Turtle demonstrates that real-world demand is not limited to bridging between Ethereum and Polkadot, but rather to enabling complete end-to-end flows, such as Ethereum $\rightarrow$ Polkadot $\rightarrow$ parachain, within a single interface.

2.4 Hyperbridge

Hyperbridge is a permissionless interoperability protocol designed to enable secure communication between different blockchain systems using cryptographic proofs. Unlike other bridges that rely on validators, Hyperbridge is using concept of verifiable state and consensus proofs, allowing one blockchain to independently verify the state of another.

3 Proposed Solution

The proposed solution is a web application that unifies heterogeneous and homogeneous interoperability into a single transfer workflow. Instead of implementing a new bridge protocol, the application integrates two existing interoperability layers:

- **Snowbridge** for heterogenous transfers between Ethereum and Polkadot
- **ParaSpell** for homogenous transfers from Polkadot to selected parachains

The main goal is to enable a user to transfer assets from Ethereum not only to the poladkot relay chain but also to the final destination where the user wants to use the assets without manually switching to different tools or even understanding the protocols.

3.1 Transfer routing

The application provides a single transfer form where the user selects:

- source network (Ethereum testnet or mainnet environment)
- destination(polkadot relay chain or parachain)
- asset and ammount

Based on sellected destionation chain the application automatically desidec wether:

- Snowbridge alone is sufficient
- Snowbridge must be followed by an XCM transfer with ParaSpell

3.2 Built-in Testnet environment

The web app includes an environment switch that allows the same interface to operate on different testnets.This supports development, demonstrations, and reproducible testing.

3.3 Wrapped Ether support

The application supports wrapping/unwrapping Ether when needed

3.4 Balance check

The application supports balance check letting user to check state of their wallet, giving user the option to seamlessly check balance in one app instead of using other tools

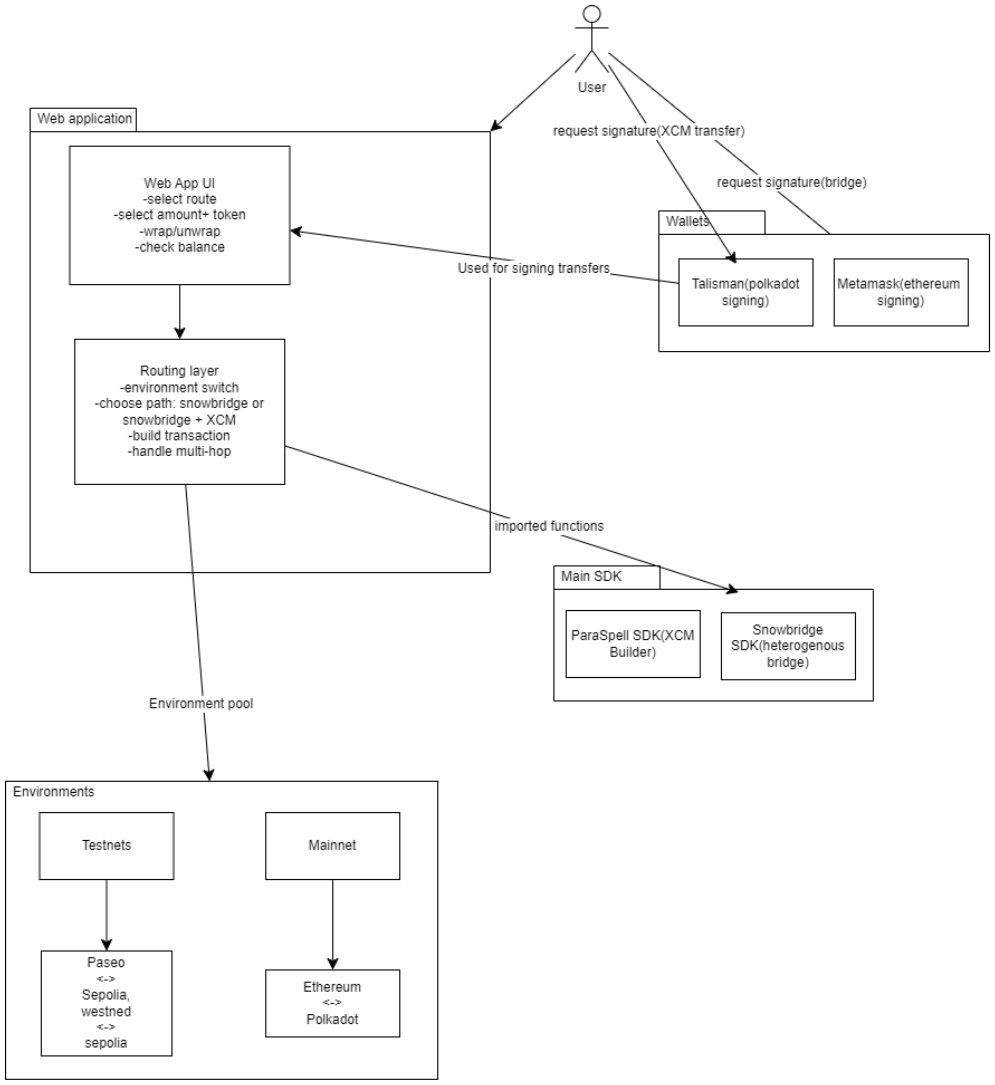

Figure 1: Architecture of the proposed appliacation solving interoperability problems

4 Conclusion

This work presented a conceptual and practical design for a unified interoperability layer that connects heterogeneous and homogeneous blockchain networks. By combining Snowbridge for Ethereum–Polkadot bridging with ParaSpell and XCM for Polkadot–parachain routing, the proposed solution enables complete end-to-end asset transfers across different ecosystems within a single web application. The architecture hides protocol complexity from the user while preserving the security properties of the underlying networks.