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Blockchain Interoperability for Cross-Border Payments through Settlement Protocol Analysis

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Abstract

Cross-border payments remain characterized by high costs, slow settlement times, limited transparency, and fragmented regulatory compliance. Blockchain and distributed ledger technology offer a transformative alternative, yet the proliferation of isolated blockchain networks has created a new challenge: the interoperability gap between distinct ledger systems, between DLT and legacy infrastructure, and across differing regulatory regimes. This article provides a critical analysis of blockchain interoperability protocols for cross-border payment settlement, examining three principal approaches: notary-based schemes, hash-time-locked contracts, and relay-chain architectures. The analysis evaluates recent industry implementations including Swift's shared ledger, the Bank for International Settlements' Project Agorá and Project Rialto, and emerging cross-chain payment channel protocols. Findings indicate interoperability as the decisive factor in DLT adoption for cross-border payments, with hybrid models combining shared ledgers, tokenised central bank money, and ISO 20022 standards demonstrating the most promising path forward. Persistent challenges include latency-security trade-offs, regulatory fragmentation, and the absence of global governance for cross-border DLT settlements.

Keywords: blockchain interoperability; cross-border payments; settlement protocols; distributed ledger technology; payment-versus-payment; tokenised central bank money

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1. Introduction

The global cross-border payments market reached approximately $195 trillion in 2024, with projections suggesting growth to $320 trillion by 2032 (BIS, 2026). Wholesale interbank transactions account for roughly 91% of this volume, yet the infrastructure supporting these flows remains remarkably inefficient by contemporary standards. Despite the G20's roadmap for enhancing cross-border payments, the correspondent banking model continues to impose significant friction: settlement times measured in days rather than seconds, opaque fee structures, limited end-to-end visibility, and complex compliance obligations across multiple jurisdictions (World Bank Group, 2025).

Blockchain and distributed ledger technology have been widely proposed as a solution to these persistent inefficiencies. By enabling peer-to-peer value transfer without intermediaries, DLT promises faster settlement, reduced costs, enhanced transparency, and programmable compliance through smart contracts (Zenodo, 2025). Yet as blockchain networks have proliferated, each with its own consensus mechanism, token standard, and governance model, a new challenge has emerged: the interoperability gap.

Interoperability has become the critical bottleneck in the adoption of DLT for cross-border payments. Without interoperable settlement protocols, blockchain networks remain siloed, replicating the fragmentation of the correspondent banking system rather than resolving it. The challenge extends beyond technical compatibility to encompass regulatory interoperability, institutional interoperability, and semantic interoperability.

This article provides a critical analysis of blockchain interoperability protocols for cross-border payment settlement. It examines three principal technical approaches as codified in the IEEE 3221.01-2025 standard for cross-chain transaction consistency. It then evaluates recent industry implementations including Swift's blockchain-based shared ledger, the Bank for International Settlements' Project Agorá and Project Rialto, and emerging cross-chain payment channel protocols.

The analysis concludes by identifying persistent challenges and outlining a path toward a more interoperable cross-border payment ecosystem.

2. Materials and Methods

2.1 Analytical Framework

This study adopts a qualitative, comparative case study approach to examine blockchain interoperability protocols for cross-border payment settlement. The analysis is structured around a tripartite framework: technical interoperability, institutional interoperability, and regulatory interoperability.

2.2 Protocol Classification

Interoperability protocols are classified according to the IEEE 3221.01-2025 standard, which identifies three primary cross-chain approaches: notary-based schemes, hash-time-locked contracts, and relay-chain architectures. Each approach is evaluated against criteria including settlement finality, latency, trust assumptions, scalability, and regulatory compatibility.

2.3 Case Study Selection

Three major industry initiatives are selected for in-depth analysis: Swift's blockchain-based shared ledger (announced September 2025), the BIS's Project Agorá (2024-2026), and the BIS's Project Rialto (completed December 2025). These cases represent distinct interoperability models and provide comprehensive coverage of the current landscape.

2.4 Data Sources

The analysis draws on primary sources including official announcements, technical reports, and press releases from Swift, the Bank for International Settlements, and the IEEE Standards Association. Secondary sources include peer-reviewed literature on blockchain interoperability and cross-border payments, industry analyses, and regulatory guidance from the Financial Action Task Force and the G20.

3. Results

3.1 IEEE 3221.01-2025: A Taxonomy of Cross-Chain Settlement Protocols

The IEEE 3221.01-2025 standard, published in June 2025, establishes a uniform framework for blockchain interoperability with specific application to cross-chain transaction consistency. The standard identifies three principal technical approaches, each with distinct implications for cross-border payment settlement:

Notary-Based Cross-Chain Technology. This approach relies on a trusted third party to verify and validate transactions across chains. In the context of cross-border payments, notary schemes offer the advantage of familiarity by mirroring the trusted intermediary role of correspondent banks. However, they reintroduce the very centralization that DLT seeks to overcome, creating single points of failure and trust dependencies. The standard distinguishes between centralized notaries and multi-signature notary groups, the latter offering greater resilience.

Hash-Time-Locked Contract Based Cross-Chain Technology. HTLCs enable atomic swaps across chains without trusted intermediaries. A transaction is conditional upon the revelation of a cryptographic secret within a specified timeframe; if the condition is not met, funds are refunded. This approach preserves decentralization and eliminates counterparty risk. However, HTLCs face practical limitations for cross-border payments: they require both chains to support scripting capabilities, they are vulnerable to transaction latency and time-lock discrepancies across chains, and they do not natively address the compliance requirements of regulated financial institutions.

Relay Chain-Based Cross-Chain Technology. Relay chains serve as an intermediary layer that connects multiple blockchains, providing shared security and consensus. Transactions are submitted to the relay chain, which verifies and finalizes them before notifying the source and destination chains. This approach offers high scalability and shared security but introduces additional complexity and latency. The relay chain itself becomes a critical infrastructure node, requiring robust governance and security.

The standard does not prescribe a single optimal approach. For cross-border payments, the trend has been toward hybrid models that combine elements of all three approaches.

3.2 Swift's Blockchain-Based Shared Ledger: Institutional Orchestration

In September 2025, Swift announced a landmark initiative: the addition of a blockchain-based shared ledger to its technology infrastructure. The ledger, developed in collaboration with over 30 global financial institutions and Consensys, is designed to enable instant, always-on cross-border transactions at unprecedented scale.

The ledger's architecture embodies a distinctly institutional approach to interoperability. Rather than replacing Swift's existing messaging infrastructure, the ledger complements it, adding a shared digital orchestration layer that records and validates interbank payment commitments. The ledger is being built on open-source foundations using an Ethereum Virtual Machine compatible architecture based on Hyperledger Besu.

Key interoperability features include: compatibility with existing and emerging networks, allowing banks to transact using any form of regulated tokenised value; integration with Swift's messaging, APIs, and ISO 20022 standards; and the ability to orchestrate transactions across both traditional and emerging systems.

By March 2026, the ledger had progressed from design to MVP implementation, with live transactions planned for 2026. Participating banks will begin live transactions using tokenised deposits. This represents a significant departure from earlier blockchain pilots: rather than replacing the existing financial infrastructure, Swift is layering DLT onto it, creating a hybrid model that maintains interoperability with the legacy system while enabling new digital capabilities.

3.3 Project Agorá: The Unified Ledger Model

Project Agorá, a collaboration between the BIS, the Institute of International Finance, seven central banks, and over 40 financial institutions, represents a more ambitious interoperability model: a shared programmable platform for cross-border interbank payments based on tokenised central bank reserves and commercial bank deposits.

The platform's architecture consists of two layers: a shared layer for recording tokenised commercial bank deposits and separate national ledgers for tokenised central bank reserves. This dual-layer design enables interoperability while preserving national monetary sovereignty. The platform can reduce payment processing times to just a few seconds and lower settlement risk through atomic transaction execution.

Project Agorá's interoperability model is distinctive in several respects. It leverages a common token standard across participating jurisdictions, enabling seamless exchange of tokenised value. It integrates ISO 20022 standards and Legal Entity Identifiers, ensuring semantic interoperability with existing financial messaging. It also preserves the existing correspondent banking model while making it more efficient through tokenisation and smart contracts.

The project's legal assessment found that the use of tokenised reserves and deposits does not alter the legal nature of money and could be implemented within existing regulatory frameworks in participating jurisdictions. This finding is significant: it suggests that regulatory interoperability may be achievable through careful design that respects existing legal structures.

3.4 Project Rialto: Modular FX and Settlement Interoperability

Project Rialto, completed by the BIS Innovation Hub in collaboration with the Bank of France, the Bank of Italy, Bank Negara Malaysia, and the Monetary Authority of Singapore, took a different approach to interoperability: a modular foreign exchange component combined with settlement in tokenised wholesale central bank money.

The project focused on mitigating FX and settlement frictions in retail cross-border payments. Its goal was to demonstrate the technical feasibility of connecting non-tokenised payment systems to tokenised FX and settlement. The proof of concept successfully simulated direct transactions between senders and receivers in different jurisdictions, as well as transactions with a vehicle currency.

Project Rialto's interoperability contribution lies in its modular architecture: it integrated interlinked instant payment systems with an FX mechanism leveraging automated market makers and tokenised central bank money as a safe settlement asset. This approach enables payment-versus-payment settlement, meaning currency exchange and settlement happen simultaneously and atomically (BIS, 2025a). By connecting to the AMM, FX participants can exchange currencies at predetermined rates and benefit from atomic settlement of transactions in tokenised central bank money.

3.5 Cross-Chain Payment Channel Protocols

Beyond institutional initiatives, academic and open-source research has advanced the technical frontier of interoperability protocols. Recent proposals include cross-chain payment channel networks that extend payment channels to support multi-hop paths across multiple blockchains. The Tombolo protocol introduces a fully distributed mechanism for establishing cross-chain payment channels designed to operate seamlessly across different blockchains (Jana et al., 2025). SightCVC proposes a novel cross-chain payment protocol enabling unrestricted off-chain transactions among mutually distrustful users (Chen & Wang, 2025). UniCross offers a universal cross-chain payment framework independent of any specific blockchain features, providing on-demand privacy and high scalability (Liu & Zhang, 2025).

These protocols share a common objective: achieving atomic settlement across blockchains without relying on trusted intermediaries. However, they also share common limitations: they assume smart contract capabilities that many permissioned ledgers lack; they face challenges in achieving finality across chains with different consensus mechanisms; and they do not natively address the regulatory requirements of institutional cross-border payments.

4. Discussion

4.1 Interpretation of Findings

Three distinct interoperability models emerge from the analysis, each with different implications for cross-border payment settlement.

The institutional orchestration model layers DLT capabilities onto existing financial infrastructure, maintaining compatibility with legacy systems while enabling new digital capabilities. Its strength lies in institutional trust: Swift's existing network of over 11,500 institutions provides unmatched scale and resilience. However, the model's reliance on a central orchestrator raises questions about whether it fully realizes the decentralization benefits of DLT.

The unified ledger model creates a shared programmable platform connecting tokenised central bank reserves and commercial bank deposits across jurisdictions. Its strength lies in atomic settlement: transactions can be executed in seconds with settlement finality. However, the unified ledger requires significant coordination among central banks and participating institutions, raising governance and implementation challenges.

The modular integration model connects existing payment systems to a DLT-based FX and settlement layer, achieving interoperability through modular integration rather than unified infrastructure. Its strength lies in pragmatism: it can be implemented incrementally without wholesale infrastructure replacement. However, the modular approach may be limited in its ability to achieve the full benefits of DLT-based settlement.

The analysis suggests that interoperability is not a binary state but a spectrum. The most promising path forward may be a hybrid approach that combines institutional orchestration, unified ledger capabilities, and modular integration.

4.2 Comparison with Existing Literature

The findings align with prior research identifying interoperability as a critical barrier to DLT adoption in financial services (Zenodo, 2025). However, the present analysis extends this literature in three respects. First, it provides a systematic classification of interoperability approaches based on the IEEE 3221.01-2025 standard. Second, it evaluates recent industry implementations that were not available in earlier reviews. Third, it identifies the emergence of hybrid models that combine elements of multiple approaches.

4.3 Challenges and Limitations

Despite significant progress, several challenges persist. Technical interoperability remains incomplete: cross-chain protocols face latency-security trade-offs, finality challenges across heterogeneous consensus mechanisms, and scalability limitations. Regulatory interoperability is particularly intractable: divergent KYC, AML, and data protection requirements across jurisdictions create compliance burdens that DLT does not automatically resolve. Institutional interoperability requires not only technical integration but also alignment of business processes, legal frameworks, and governance models. The absence of an overarching global framework for cross-border DLT-based payments remains a fundamental challenge.

4.4 Policy Implications

For policymakers, the analysis suggests three priorities. First, support for industry-led interoperability initiatives such as Swift's ledger and the BIS's projects, which offer pragmatic, institutionally grounded approaches to DLT adoption. Second, investment in common standards, including ISO 20022, LEIs, and interoperability protocols such as IEEE 3221.01-2025, which provide the semantic and technical foundation for cross-chain settlement. Third, regulatory coordination to reduce jurisdictional fragmentation. The G20's roadmap provides a framework, but implementation remains uneven.

4.5 Limitations and Future Research

Several limitations should be acknowledged. First, the analysis focuses on institutional DLT implementations; public, permissionless blockchains and their interoperability protocols are examined only in passing. Second, the rapidly evolving nature of the field means that some findings may become outdated quickly. Third, the analysis does not quantify the economic benefits of interoperability or the costs of non-interoperability.

Future research should conduct quantitative analyses of interoperability's impact on settlement speed, cost reduction, and risk mitigation. Comparative studies of interoperability protocols under real-world conditions would provide valuable empirical evidence. The governance of cross-border DLT-based payments merits further examination.

5. Conclusion

Blockchain interoperability is emerging as the decisive factor in the adoption of distributed ledger technology for cross-border payments. The analysis of settlement protocols reveals three principal technical approaches, each with distinct trade-offs between decentralization, trust, latency, and scalability.

Recent industry implementations demonstrate that interoperability is achievable in practice. Swift's blockchain-based shared ledger offers a model of institutional orchestration, layering DLT onto existing infrastructure while maintaining compatibility with legacy systems. Project Agorá demonstrates the feasibility of a unified ledger connecting tokenised central bank reserves and commercial bank deposits across jurisdictions. Project Rialto shows how modular integration can connect existing payment systems to DLT-based FX and settlement, enabling payment-versus-payment settlement.

The analysis suggests that no single interoperability approach is optimal. Hybrid models combining institutional orchestration, unified ledger capabilities, and modular integration are likely to define the next phase of DLT adoption in cross-border payments. Persistent challenges require sustained coordination among public and private sector actors. Cross-border payments are too important to be constrained by fragmented infrastructure. The protocols and implementations analyzed offer a roadmap toward a more efficient, transparent, and inclusive global payment system.

Author Contributions

Conceptualization, M.T.C.; methodology, M.T.C. and I.M.; investigation, A.O.O.; writing — original draft preparation, M.T.C.; writing — review and editing, M.T.C., I.M., and A.O.O. All authors have read and agreed to the published version of the manuscript.

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Ethics Approval

Not applicable

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Conflicts of Interest

The authors declare no conflicts of interest to report regarding the present study.

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