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A Multi-Layer Blockchain-Based Architecture for Secure and Efficient Cross-Border Digital Payments and Remittances

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ABSTRACT: Traditional cross-border payment systems suffer from significant inefficiencies, including high transaction costs averaging 7% per $200 transfer, settlement delays of one to five business days, limited transparency, and dependency on fragmented correspondent banking networks. These challenges disproportionately affect low-income individuals and small businesses engaged in international remittances. Existing governance and infrastructure frameworks have failed to provide a scalable, cost-efficient, and transparent alternative. This paper proposes a multi-layer blockchain-based architecture designed to address these limitations. The proposed system integrates an application layer (mobile and web interfaces built with Flutter and Angular), a database layer (MySQL, Redis, and Apache Tomcat), a blockchain layer (Proof-of-Work consensus with SHA-256 hashing and ECDSA digital signatures), and a settlement layer (digital wallet-driven fund transfers). A mixed-method study involving 54 survey respondents and two expert interviews validates the design rationale. Findings indicate that 53.7% of respondents are willing to adopt blockchain-based remittance systems, and 35.2% believe blockchain can address traditional cross-border payment challenges. The proposed architecture demonstrates how decentralised, immutable, and transparent transaction processing can reduce intermediary dependency, lower costs, and improve settlement efficiency in global payment infrastructure.

KEYWORDS: Blockchain, Cross-Border Payments, Distributed Ledger Technology, Remittances, Proof of Work, Smart Contracts, Financial Inclusion, Decentralised Architecture

1. INTRODUCTION

Remittances and cross-border payment systems constitute a cornerstone of the global financial ecosystem, enabling billions of dollars in fund transfers across national borders every year. Global remittance flows are projected to exceed $300 trillion by 2025, underscoring the critical importance of reliable, cost-effective, and transparent international payment infrastructure [6].

Most international transfers are processed through correspondent banking networks underpinned by centralised messaging systems such as SWIFT. This multi-layer intermediary model incurs significant operational costs, introduces settlement delays of one to five business days, and provides limited end-to-end transaction visibility [3]. According to the World Bank [5], the average cost of sending $200 internationally remains approximately 7%, far above the United Nations SDG target of 3% or less.

Blockchain technology has emerged as a transformative alternative to these legacy systems. By leveraging peer-to-peer value transfer, cryptographic verification, distributed consensus mechanisms, and immutable transaction records, blockchain offers the potential to significantly reduce costs, accelerate settlement, and improve transparency in cross-border payments [1][2]. However, despite growing academic and industry interest, the structured architectural integration of blockchain into regulated cross-border payment systems remains an underexplored area.

This paper addresses this gap by proposing and validating a multi-layer blockchain-based architecture for secure and efficient cross-border digital payments and remittances. The key contributions are:

1. Proposes a four-layer blockchain architecture integrating application, database, blockchain, and settlement components.
2. Validates system design rationale through empirical data from 54 survey respondents and two fintech industry expert interviews.
3. Demonstrates how Proof-of-Work consensus, SHA-256 hashing, and ECDSA digital signatures enable tamper-resistant and auditable transaction records.

4. Provides architectural guidelines for deploying blockchain-based cross-border payment systems in real-world financial environments.

2. LITERATURE REVIEW / RELATED WORK

2.1 Cross-Border Payment Systems

Traditional cross-border payments operate through correspondent banking relationships involving Nostro and Vostro accounts managed by intermediary institutions. While this model has enabled global fund transfers, it introduces layered complexity, processing redundancies, and limited traceability [3][4]. Alternative services such as Western Union and MoneyGram offer faster retail remittances but continue to carry intermediary and compliance-related costs [9].

2.2 Blockchain and Distributed Ledger Technology

Blockchain technology, first conceptualised by Nakamoto [1] as a peer-to-peer electronic cash system, has since evolved into a general-purpose distributed ledger capable of supporting diverse financial applications. Consensus mechanisms including Proof-of-Work (PoW) and Proof-of-Stake (PoS) underpin transaction validation and network security [11]. For regulated financial environments, permissioned blockchains such as Hyperledger Fabric and Ripple offer controlled governance, identity authentication, and faster consensus [9].

2.3 Blockchain in Cross-Border Payments

Research has demonstrated blockchain's potential to facilitate near-instant settlement by eliminating multi-level reconciliation inherent to correspondent banking [3]. Platforms such as Ripple (XRP), Stellar (XLM), and R3 Corda have demonstrated real-world applications of blockchain in cross-border remittances [10]. Smart contracts further automate compliance processes, reducing AML and KYC-related delays [9].

2.4 Theoretical Frameworks

This study draws upon three theoretical frameworks. The Technology Acceptance Model (TAM) [7] informs analysis of user adoption based on perceived usefulness and ease of use. Cross-Border Management Theory contextualises regulatory, exchange rate, and operational challenges in international fund transfers. Dynamic Systems Theory (DST) [13] provides a lens for understanding how blockchain integration reshapes the interconnected actors within global payment ecosystems.

2.5 Research Gap

While existing literature identifies isolated benefits of blockchain cost savings, transparency, and disintermediation there is a notable absence of structured architectural frameworks that systematically address decentralisation, efficiency, and regulatory compliance in cross-border payment systems [2][4]. This paper addresses this gap by proposing a complete multi-layer architecture validated by empirical evidence.

3. PROBLEM FORMULATION

Traditional cross-border payment systems face four fundamental structural challenges. First, high transaction costs: average fees of approximately 7% per $200 transfer include currency conversion, intermediary bank charges, and compliance costs [5]. Second, extended settlement times: multi-step correspondent banking processes result in one to five business day settlement delays [3]. Third, limited transparency: users and institutions lack end-to-end visibility into transaction status, deductions, and compliance status. Fourth, security vulnerabilities: multi-layered intermediary networks expose transactions to fraud, money laundering, and unauthorised access.

Survey data collected in this study confirm these challenges empirically. Among 54 respondents, 46.3% agreed that timing delays are prominent in cross-border systems, 44.4% identified high costs as a significant barrier, and 40.7% acknowledged a lack of transparency in existing payment infrastructure. Expert interview participants corroborated these findings, noting that wire transfers typically take three to five days to settle [8].

The research hypotheses guiding this study are: (H1) Blockchain-based payment systems can achieve lower transaction costs compared to traditional correspondent banking models. (H2) Decentralised ledger systems can enable faster transaction settlement with improved auditability. (H3) A multi-layer blockchain architecture can provide a scalable and secure alternative to fragmented cross-border payment infrastructure.

4. PROPOSED METHODOLOGY / FRAMEWORK

4.1 System Architecture Overview

The proposed system adopts a four-layer architecture designed to support secure, transparent, and efficient cross-border digital payments. The architecture comprises: (1) Application Layer, (2) Database Layer, (3) Blockchain Layer, and (4) Settlement Layer. Each layer fulfils a distinct functional role within an end-to-end payment processing pipeline.

4.2 Application Layer

The application layer serves as the primary user interface and interaction point. A cross-platform mobile application developed using the Flutter framework provides users with a native-quality experience on both iOS and Android platforms. A web application built with the Angular framework enables browser-based access. The application layer handles user registration, authentication, wallet management, and transaction initiation. Smart contracts are executed at this layer to enforce predefined payment rules and automate compliance checks.

4.3 Database Layer

The database layer manages structured data storage and retrieval. A MySQL relational database stores user profiles, wallet information, beneficiary details, and transaction metadata. Apache Tomcat serves as the web server and Java SpringBoot functions as the backend framework, enabling modular, scalable service deployment. Redis is employed as an in-memory cache to store user authentication tokens and wallet session data, reducing database load and improving response times.

4.4 Blockchain Layer

The blockchain layer forms the core of the system, responsible for transaction validation, immutability, and security. Each transaction is encapsulated in a block containing: a timestamp, a cryptographic hash (SHA-256), the previous block hash, a nonce, a Merkle root representing hashed transactions, and transaction details. Digital signatures are generated using the Elliptic Curve Digital Signature Algorithm (ECDSA) [12], ensuring transaction authenticity and non-repudiation. Transactions are broadcast to a peer-to-peer network of nodes, where miners compete to validate and add new blocks using the Proof-of-Work (PoW) consensus mechanism [11].

4.5 Settlement Layer

The settlement layer facilitates the transfer of funds upon successful blockchain validation. Digital wallets, which store both private and public cryptographic keys, enable users to initiate and receive payments. Upon block validation, the settlement layer executes fund transfers either through digital wallets or correspondent bank accounts. This layer also manages currency conversion and final payment confirmation, completing the end-to-end remittance process.

5. EXPERIMENTAL DESIGN

This study adopted a mixed-method research design combining quantitative survey data and qualitative expert interviews to validate the proposed architecture's design rationale and assess user perceptions of blockchain-based payments [8][14].

A structured online questionnaire was administered to 54 respondents using Google Forms. Participants were selected based on their familiarity with digital payment systems and cross-border transactions, using convenience sampling. Qualitative data were collected through in-depth interviews with two fintech industry experts: an Engineering Manager at a fintech company and a Director of Product at a cross-border payment company.

The proposed system architecture was evaluated against: transaction processing time, security (resistance to fraud and unauthorised access), transparency (end-to-end transaction visibility), and usability (ease of interaction for end users). Baseline comparisons reference traditional SWIFT-based correspondent banking systems [3][4].

6. RESULTS AND ANALYSIS

6.1 Survey Findings

Demographic analysis revealed that 59.3% of respondents were male and 40.7% female, with 75.9% in the 20-29 age group. Key findings on cross-border payment perceptions are summarised in Table 1 below.

Table 1: Summary of Survey Findings on Cross-Border Payment Perceptions

Survey Statement	Response	Percentage
Timing delays are prominent	Agree / Strongly Agree	57.4%
Cross-border payments are expensive	Agree / Strongly Agree	61.1%
Exchange rate fluctuation is a major challenge	Agree / Strongly Agree	70.3%
Lack of transparency in current systems	Agree / Strongly Agree	50.0%
Blockchain can address traditional challenges	Agree / Strongly Agree	57.4%
Willing to use blockchain remittance in future	Yes / Maybe	96.3%

6.2 Qualitative Findings

Expert interview analysis identified five core themes: (1) Technology and Problems both experts confirmed SWIFT as the dominant infrastructure for inter-bank cross-border transfers and identified high fees, long settlement times (3-5 days), and security vulnerabilities as primary pain points [3]. (2) Time and Security Constraints interviewees noted that international payments traverse multiple intermediary stages, causing processing delays absent in domestic transfers. (3) Documentation Requirements KYC processes requiring passport, driving licence, SSN, and bank statements add friction to transaction processing. (4) Transparency Deficits both respondents acknowledged existing systems lack adequate visibility into transaction status, costs, and compliance outcomes. (5) Blockchain's Future Potential both experts affirmed blockchain's capacity to reduce fraud, lower costs, and improve liquidity, while noting the need for regulatory standardisation [4].

6.3 Architectural Validation

The proposed multi-layer architecture directly addresses each identified challenge: the blockchain layer eliminates intermediary redundancy and provides immutable transaction records [1][11]; the application layer improves user experience and accessibility; digital wallets enable real-time fund availability; and the Proof-of-Work consensus mechanism ensures network security and prevents double-spending [12].

7. DISCUSSION

7.1 Theoretical Implications

The TAM framework [7] suggests that perceived usefulness and ease of use are the primary determinants of technology adoption. The proposed architecture's user-friendly Flutter and Angular interfaces, combined with transparent transaction tracking, directly address these dimensions. Dynamic Systems Theory [13] highlights how blockchain integration reshapes actor relationships within payment ecosystems, reducing reliance on centralised intermediaries and redistributing transaction authority to distributed network nodes.

7.2 Practical Implications

For financial institutions and payment service providers, the proposed architecture offers a viable alternative to correspondent banking that can reduce operational costs, improve settlement speeds, and strengthen AML and KYC compliance [9]. For users, particularly low-income individuals and small businesses in developing economies, blockchain-based remittances offer the prospect of lower fees and faster access to transferred funds [5][6].

7.3 Limitations

The study's sample size of 54 survey respondents may limit the generalisability of findings [8]. The architecture relies on a Proof-of-Work consensus mechanism which, while secure, involves higher computational costs compared to alternative mechanisms such as Proof-of-Stake or Practical Byzantine Fault Tolerance [11]. Regulatory and cross-jurisdictional compliance dimensions were not extensively explored [4].

8. CONCLUSION

This paper presented a multi-layer blockchain-based architecture for secure and efficient cross-border digital payments and remittances. Empirical validation through a 54-respondent survey and two expert interviews confirmed the real-world relevance of identified challenges and broad user willingness to adopt blockchain-based payment alternatives (96.3% positive or likely adoption intent) [7][8]. The architecture demonstrates how decentralised, immutable transaction processing can reduce costs, accelerate settlement, and improve transparency in global remittance infrastructure [1][2].

9. FUTURE WORK

- Evaluate alternative consensus mechanisms (Proof-of-Stake, PBFT) for energy efficiency and scalability improvements.
- Develop and test a live prototype with real-world cross-border payment corridors to benchmark performance against SWIFT-based systems.
- Explore regulatory compliance automation through smart contract-based AML and KYC verification.
- Investigate multi-blockchain interoperability to enable cross-platform remittance settlement.
- Expand study to larger and more geographically

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