A Survey on Central Bank Digital Currency (CBDC) Implementation Using Hyperledger Fabric: Architecture, Challenges, and Future Prospects

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***Abstract*—The emergence of Central Bank Digital Currencies (CBDCs) marks a significant shift in the evolution of digital financial systems. As central banks worldwide explore CBDCs to mod- ernize payment infrastructures, Distributed Ledger Technology (DLT), particularly Hyperledger Fabric, has gained prominence as a preferred blockchain framework for secure and scalable implementations. This survey paper provides a comprehensive analysis of CBDCs with a specific focus on their design, implementation, and operational aspects using Hyperledger Fabric as the core engine. It explores the key architectural models, transaction mechanisms, consensus protocols, privacy features, and regulatory considerations that shape CBDC deployment. Additionally, the paper presents case studies of global CBDC initiatives, highlighting the role of permissioned blockchain networks in enhancing security, transparency, and efficiency in digital monetary systems. The paper also examines challenges such as privacy concerns, interoperability, regulatory constraints, and financial stability risks. Finally, future research directions, including programmability, smart contracts, and cross-border transactions, are discussed to provide insights into the evolving landscape of blockchain-based CBDCs.**

***Index Terms*—Central Bank Digital Currency (CBDC), Blockchain, Hyperledger Fabric, Digital Payments, UTXO Model, Account-Based Model, Smart Contracts, Cryptography, Consensus Mechanism, Distributed Ledger Technology (DLT), Financial Technology (FinTech), Digital Wallets, Multi-Signature Transactions, Tokenization, Privacy and Security, Regulatory Compliance, Case Studies, Cross-Border Payments.**

I. INTRODUCTION

The rapid evolution of digital financial systems has led to a growing interest in Central Bank Digital Currencies (CBDCs), which are digital representations of sovereign currency issued and regulated by central banks. Unlike cryptocurrencies such as Bitcoin, which operate on decentralized, permissionless networks, CBDCs are designed to function within a centralized framework while leveraging advancements in distributed ledger technology (DLT) to enhance efficiency, security, and financial inclusivity [1]. As cash usage declines globally and digital payments become the norm, many governments and financial institutions are exploring CBDC implementations to ensure monetary stability, provide public access to central bank money, and improve the resilience of payment systems [2].

The motivations for CBDC adoption vary across jurisdictions. Some of the primary objectives include:

- Enhancing Financial Inclusion: A significant portion of the global population remains unbanked or underbanked, limiting their access to financial services. CBDCs, particularly retail CBDCs, have the potential to bridge this gap by offering a digital alternative to cash that is universally accessible [3].
- Improving Payment System Efficiency: Traditional banking infrastructure relies on intermediaries, resulting in high transaction costs and delays. CBDCs can stream- line transactions by providing a direct, cost-effective means of transferring funds between parties [4].
- Ensuring Monetary Sovereignty: The rise of private digital currencies and stablecoins issued by corporations poses risks to national financial stability. By issuing a sovereign digital currency, central banks can maintain control

over monetary policy and prevent reliance on private entities for digital transactions [5].

A. *Technological Foundations and Design Considerations*

CBDCs can be broadly categorized into two types:

- Retail CBDCs: Designed for the general public, these are digital equivalents of cash and can be used for everyday transactions.
- Wholesale CBDCs: Restricted to financial institutions, wholesale CBDCs facilitate interbank settlements and large-scale transactions, improving efficiency and reducing systemic risks in the financial system.

The choice of technology for CBDC implementation is crucial to achieving security, scalability, and privacy. While some central banks explore centralized database solutions, blockchain-based implementations are gaining traction due to their tamper-resistant, auditable, and decentralized properties. Among various blockchain frameworks, Hyperledger Fabric has emerged as a leading choice for CBDC development due to its permissioned nature, modular architecture, and support for smart contracts (chaincode).

B. *Hyperledger Fabric as the Backbone of CBDC Systems*

Hyperledger Fabric is an open-source enterprise blockchain framework that offers several advantages for CBDC deployment:

- Permissioned Network: Unlike public blockchains, Fabric operates on a permissioned basis, ensuring that only authorized entities, such as banks and regulatory bodies, participate in the network.
- Smart Contracts (Chaincode): CBDCs require pro- grammability for functions like automated compliance, interest payments, and conditional transactions. Fabric's chaincode enables the development of these functionalities while maintaining security.
- Modular Architecture: The flexibility of Fabric allows for customization in consensus mechanisms, identity management, and data privacy, making it adaptable to different regulatory and operational requirements.
- Scalability and Performance: Financial institutions re- quire high throughput and low-latency transaction processing. Hyperledger Fabric's efficient consensus and endorsement model ensure that CBDC transactions can be executed at scale without bottlenecks.
- Privacy and Data Confidentiality: Fabric supports private transactions using channels and data encryption mechanisms, addressing privacy concerns while maintaining compliance with regulatory frameworks.

C. *Scope of this Paper*

This paper investigates the design, implementation, and implications of Central Bank Digital Currencies (CBDCs) with a primary focus on Hyperledger Fabric as the underlying blockchain framework. We analyze the advantages, challenges, and future directions of blockchain-based CBDC models. Our key contributions include:

- A systematic review of the motivations, classifications, and evolving landscape of CBDCs, highlighting major global initiatives.
- A detailed examination of Hyperledger Fabric's modular architecture, consensus mechanisms, and smart contract capabilities tailored for CBDC implementation.
- A comparative analysis of blockchain platforms for CBDC, addressing security, scalability, interoperability, and privacy considerations.
- Real-world case studies of CBDC prototypes from leading economies, including India, China, and cross-border projects, assessing their design choices and outcomes.
- Identification of research gaps and future directions in areas such as transaction scalability, privacy-enhancing techniques (e.g., Zero-Knowledge Proofs), financial sys- tem integration, and cross-border interoperability frame- works.

The remainder of this paper is organized as follows: Section II provides an overview of the background, evolution, and fundamental concepts of CBDCs. Section III delves into the technical architecture of Hyperledger Fabric, examining its suitability for CBDC deployment. Section V presents case studies of existing CBDC initiatives and their impact. Section IV-F offers a comparative analysis of blockchain platforms for CBDC implementation. Section IV discusses security, scalability, and privacy challenges. Section VI identifies key research gaps and future directions. Finally, Section VII summarizes the findings and presents concluding remarks.

II. BACKGROUND AND RELATED WORK

Central Bank Digital Currency (CBDC) is a digital representation of a nation's currency issued and regulated by the central bank. It serves as a legal tender and can be implemented in two models: retail CBDC, accessible to the general public, and wholesale CBDC, designed for interbank transactions [6], [7]. Blockchain and Distributed Ledger Technology (DLT) have gained significant attention for CBDC implementation due to their ability to provide transparency, security, and immutability. Among various DLT platforms, Hyperledger Fabric has emerged as a preferred choice for CBDC development because of its permissioned structure, modular architecture, and support for smart contracts [8].

Hyperledger Fabric is an enterprise-grade, permissioned blockchain platform designed to facilitate secure and scalable applications. Unlike public blockchains such as Bitcoin and Ethereum, Fabric allows only authorized participants to join the network, ensuring privacy and regulatory compliance. Fabric's key features include: (1) modular consensus mech- anisms, (2) private channels for confidential transactions, (3) chaincode (smart contracts) for executing business logic, and (4) a scalable architecture with high throughput [9], [10]. Several central banks and financial institutions have explored Hyperledger Fabric for CBDC prototypes. The People's Bank of China (PBoC) has conducted extensive research on digital yuan, utilizing blockchain for secure transactions while ensuring compliance with monetary policies [11]. The Bank of Thailand and the Hong Kong Monetary Authority collaborated on Project Inthanon-LionRock, leveraging Hyperledger Fabric for cross-border CBDC transactions [12].

Recent studies suggest that while Hyperledger Fabric pro- vides essential security and privacy measures, scalability remains a concern for large-scale CBDC implementations. Research by [13] explores transaction throughput challenges and proposes optimization techniques to enhance efficiency. Another critical aspect is regulatory compliance, where frame- works for digital identity verification and anti-money launder- ing (AML) measures are integrated within Fabric [14]. Studies [15], [16] highlight the necessity of interoperability with existing financial infrastructures to ensure seamless adoption of CBDC.

Additionally, Hyperledger Fabric's smart contract (chain- code) functionality enables programmability in financial trans- actions. Researchers have explored the implementation of multi-signature transactions, time-locked contracts, and conditional payments using Fabric's chaincode [17]. The modularity of Fabric also allows integration with emerging financial technologies such as decentralized finance (DeFi) and cross- border payment systems [18].

The evolution of CBDC with Hyperledger Fabric continues to attract interest from governments and enterprises, demonstrating its potential to revolutionize digital payments while maintaining regulatory control and security

III. CBDC DESIGN CONSIDERATIONS

The design of Central Bank Digital Currency (CBDC) is a multifaceted challenge that requires balancing security, efficiency, privacy, regulatory compliance, and financial stability. A general architecture of a CBDC system, as proposed in [21], is shown in Figure 1.This section outlines the critical considerations for CBDC design, particularly in the context of blockchain-based implementations such as Hyperledger Fabric.

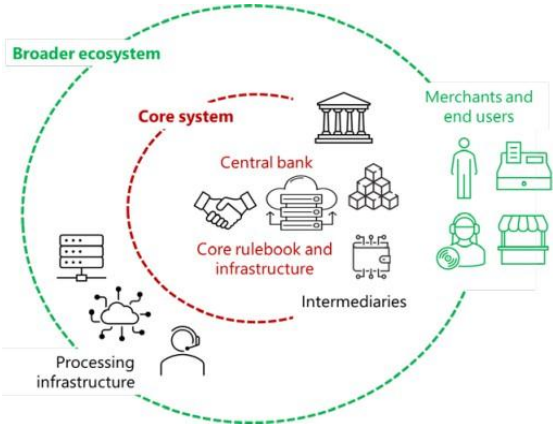

Fig. 1. CBDC System Design Model [21]

A. *Privacy and Security*

CBDC systems must ensure transactional privacy while allowing regulatory oversight. Privacy-preserving techniques such as zero-knowledge proofs (ZKPs) and ring signatures can help maintain user anonymity while enabling auditability [6], [7]. Hyperledger Fabric's private data collections and access control mechanisms facilitate secure and confidential transactions [8].

B. Scalability and Performance

A CBDC platform must support high transaction throughput and low latency to accommodate national-scale operations. Hyperledger Fabric offers modular consensus mechanisms, allowing optimization based on network requirements. Studies highlight the importance of efficient transaction validation, state management, and endorsement policies to enhance scalability [9], [10].

C. Interoperability

Interoperability between CBDC platforms, banking infrastructure, and cross-border payment networks is essential. Blockchain interoperability frameworks, such as Interledger and cross-chain protocols, aim to facilitate seamless transactions between different financial systems [12], [14]. Hyper- ledger Fabric supports multiple identity providers and integration with existing payment rails, improving its interoperability.

D. Regulatory Compliance and Governance

CBDC must comply with anti-money laundering (AML) and counter-terrorism financing (CTF) regulations. Hyper- ledger Fabric provides identity management and permissioned access, allowing central banks to enforce regulatory policies. The governance model should define roles, access control, and consensus policies to ensure compliance with national and international regulations [11], [13].

E. Resilience and Fault Tolerance

CBDC platforms should be resilient against cyber threats and operational failures. Hyperledger Fabric's modular architecture enables redundancy, Byzantine Fault Tolerance (BFT)- based consensus mechanisms, and secure backup strategies to prevent data loss or malicious attacks [12].

F. Smart Contract and Programmability

Smart contracts enable programmable monetary policies, automated compliance, and financial innovations. Hyperledger Fabric's chaincode supports custom business logic while maintaining security and auditability. The programmability of CBDCs can help implement conditional payments, interest- bearing accounts, and tax automation [8].

The successful design of a CBDC depends on a well- balanced approach that integrates technological advancements with regulatory requirements. Hyperledger Fabric provides a robust foundation to address these design considerations while ensuring compliance, scalability, and financial stability.

IV. IMPLEMENTATION CHALLENGES AND SOLUTIONS

The implementation of CBDC using Hyperledger Fabric presents multiple challenges that require careful consideration. Several studies have explored these challenges and proposed solutions to enhance the effectiveness of CBDC deployment.

A. Scalability Issues

CBDCs require high transaction throughput to handle mil- lions of daily transactions. Hyperledger Fabric's default consensus mechanisms (such as Raft) may limit scalability when compared to public blockchains like Ethereum [8]. Solutions such as:

- Sharding and Parallel Processing: Implementing trans- action sharding to distribute the load across multiple network nodes [10].
- Layer-2 Scaling: Introducing off-chain transaction settle- ment mechanisms to reduce on-chain congestion [13].

B. Privacy and Security Concerns

While Hyperledger Fabric offers private channels, main- taining strong privacy between transaction participants while ensuring regulatory compliance remains a challenge [14]. Proposed solutions include:

- Zero-Knowledge Proofs (ZKP): Enabling transaction verification without revealing sensitive information [13].
- Ring Signatures and Multi-Party Computation (MPC): Enhancing anonymity for retail CBDC users while maintaining auditability [6].

C. Regulatory and Compliance Challenges

Regulatory frameworks for CBDCs differ across jurisdictions, requiring adaptable compliance mechanisms. Key solutions include:

- Smart Contract-Based Compliance: Encoding regulatory policies into Fabric's chaincode to automate compliance checks [11].
- Permissioned Identity Management: Implementing robust KYC/AML protocols within the Fabric network [12].

D. Interoperability with Existing Financial Systems

Integrating CBDC with traditional banking infrastructure re- quires interoperability across different platforms [7]. Solutions include:

- Cross-Chain Communication Protocols: Utilizing blockchain interoperability frameworks such as Interledger or Polkadot bridges [14].
- API-Driven Integration: Developing APIs that enable seamless interaction between Fabric-based CBDCs and legacy financial systems [12].

E. Governance Model and Network Management

CBDC networks must have clear governance structures defining roles and responsibilities among central banks, financial institutions, and end-users [6]. Key recommendations include:

- Hierarchical Network Administration: Defining multi- tiered administrative roles with differentiated access con- trol [7].
- Consensus Mechanism Customization: Adapting consen- sus protocols based on the network's security and scala- bility requirements [9].

These challenges highlight the need for continued research and innovation in the design and deployment of CBDCs using Hyperledger Fabric.

F. Comparative Analysis of Blockchain Platforms for CBDC

Table I presents a comparative analysis of different blockchain platforms used for the implementation of CBDC, including Hyperledger Fabric, Corda, Quorum, and Hyper- ledger Besu.

V. CASE STUDIES OF CBDC IMPLEMENTATIONS

This section examines real-world Central Bank Digital Currency (CBDC) projects that have utilized blockchain technologies, including Hyperledger Fabric, focusing on their design choices, outcomes, and challenges.

A. Project Inthanon-LionRock

Participants: Bank of Thailand (BOT) and Hong Kong Monetary Authority (HKMA)

Objective: To explore the application of Distributed Ledger Technology (DLT) in enhancing cross-border payments be- tween Thailand and Hong Kong.

Design Choices: The project developed a cross-border corridor network prototype to facilitate real-time cross-border fund transfers and foreign exchange transactions using DLT.

Outcomes: The prototype demonstrated the potential of DLT to increase efficiency, reduce settlement risks, and lower costs in cross-border transactions.

Challenges: Issues related to governance, regulatory com- pliance, and technical interoperability between different DLT platforms were identified during the project.

B. Project Jasper

Participant: Bank of Canada

Objective: To investigate the use of DLT for wholesale interbank payments.

Design Choices: The project developed a DLT-based in- terbank payment system prototype to assess its feasibility for clearing and settlement.

Outcomes: The prototype showcased that DLT could fulfill the core functions of a wholesale payment system, offering benefits like enhanced traceability and resilience.

Challenges: The project highlighted concerns regarding scalability, privacy, and the need for a robust legal framework to support DLT-based payment systems.

TABLE I: COMPARISON OF BLOCKCHAIN PLATFORMS FOR CBDC

Feature	Hyperledger Fabric	Corda	Quorum	Hyperledger Besu
Consensus Mechanism	RAFT, PBFT	Notary-based	IBFT, RAFT	IBFT, Clique
Privacy	Private channels	Point-to-point transactions	Private transactions	Private transactions
Scalability	High	Medium	High	High
Smart Contracts	Chaincode(Go, Java, Node.js)	CorDapps (Java, Kotlin)	Solidity	Solidity
Governance	Permissioned	Permissioned	Permissioned	Permissioned/Public
Use Case Suitability	Enterprise, Financial	Financial, Legal	Enterprise, Banking	Enterprise, Public-Private

C. Project Aber

Participants: Saudi Central Bank (SAMA) and Central Bank of the United Arab Emirates (CBUAE)

Objective: To evaluate the feasibility of issuing a joint digital currency for cross-border settlements between Saudi Arabia and the UAE.

Design Choices: The project implemented a dual-issued digital currency as a unit of settlement between commercial banks in both countries, leveraging DLT for enhanced security and efficiency.

Outcomes: The initiative demonstrated that a cross-border digital currency could streamline transactions and reduce transfer times and costs.

Challenges: The project faced challenges related to aligning monetary policies, regulatory frameworks, and ensuring technical interoperability between the two nations.

D. Digital Yuan (e-CNY)

Participant: People's Bank of China (PBOC)

Objective: To develop a digital version of the Chinese yuan to modernize the payment system and reduce reliance on cash. Design Choices: The e-CNY employs a two-tier system where the central bank issues the digital currency to commercial banks, which then distribute it to the public. The system utilizes a hybrid architecture combining centralized management with aspects of DLT.

Outcomes: The e-CNY has undergone extensive pilot testing across various regions and sectors in China, with transactions reportedly reaching approximately 987*billion.*

Challenges: The PBOC has addressed issues related to user privacy, data security, and achieving widespread adoption among a population accustomed to existing digital payment platforms.

E. Digital Rupee (e)

Participant: Reserve Bank of India (RBI)

Objective: To introduce a digital version of the Indian rupee to enhance the efficiency of the monetary system and reduce dependency on physical cash.

Design Choices: The RBI launched pilot projects for both wholesale (e-W) and retail (e-R) use cases. The e-W focuses on settling secondary market transactions in government securities, while the e-R aims to facilitate retail transactions.

Outcomes: The e-W pilot commenced on November 1, 2022, involving major banks like the State Bank of India and HDFC Bank. The e-R pilot began on December 1, 2022, in select cities, with plans for gradual expansion.

Challenges: The RBI is addressing challenges related to technological infrastructure, user adoption, and ensuring the digital currency's compatibility with India's diverse financial ecosystem.

F. DCash

Participant: Eastern Caribbean Central Bank (ECCB)

Objective: To implement a digital version of the Eastern Caribbean dollar to promote financial inclusion and enhance payment efficiency across member countries.

Design Choices: DCash was developed using Hyperledger Fabric, chosen for its strong security architecture and open- source flexibility. The digital currency is issued by the ECCB and distributed through licensed financial institutions.

Outcomes: Launched in 2021, DCash became the first CBDC introduced within a currency union, facilitating trans- actions across multiple island economies.

Challenges: The project encountered obstacles related to technological infrastructure, public awareness, and achieving uniform adoption across all member states.

G. eNaira

Participant: Central Bank of Nigeria (CBN)

Objective: To introduce a digital currency that complements the physical naira, aiming to enhance financial inclusion and improve the efficiency of monetary transactions.

Design Choices: The eNaira utilizes a variant of DLT, providing the CBN with capabilities to efficiently support and oversee digital wallets associated with the eNaira.

Outcomes: Nigeria became one of the first African countries to launch a CBDC, with the eNaira facilitating various transactions and aiming to integrate more citizens into the formal financial system.

Challenges: The CBN faced challenges related to public trust, technological literacy, and ensuring robust security measures to prevent fraud.

H. Project Bakong

Participant: National Bank of Cambodia

Objective: To enhance the payment system's efficiency and promote financial inclusion through a blockchain-based digital currency.

Design Choices: Project Bakong was built using Hyper- ledger Iroha, facilitating real-time transactions and integrating various payment service providers into a single platform.

Outcomes: Recognized as a significant retail CBDC initiative, Bakong has improved transaction speeds and accessibility, contributing to increased financial inclusion in Cambodia.

Challenges: The project addressed issues related to interoperability with existing financial systems, user adoption, and maintaining a balance between innovation and regulatory compliance.

VI. FUTURE RESEARCH DIRECTIONS

While several CBDC projects have demonstrated promising outcomes, there remain significant areas for further research and development. Addressing these challenges will be crucial for the widespread adoption and efficient operation of CBDCs.

A. *Scalability Improvements for CBDC Transactions*

Scalability remains a critical challenge for CBDCs, particularly in high-volume transaction environments. Future research should focus on:

- Implementing sharding techniques to distribute transaction processing loads efficiently.
- Exploring Layer-2 solutions, such as rollups, to enhance transaction throughput while maintaining security.
- Developing consensus algorithms optimized for high- speed financial transactions, such as DAG-based approaches.

B. *Privacy-Preserving Mechanisms*

CBDCs need to balance user privacy with regulatory compliance. Emerging cryptographic techniques that could be integrated into CBDC architectures include:

- Zero-Knowledge Proofs (ZKPs): Allow transaction validation without revealing sensitive information, ensuring confidentiality.
- Multi-Party Computation (MPC): Enables collaborative data processing while preserving individual privacy.
- Ring Signatures and Stealth Addresses: Offer enhanced anonymity in CBDC transactions.

  Despite these advancements, ensuring regulatory acceptance and scalability of privacy-preserving technologies remains a challenge.

C. *Integration with Existing Financial Infrastructure*

Seamless integration of CBDCs with current banking and financial systems is essential for adoption. Key research areas include:

- Interfacing CBDCs with traditional payment systems (SWIFT, RTGS, UPI, etc.).
- Developing API-driven architectures that allow banks and fintech firms to integrate CBDCs seamlessly.
- Ensuring compliance with Anti-Money Laundering (AML) and Know Your Customer (KYC) regulations in digital transactions.

D. *Cross-Border Interoperability Frameworks*

For CBDCs to facilitate international trade and remittances, interoperability between different national digital currencies is necessary. Research should focus on:

- Standardized smart contract protocols that allow inter- bank and cross-border transactions.
- Developing blockchain bridges between different CBDC implementations to enable seamless value transfer.
- Regulatory cooperation and legal frameworks to support cross-border CBDC transactions.

E. *Other Emerging Areas*

Other potential areas for future research include:

- Decentralized Identity (DID): Using blockchain-based identity solutions to ensure secure and verifiable transactions.
- Post-Quantum Cryptography: Exploring quantum- resistant cryptographic techniques for future-proofing CBDCs.
- AI-Driven Fraud Detection: Utilizing machine learning models to detect fraudulent CBDC transactions in real time.

VII. CONCLUSION

The development and adoption of Central Bank Digital Currencies (CBDCs) have gained significant momentum, with various nations actively exploring blockchain-based implementations. This paper provided an in-depth survey of real- world CBDC initiatives using Hyperledger Fabric, highlighting their design choices, advantages, and challenges.

Through an analysis of prominent CBDC projects, including those from China, India, and other major economies, we identified key technological and regulatory considerations that impact CBDC deployment. Hyperledger Fabric, as a permissioned blockchain platform, offers strong security and customizability, yet it faces challenges in scalability, interoperability, and privacy.

We outlined critical research directions, including scalability improvements via sharding and Layer-2 solutions, enhanced privacy through Zero-Knowledge Proofs and Multi- Party Computation, seamless integration with traditional financial systems, and cross-border interoperability frameworks. Addressing these challenges is essential for realizing the full potential of CBDCs in modern financial ecosystems.

As global economies continue to experiment with digital currencies, future advancements in blockchain technology, cryptography, and regulatory compliance will shape the effectiveness and adoption of CBDCs. The insights presented in this paper contribute to ongoing discussions and provide a foundation for further research in designing secure, scalable, and globally interoperable digital currencies.

REFERENCES

[1] J. Lovejoy, C. Fields, M. Virza, T. Frederick, A. Brownworth, K. Karwaski, D. Urness, and N. Narula, “A High Performance Payment Processing System Designed for Central Bank Digital Currencies,” 2022.

[2] J. Zhang, R. Tian, Y. Cao, X. Yuan, Z. Yu, X. Yan, and X. Zhang, “A Hybrid Model for Central Bank Digital Currency Based on Blockchain,” *IEEE Access*, vol. 9, pp. 53589–53601, 2021. doi:10.1109/ACCESS.2021.3071345

[3] E. Androulaki, M. Brandenburger, A. De Caro, K. Elkhiyaoui, A. Filios, L. Funaro, Y. Manevich, S. Natarajan, and M. Sethi, “A framework for resilient, transparent, high-throughput, privacy-enabled central bank digital currencies,” *Cryptology ePrint Archive*, 2023. [Online]. Available: https://eprint.iacr.org/2023/1717

[4] C. Gorenflo, S. Lee, L. Golab, and S. Keshav, “FastFabric: Scaling Hyperledger Fabric to 20,000 Transactions per Second,” 2019.

[5] A. Augusto, R. Belchior, I. Kocsis, L. Go¨nczy, A. Vasconcelos, and M. Correia, “CBDC Bridging Between Hyperledger Fabric and Permissioned EVM-Based Blockchains,” 2023. [Online]. Available:

[6] C. Boar and A. Wehrli, ”The Rise of Central Bank Digital Currencies: Drivers, Approaches, and Technologies,” BIS Quarterly Review, 2020.

[7] Bank for International Settlements, ”Retail Central Bank Digital Cur- rency: Design Considerations,” 2021.

[8] E. Androulaki et al., ”Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains,” Proceedings of the Thirteenth EuroSys Conference, 2018.

[9] C. Cachin, ”Architecture of the Hyperledger Blockchain Fabric,” IBM Research, 2016.

[10] T. Dinh et al., ”Untangling Blockchain: A Data Processing View of Blockchain Systems,” IEEE Transactions on Knowledge and Data Engineering, 2018.

[11] Y. Fan, ”Central Bank Digital Currency and the Future of Monetary Policy,” PBoC Research Paper, 2020.

[12] S. Bohm et al., ”Cross-Border Payments with CBDC: Lessons from Project Inthanon-LionRock,” Bank of Thailand, 2021.

[13] L. Gudgeon et al., ”Defi and the Future of Decentralized Finance,” ACM Conference on Financial Cryptography and Data Security, 2020.

[14] R. Belchior et al., ”A Survey on Blockchain Interoperability: Past, Present, and Future Trends,” ACM Computing Surveys, 2021.

[15] Bank for International Settlements, ”Interoperability and CBDC: Exploring Design Considerations,” 2022.

[16] J. Lee, ”Governance Challenges in CBDC Implementations Using Hyperledger Fabric,” Journal of Financial Innovation, 2023.

[17] K. Smith, ”Programmable CBDCs: Leveraging Hyperledger Fabric for Secure and Flexible Transactions,” International Journal of Digital Currency Research, 2022.

[18] M. Jones, ”The Evolution of CBDC:

Integration with Emerging Financial Technologies," IEEE Conference on Blockchain and Crypto currency, 2023.

[19] Atlantic Council, "Global CBDC Developments: Trends and Challenges," Sep. 2024. [Online]. Available: https://www.atlanticcouncil.org/global-cbdc

[20] E. Prasad, "Central Bank Digital Currencies: Benefits, Risks, and the Future of Money," Brookings Institution Press, 2024.

[21] Bank for International Settlements, "CBDC system design and considerations," BIS Publications, 2021. [Online]. Available: https://www.bis.org/publ/othp42$_s$*ystem*$_d$*esign.pdf.*