

Project “SAN”

Technical Report:

Prototype of Tokenization for
Domestic Settlement

Acknowledgements

Authors

Kasidit Tansanguan

Director, Financial Institutions Strategy Department | Bank of Thailand

Peerapong Thonnagith

Deputy Director, Digital Currency and Policy Development Unit | Bank of Thailand

Witit Synsatayakul

Deputy Director, Digital Currency and Policy Development Unit | Bank of Thailand

Nuntapun Bhensook

Assistant Director, Digital Currency and Policy Development Unit | Bank of Thailand

Jadesada Palotaitakerng

Assistant Director, Digital Currency and Policy Development Unit | Bank of Thailand

Tanakorn Kerdrattikal

Assistant Director, Digital Currency and Policy Development Unit | Bank of Thailand

Pakaporn Tohwisessuk

Senior Specialist, Digital Currency and Policy Development Unit | Bank of Thailand

Prempoon Srimonta

Senior Specialist, Digital Currency and Policy Development Unit | Bank of Thailand

Lalitwadee Damyos

Senior Specialist, Digital Currency and Policy Development Unit | Bank of Thailand

Jakkapong Pansit

Senior Specialist, Digital Currency and Policy Development Unit | Bank of Thailand

Siwapol Jumnongsaksub

Senior Specialist, Digital Currency and Policy Development Unit | Bank of Thailand

Table of Contents

1. Executive Summary	4
2. Problem Statement and Intended Outcome	5
3. Prototype, Scope and Requirements	8
3.1) Prototype: Orchestrated settlement across different networks	8
3.2) Scope and Requirements	10
3.3) Business and Operational Workflow	12
4. Technical Design	15
5. Key Findings	18
6. Conclusion and Further Considerations	20

1. Executive Summary

The private sector is currently developing use cases that leverage tokenization and distributed ledger technology (DLT) to enhance operational efficiency and promote innovation in programmable payment services. Nevertheless, this rapid development presents two key challenges: (1) the emergence of fragmented, closed-loop DLT payment networks with limited interoperability, and (2) the lack of integration between DLT-based systems and existing centralized financial infrastructures. In the absence of a secure, reliable, and technology-agnostic interoperability framework, the full potential of DLT, including atomic settlement through Delivery versus Payment (DvP), cannot be realized. Such fragmentation may also increase transaction costs, create friction in user experience, and heighten complexity in liquidity management.

In response, the Bank of Thailand (BOT) launched the SAN Project to design and test a prototype of tokenization for domestic settlement. The project seeks to evaluate interoperability mechanisms both among distinct DLT-based payment networks and between DLT-based systems and centralized financial infrastructures. The prototype employs an orchestrated interoperability model, underpinned by an Interoperability Layer (IL) that facilitates seamless data exchange and connectivity between heterogeneous platforms.

The prototype consists of three key components: (1) the Interoperability Layer (IL), (2) a wholesale settlement system operating on centralized technology, and (3) tokenized money networks operated by private-sector institutions on DLT platforms¹. The IL design follows three guiding principles: modularity, interoperability (via international standards such as ISO 20022), and robust functionality to ensure accurate, reliable, and continuous settlement operations.

Prototype testing focused on two primary use cases: (1) tokenization-based domestic fund transfers between customers and financial service providers (FSPs), and (2) tokenization-based asset settlements between customers of different FSPs. Results demonstrate that the IL can successfully facilitate tokenized fund transfers with low latency,

¹ Simulated by BOT for testing purposes; no private-sector institutions involved.

high throughput, and scalability. Moreover, the IL architecture is designed to support asset-agnostic settlement, thereby enabling future use cases such as atomic DvP.

Although the prototype validates technological feasibility, real-world implementation requires further consideration of business rules, regulatory compliance², and alignment with internal operational procedures. Cross-border interoperability also remains a critical area to ensure broader integration.

Insights derived from SAN Project—through its design, development, and testing—will inform the modernization of Thailand’s Real-Time Gross Settlement (RTGS) system, ensuring its capacity to support interoperability in a tokenized environment. Findings also provide a foundation for developing guidelines and standards for secure and efficient connectivity between private-sector DLT-based payment networks.

The BOT and the Hong Kong Monetary Authority (HKMA) have been collaborating under SAN and Ensemble projects since October 2024. As part of ongoing collaboration efforts, the prototype of SAN is being further developed by integrating with asset platforms to test cross-border asset purchase transactions using a DvP settlement model.

2. Problem Statement and Intended Outcome

The private sector is currently developing use cases leveraging tokenization and DLT to enhance operational efficiency such as data transmission, verification, and transaction execution. These developments also support payment innovation through programmability, enabling payments to be executed based on predefined conditions. Such conditions may rely on off-chain data sources; for example, escrow payments may be triggered by the delivery of goods, which requires integrating information about physical assets outside the DLT network.

Problem Statement

Despite these advancements, the absence of a comprehensive technology-agnostic interoperability framework poses critical challenges in two dimensions:

- 1) Interoperability across DLT-based networks:** Distinct DLT-based payment systems remain siloed, forming fragmented, closed-loop networks that cannot interoperate. This limits the

² Tokenized funds transfer and payment are subject to the regulations of the Bank of Thailand (BOT).

realization of DLT's full potential, such as atomic settlement across platforms, while also increasing operational costs and risks. For instance, customers of FSP A may be unable to transact with or transfer funds to customers of FSP B. At a systemic level, fragmentation risks undermining the singleness of money by generating value discrepancies across tokenized deposits.

- 2) **Interoperability between DLT-based networks and traditional financial system:** The absence of interoperability between DLT-based networks and the traditional financial system may limit the ability to leverage innovative services built upon the traditional financial system, which is characterized by high efficiency and robust security. For example, integration with high-value interbank payment systems such as Real-Time Gross Settlement (RTGS) could be hindered.

Intended Outcome

To address these challenges, the BOT has initiated the SAN project to study, develop, and test a prototype of tokenization for domestic settlement focusing on **technology-agnostic interoperability across different payment networks**. The objective is to enable effective utilization of tokenization and support innovative use cases through interoperability across different systems and networks, including asset platforms. The BOT has developed and tested the prototype across two key dimensions:

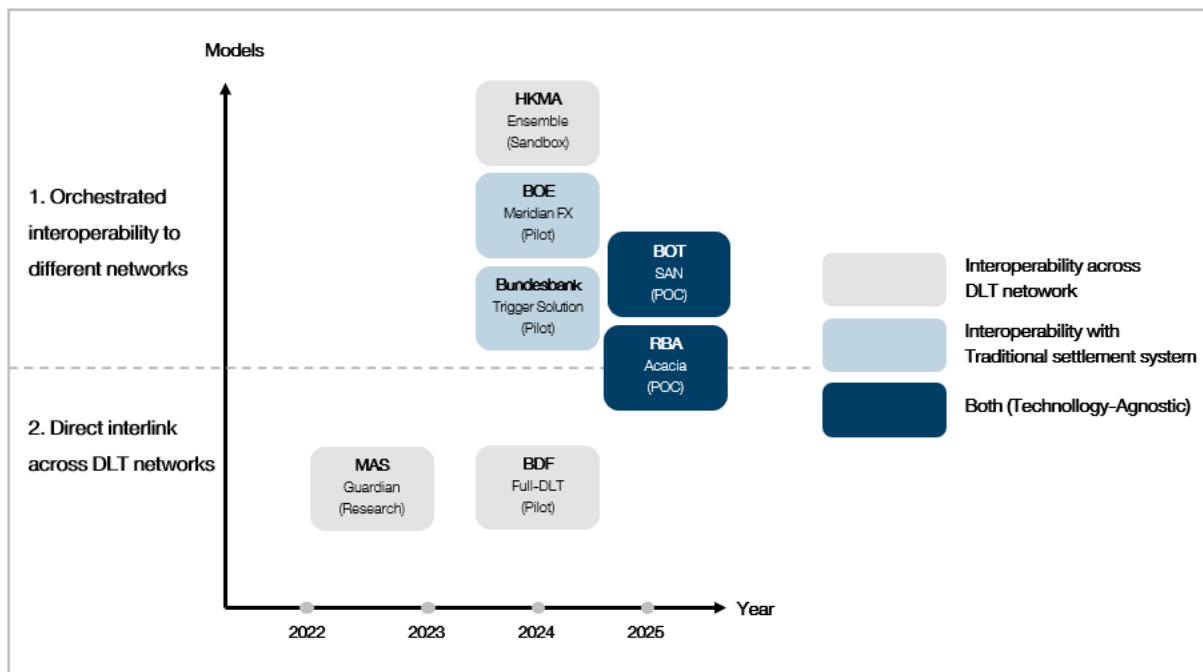
- 1) **Interoperability across DLT-based network:** Developed and tested the functionality of the IL to enable seamless connectivity, data exchange, and transaction initiation for domestic fund transfers across payment systems operated by different FSPs on distinct DLT-based networks. For instance, the IL facilitates the transfer of tokenized deposits between separate private-sector DLT-based payment networks.
- 2) **Interoperability with traditional financial system (wholesale settlement system):** Developed and tested the functionality of the IL to facilitate connectivity, data exchange, and transaction initiation for domestic fund transfers between DLT-based payment systems and traditional wholesale settlement system. For example, the IL supports cross-FSP transfers within wholesale settlement system based on centralized technology.

Prototype testing evaluates both functional aspects and non-functional capabilities, such as transaction processing efficiency (response time), capacity to handle adequate transaction

volumes (throughput), and scalability to support an increasing number of participating networks (network scalability).

Review of Interoperability Models

A review of interoperability models pursued by central banks in other jurisdictions highlights two primary considerations: (1) **Messaging interoperability**, which enables standardized data exchange between distinct payment networks operated by different FSPs, and (2) **Transactional interoperability**, which supports the seamless processing and settlement of payments across platforms operated by FSPs on DLT-based networks.



Authors' categorization, based on public information from central banks.

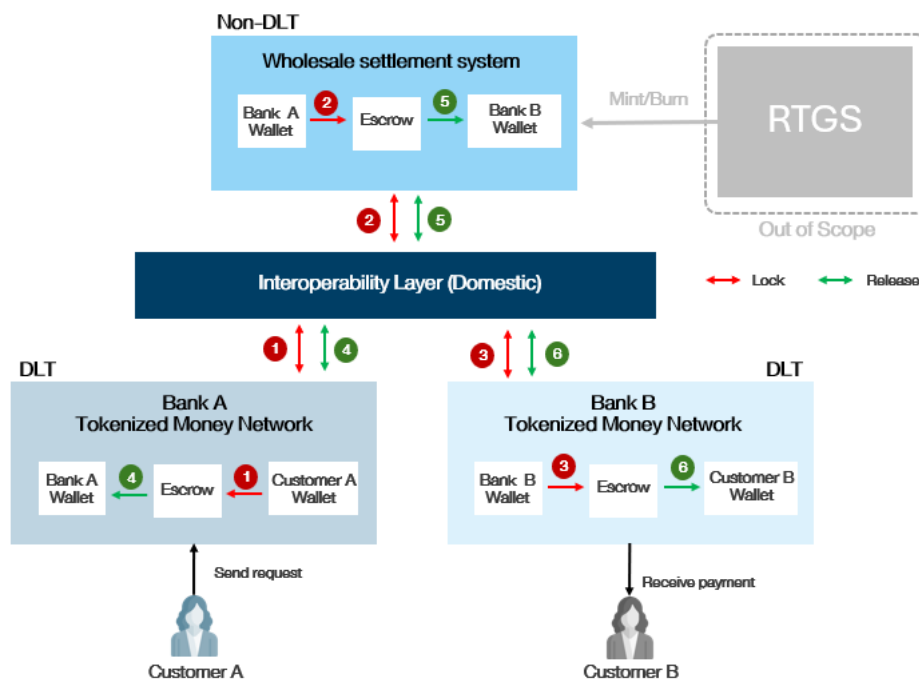
- 1) **Orchestrated interoperability across different networks:** In this interoperability model, transaction processing and settlement finality remain within the domain of each FSP's network. The interoperability mechanism functions solely as a facilitator for data exchange and message transmission between payment systems, without executing settlement itself (orchestrated settlement). Several central banks, including those in Hong Kong, Germany, and the United Kingdom, are currently exploring or piloting this approach.
- 2) **Direct interlink across DLT-based networks:** This model leverages interoperability protocols and smart contract mechanisms to facilitate data exchange, transaction processing, verification, and settlement finality between distinct DLT networks. Central banks in Singapore and France are exploring and piloting this approach.

To achieve the intended outcomes, the prototype developed under the SAN project adopts the **orchestrated interoperability across different networks model**. This architecture is technology-agnostic, providing flexibility to interconnect systems built on both DLT and centralized infrastructures, while enabling efficient integration with traditional financial systems. Key enhancements, such as the introduction of fund escrow mechanisms, are introduced without materially affecting the core architecture or existing operational processes. In contrast, the direct interlink across DLT-based networks model exclusively supports payment systems built on DLT technology.

3. Prototype, Scope and Requirements

3.1) Prototype: Orchestrated settlement across different networks

Architecture and Operational Mechanism



The developed prototype employs an orchestrated settlement model, enabling **simultaneous transaction processing across all payment systems** via the IL. This design ensures tokenized domestic fund transfers are executed accurately, efficiently, and promptly, effectively eliminating settlement risks between FSPs. Additionally, the system accommodates payment networks operating on different DLT platforms across multiple FSPs, while mitigating operational inconsistencies between networks.

The prototype comprises three key components³:

- 1) **Interoperability Layer (IL):** Facilitates connectivity across payment networks and orchestrated domestic fund transfer transactions.
- 2) **Wholesale Settlement System:** Enables domestic fund transfers between different FSPs using centralized technology.
- 3) **Tokenized Money Networks:** Operated by private-sector participants on DLT platforms.

The IL serves as the key mechanism for data transmission and the transaction orchestration between customers and financial service providers, ensuring atomic and simultaneous settlement. For instance, when a customer of FSP A initiates a fund transfer, FSP A forwards the instruction via the IL. The IL simultaneously submits the instructions to the payment systems of both FSP A and FSP B. FSP A then reserves the funds within its escrow account and the wholesale settlement system, subsequently confirming the transaction status. After that, the IL orchestrates the simultaneous transfer of funds on both the customer and FSP sides, ensuring the transaction is completed.

To enhance transparency and trust in cross-platform transactions, the prototype leverages a fund escrow mechanism. This mechanism facilitates atomic settlement by enabling real-time verification and tracking of transaction status, while reducing counterparty and operational risks from potential errors or delays in any single system.

Key components of the prototype

Components	Technology	Main functions
Interoperability Layer (IL): The mechanism enabling connectivity between payment systems	Leverages APIs and ISO 20022 standards to enable interoperability across diverse networks and technologies (technology-agnostic).	● Receives and submits instructions for fund escrow and transfer across payment systems. ● Manages end-to-end transaction process.

³ All components were developed and tested by BOT within its experimental environment. The tokenized money networks were simulated by BOT for testing purposes; no private-sector institutions were involved.

Components	Technology	Main functions
		Coordinates and orchestrates customer and FSP fund transfers to achieve simultaneous, atomic settlement.
Wholesale Settlement System: a system enabling fund transfers between different FSPs using Wholesale CBDC and operates on centralized technology	Utilizes centralized technology because: - It can efficiently and rapidly process a high volume of cross-platform transactions. - It aligns with the current design of high-value interbank funds transfer systems (RTGS) that operate on centralized technology.	- Receives and submits fund escrow and transfer instructions from the IL. - Executes fund transfers between the accounts of FSPs.
Tokenized money networks: Payment systems operating on the DLT networks of private sector FSPs.	Utilizes DLT because: - It improves transparency and efficiency in transaction management through smart contract mechanisms. - It enables further innovation in payment services, such as programmability.	- Executes fund transfers within its system. - Receives and submits fund escrow and transfer instructions from the IL. - Executes customer fund transfers within its own system.

3.2) Scope and Requirements

Prototype development focuses primarily on the technological design, development, and testing of the system's operational mechanisms. Assumptions and requirements for transaction flows have been established to enable effective technological evaluation.

Scope of Prototype Development (In-scope)

The development of the tokenization for domestic settlement covers three main areas as follows:

Scopes	Details
Prototype design	Utilizes an orchestrated settlement mechanism for simultaneous transaction processing across all platforms, encompassing (1) the IL, (2) wholesale settlement system, and (3) tokenized money networks of private-sector FSPs.
Prototype development	Deploys and integrates the IL with the wholesale settlement system and the private-sector FSPs' tokenized money networks.
Prototype experiment	Tests tokenization-based domestic funds transfers between customers and FSPs, assessing core functionality and non-functional performance (e.g., throughput, latency, scalability).

Assumptions and Requirements

Assumptions and requirements for transaction flows have been established to enable effective technological evaluation. The details are as follows:

Assumptions and Requirements	Details
Transaction Management	Funds are managed using a lock-and-release escrow mechanism, where funds are reserved prior to transfer to mitigate payment default risk.
Funds Transfer	- Funds are transferred on a real-time, transaction-by-transaction basis (RTGS), without batch processing or netting. - The system supports off-us⁴ customer fund transfers across different FSPs and cross-network transfers.

⁴ Transactions in which the payer's and payee's accounts are held at different FSPs.

Assumptions and Requirements	Details
Funds Preparation	Full prefunding of transaction amounts is maintained for both providers and customers to ensure no liquidity constraints during fund transfers.

Out-of-Scope of Prototype Development

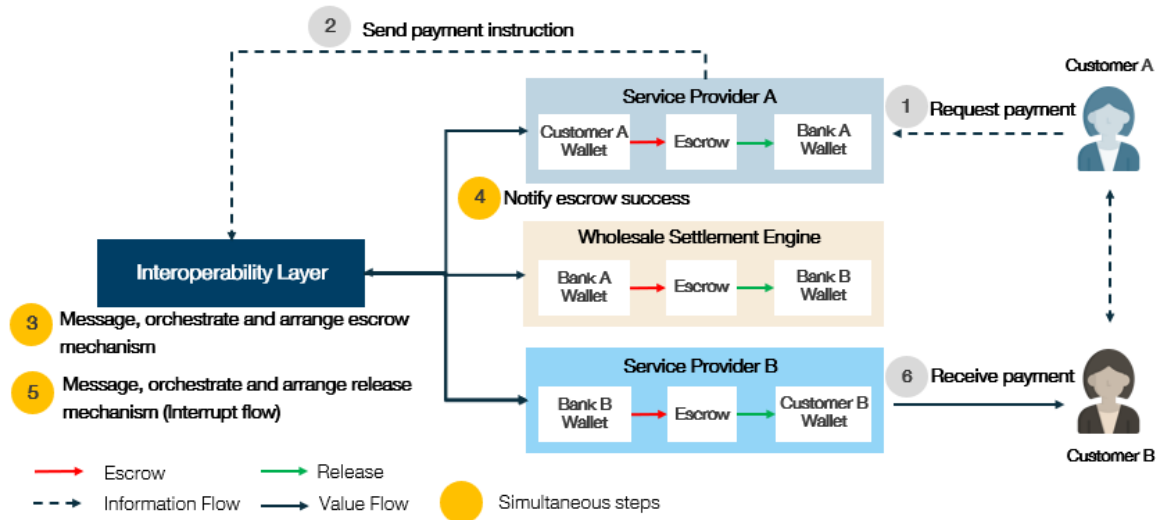
To ensure that development and testing focus on the core technical performance of the prototype, the following items have been defined as out-of-scope for testing:

Out-of-scope	Details
Internal operational processes related to customer funds transfers	● Customer processes, such as opening wallets and escrow accounts for tokenized fund transfers ● Liquidity management (payment instruction queuing, net settlement processes). ● Accounting, verification, and audit of internal financial transaction records.
Issuance and redemption of wholesale CBDC between FSPs and central bank	● Integration with the RTGS system for issuance and redemption. ● Opening of wallet and escrow accounts for wholesale CBDC transactions.
Delivery-versus-Payment (DvP) transactions for settlement of payments and asset transfers	● Use case testing for DvP transactions.

3.3) Business and Operational Workflow

The prototype testing focused on tokenization-based domestic fund transfers between customers and FSPs. Customer-to-customer transfers are conducted via **DLT-based networks**, while FSP-to-FSP transfers are carried out through **centralized technology-based systems**.

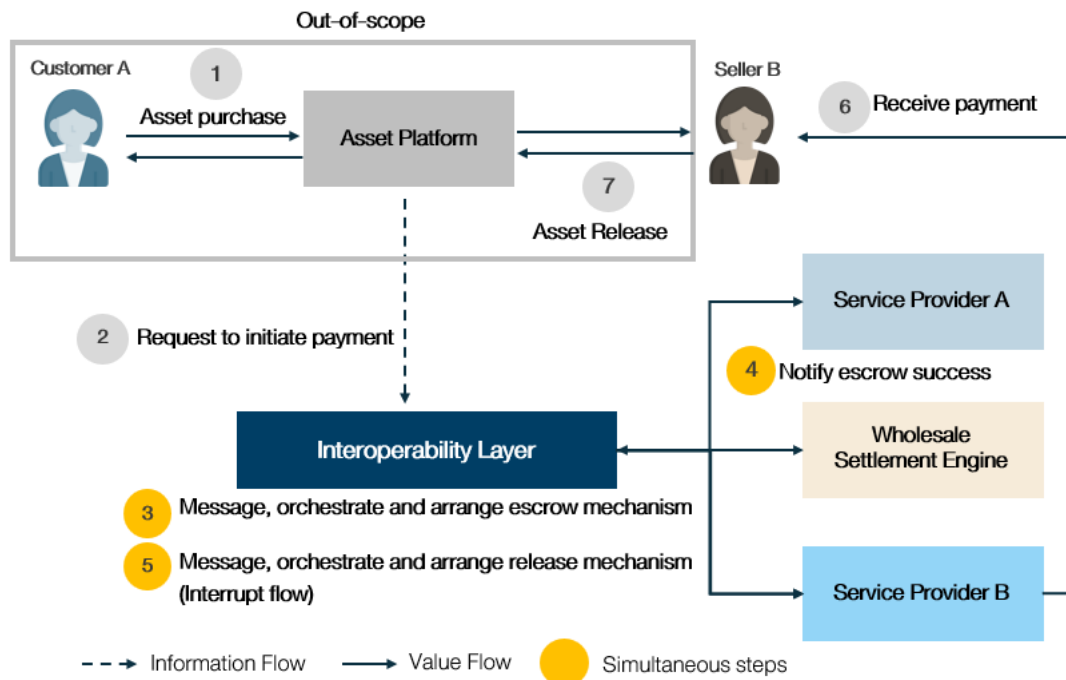
Use-case 1: Tokenization-based domestic fund transfers between customers and FSPs



The tokenization-based domestic fund transfers between customers of different FSP networks are executed in a step-by-step manner, from instruction submission, followed by escrow account funding, and concluding with the transfer of funds from the FSP to the recipient customer. The details are as follows:

Steps	Details
Submission of fund transfer instruction from the customer to FSP A	Customer A submits funds transfer instruction along with transaction details to FSP A.
Submission of fund transfer instruction from FSP A to IL	FSP A sends the instruction to the IL.
Request for fund escrow from IL to the FSP's system	The IL orchestrates the fund escrow mechanism, simultaneously sending instructions to: 1. FSP A's tokenized money network 2. Wholesale settlement system 3. FSP B's tokenized money network
Confirmation of successful fund escrow from the FSP's system to IL	Each system confirms successful fund escrow back to the IL.
Transfer of funds held in escrow between the systems of FSPs	The IL simultaneously instructs all systems to execute the fund transfer.
Transfer of funds from FSP B to Customer B	FSP B transfers funds to Customer B, completing settlement.

Use-case 2: Tokenization-based asset settlement between customers of different FSPs.



Building on the use case of tokenization-based domestic fund transfers between customers and FSPs, the prototype can be extended to support tokenization-based asset settlement between customers, enabling **Delivery versus Payment (DvP)** where payment and asset delivery occur simultaneously. The system is designed to be flexible, exchanging information only with the asset network platform and not involving the asset transaction management process, which may vary, allowing it to be asset-agnostic and support different types of assets for settlement, including both financial assets and real-world assets (non-financial assets).

However, **tokenization-based asset settlement between customers of different FSPs is not covered in the scope of this experiment.** As part of ongoing collaboration efforts with the Hong Kong Monetary Authority (HKMA) under the SAN and Ensemble projects, cross-border asset trading is being explored and tested under a Delivery versus Payment (DvP) model.

4. Technical Design

4.1) Design principles

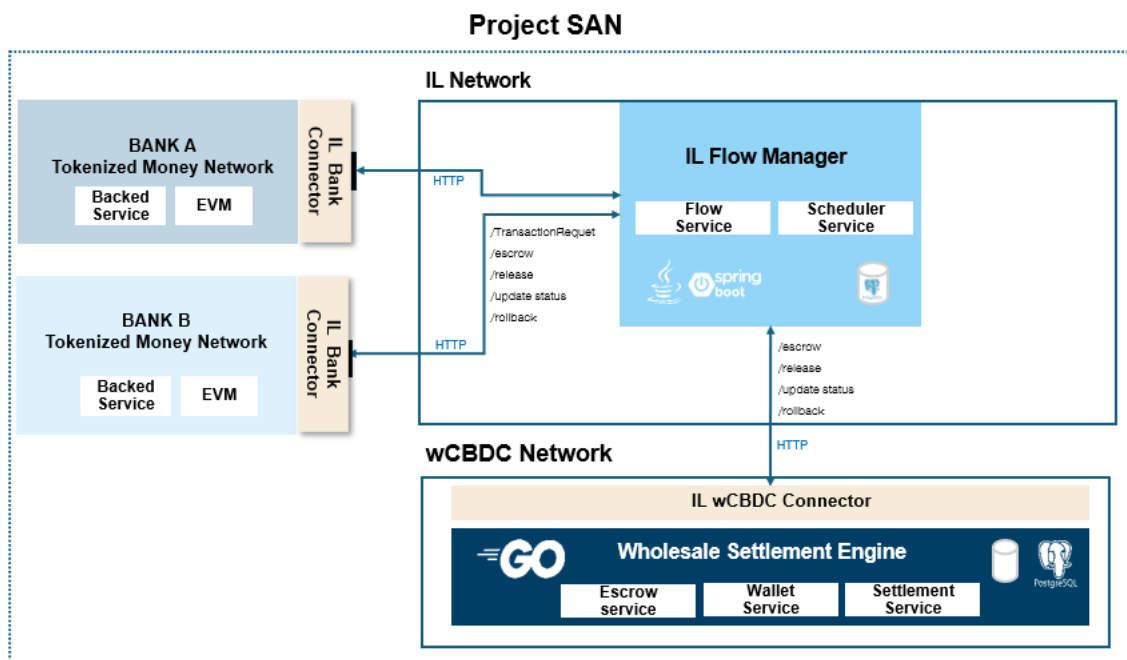
The SAN project's prototype of tokenization for domestic settlement is founded on three core design principles: **modularity**, **interoperability**, and **functionality**. These principles ensure flexibility, scalability, and operational reliability across heterogeneous payment networks.

Principles	Benefits
Modularity: The system is divided into smaller, independent components, each performing specific functions autonomously.	Higher flexibility: Components can be modified, upgraded, or developed independently without impacting other parts of the system. Efficient maintenance: Issues can be identified and resolved within specific modules, minimizing operational disruption. Enable division of operations: FSPs can manage specific functions independently, facilitating operational segregation.
Interoperability: The system can connect and support data exchange and operations across systems built on different technologies by utilizing common standards.	Technology agnostic: The system can connect with other payment systems built on diverse technologies, including DLT-based networks, RTGS, or wholesale CBDC on centralized platforms, and supports a wide range of tokenized money and assets. Scalability: The system efficiently supports connectivity with multiple systems through common standards, such as RESTful APIs and ISO 20022 messaging standards.
Functionality: The system operates accurately, comprehensively, and continuously, without errors.	Near real-time atomic settlement: The system can process and exchange transaction data accurately, comprehensively, and continuously, supporting simultaneous transactions on both sides (Payment versus Payment: PvP).

4.2) Architecture Design and Key Technical Components

4.2.1) High level architecture diagram

The prototype architecture integrates three key layers⁵: the interoperability layer (IL), the Wholesale settlement system (wCBDC), and the tokenized money networks of private-sector FSPs. Each layer performs specialized functions while ensuring seamless end-to-end transaction orchestration and atomic settlement.



4.2.2) Technical Components

Components	Details
Interoperability Layer (IL) Network	Serves as an orchestrator, managing and controlling the end-to-end transaction flow, handling messaging to ensure completion across all systems. It consists of three functional modules: IL flow manager: Oversees the complete transaction lifecycle, including request reception, data validation, processing, flow control, response generation, status updates, escrow management, fund release, and transaction rollback.

⁵ All components were developed and tested by BOT within its experimental environment. The tokenized money networks were simulated by BOT for testing purposes; no private-sector institutions were involved.

Components	Details
	2. IL bank connector: Connects the IL with various tokenized money networks of FSPs, handling messaging, instruction validation (ISO message validation), categorizing escrow/release/rollback instructions, and receiving status updates. 3. IL wholesale CBDC connector: Connects the IL with wholesale CBDC networks, performing messaging management, instruction validation, categorization of escrow/release/rollback instructions, and status updates.
Wholesale Settlement System (wCBDC) Network	Facilitates cross-platform fund transfers and comprises three service functions: 1. Escrow Service: Manages and prepares escrow and release instructions between providers according to predefined conditions. 2. Wallet Service: Manages wallet accounts, prepares transfer instructions from sender to recipient wallets, and handles messaging. 3. Settlement Service: Processes transactions to execute fund transfers between FSPs, ensuring settlement finality.
Tokenized Money Network (Simulation)	Simulated DLT-based payment system of private-sector FSPs, consisting of: 1. Backend Service: Manages and prepares escrow and release instructions within the tokenized money network, validates transactions, and provides status updates. 2. Ethereum Virtual Machine (EVM): Executes transactions via smart contracts according to predefined conditions, including transfers, locks, and refunds.

5. Key Findings

5.1) Results of the Prototype Experiment: IL Mechanism

5.1.1) Functional Performance

The prototype operates continuously and reliably, demonstrating high efficiency without technical or operational errors. The IL is capable of:

- 1) Receiving and sending fund escrow instructions to connected systems.
- 2) Executing fund transfers to the relevant systems to ensure transaction completion, with payments settled simultaneously on both sides (atomic settlement).

5.1.2) Non-functional Performance

The prototype exhibits robust non-functional performance, including transaction processing capacity and scalability to accommodate an increasing number of connected networks. Key indicators are summarized as follows:

Indicators	Test Results
1) Response Time: Duration required for transaction processing and message transmission.	Supports near real-time transactions, with an average processing time of 12.42 seconds per transaction ⁶
2) Throughput: Transaction processing capacity.	Capable of processing transactions at an average throughput of 103 transactions per second .
3) Network Scalability: Capacity to support the expansion of connected FSP networks.	Accommodates an increasing number of FSP networks, as the IL is designed with standardized APIs and flexible configuration for new network connections.

⁶ Minimum and maximum processing time per transaction is 12.36 seconds and 12.49 seconds respectively.

5.2) Insights and Lessons Learned

5.2.1) Modularity

The IL prototype divides functionality into discrete modules, enabling modification or addition of functions (e.g., transaction management or data validation) without affecting the rest of the system. However, testing indicated that higher modularity could introduce additional operational overhead between related modules, potentially affecting overall processing performance. Practical deployment of an interoperability system should carefully balance modularity to ensure both flexibility and optimal system performance.

5.2.2) Interoperability

- 1) **Standards Alignment:** The adoption of ISO 20022, an international standard for financial messaging, requires careful consideration of the alignment of data requirements across systems to ensure efficient communication and operation. For example, the IL's data structure must be adjusted to align with the data fields and formats used in Thailand's RTGS system in accordance with ISO 20022 standards. Future connections to additional systems will require similar mapping and alignment.
- 2) **Data Accuracy:** The IL assumes that incoming data from connected systems is complete and accurate, with verification of the responsibility of each FSP. Each system may present system-specific risks that could lead to errors in transmitted data. Therefore, the IL's design should incorporate mechanisms for data validation and verification of incoming messages, and dispute resolution procedures to address errors or inconsistencies.

5.2.3) Functionality

The prototype demonstrates flexibility in supporting new use cases, building upon existing core functions such as escrow, release, and rollback. However, it cannot yet accommodate use cases that require basic functions not currently implemented, such as liquidity management. Therefore, the IL design should consider incorporating additional core functions to enable a broader range of use cases in the future.

5.2.4) Security

The prototype prioritized functional performance and did not incorporate data security measures, such as encryption in transit or encryption at rest. For future production deployment, the IL should implement robust security mechanisms to ensure system integrity, confidentiality, and compliance with best practices.

6. Conclusion and Further Considerations

The SAN project prototype of tokenization for domestic settlement aims to test core functional mechanisms and focuses on system design. It comprises three main components developed and simulated by BOT:

- 1) **Interoperability Layer (IL):** Central component connecting DLT-based and centralized payment systems.
- 2) **Wholesale Settlement System:** Facilitates fund transfers among different FSPs.
- 3) **Tokenized Money Networks:** Operated by private-sector DLT platforms.

Testing demonstrated that the prototype performs effectively. The IL operates continuously and accurately, supports adequate transaction volumes, maintains scalability for additional FSP networks, and is technology-agnostic. Furthermore, the IL can be extended to support asset-agnostic settlements, enabling simultaneous payment and asset delivery (Delivery versus Payment: DvP).

The development and testing of the IL highlighted several practical considerations for future system design:

- 1) Determining the optimal degree of modularity and defining the IL's roles in data validation and dispute management.
- 2) Aligning IL data formats with the data requirements of connected systems in accordance with ISO 20022 standards.
- 3) Expanding core functions to support a broader range of future use cases.

While the prototype focuses primarily on functional and technological mechanisms, real-world implementation requires additional considerations, including business rules, regulatory compliance, internal operational procedures of both the wholesale settlement

systems and private-sector payment systems, and integration of cross-border transaction systems to ensure interoperability.

The development and testing of this prototype provides insights and lessons learned that will inform the modernization of Thailand's Real-Time Gross Settlement (RTGS) system to support tokenized transactions and may serve as guidelines for establishing secure and efficient connections between private-sector DLT payment networks.

As part of the ongoing collaboration between the BOT and the HKMA under the SAN and Ensemble projects, the prototype of SAN will be extended by technical integrating with an asset platform to test cross-border asset trading transactions under a Delivery versus Payment (DvP) model.