ธนาคารแห่งประเทศไทย
BANK OF THAILAND

HONG KONG MONETARY AUTHORITY
香 港 金 融 管 理 局

Inthanon-LionRock

Leveraging Distributed Ledger Technology to Increase Efficiency in Cross-Border Payments


Transforming wholesale cross-border payments
with a streamlined intermediation model,
real-time transfers and
atomic Payment-versus-Payment settlements

Participating Banks

Hong Kong

HSBC

ZA

Thailand

Bangkok Bank ธนาคารกรุงเทพ

Krungthai กรุงไทย

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FOREWORD

By Bank of Thailand

ธนาคารแห่งประเทศไทย
BANK OF THAILAND

Advances in financial technology has provided us new opportunities and, at the same time, disrupted our traditional ways of doing businesses. For central banks around the globe, the role of a sole supplier of money and a punch-bowl taker to safeguard financial stability have been challenged by the rise of digital currencies, ranging from cryptocurrencies to private stablecoins. These new technological evolutions aim to pursue wider public usage on a global scale where efficient cross-border funds transfers are out-of-reach or costly.

Beginning in 2018 until now, Project Inthanon has finally arrived at its third phase. Partnering with the Hong Kong Monetary Authority (HKMA), the Bank of Thailand (BOT) explores a Distributed Ledger Technology (DLT) solution for cross border funds transfers under Project Inthanon-LionRock. Building on pain points and actual business cases, the proof of concept is designed and developed to offer a cross-border corridor network, where funds transfers can occur instantaneously on a peer-to-peer basis. The design allows foreign exchange (FX) price discovery on the corridor network that enables on-demand FX conversion and FX settlement is done in an atomic payment-versus-payment (PvP) manner. Regulatory monitoring and compliance are put in place where feasible.

The BOT notably recognises the valuable contributions from the HKMA, ten participating banks from both Thailand and Hong Kong, and our technology partner R3, towards the achievements of this project and the completion of this report.

The design and key findings of the Project Inthanon-LionRock have added new dimensions to central bank community on their work regarding the use of DLT on cross-border funds transfers. We hope that the project puts forward insights and ideas that could improve the use of digital currencies for cross-border financial transactions, and at the same time, preserve global financial stability. Though our Project Inthanon has come to the last phase, I believe that it is only the beginning of our next journey where central banks and relevant partners collaborate to tackle existing and incoming challenges, as well as enhance our cross-border funds transfer efficiency…just like the old saying "Going together, we go further"

Mathee Supapongse
Deputy Governor
Bank of Thailand

FOREWORD

By Hong Kong Monetary Authority

HONG KONG MONETARY AUTHORITY
香港金融管理局

With the global economy more inter-connected than ever before, the volume of money flowing across different borders has grown significantly. The high cost, inefficiencies and delays in cross-border payments have long been notorious pain points for decades. While there are claims that private, global stablecoins sponsored by large technology firms could be the solution, they may raise broader issues for the international monetary system and pose new challenges to financial stability, monetary policy and anti-money laundering efforts.

Over the past few years, international regulatory forums and central banks around the world have put in notable efforts studying the implications and the feasibility of issuing Central Bank Digital Currency (CBDC). In 2017, the Hong Kong Monetary Authority conducted a CBDC study, namely Project LionRock, and concluded that the prospect of issuing CBDC for retail payment purposes is limited in view of the efficient payment infrastructure and services available in Hong Kong. That said, CBDC may have a greater potential in cross-border payments, as it could potentially eliminate the need to go through layers of correspondent banks and enable real-time cross-border transactions, thus increasing the efficiency and lowering the overall transaction cost.

Against this backdrop, we are delighted to join forces with the Bank of Thailand in conducting a joint research project named "Project Inthanon-LionRock" to study the application of CBDC to cross-border payments, with a view of facilitating HKD-THB PvP amongst banks in Hong Kong and Thailand. This paper aims to identify and discuss the relevant issues such as token conversion, instantaneous interbank fund transfers in dual currencies, foreign exchange execution and liquidity management.

We hope this paper will offer some useful references to the central banking community. Lastly, we would like to express our gratitude to Bank of Thailand, the participating banks and institutions for their support.

Edmond Lau
Senior Executive Director
Hong Kong Monetary Authority

Inthanon

LionRock

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Admiralty, Hong Kong

01 Executive Summary

Project Inthanon-LionRock is a joint initiative between the Bank of Thailand (BOT) and the Hong Kong Monetary Authority (HKMA) to explore the application of Distributed Ledger Technology (DLT) to increase efficiency in cross-border funds transfers. With an understanding of the challenges in the existing environment, the proposed cross-border model is designed to overcome pain points including inefficiencies, high cost, limited traceability and complex regulatory compliance. The adoption of DLT in the model aims at facilitating real-time cross-border funds transfer and pursues the path of atomic PvP for foreign exchange transactions.

Led by the Thai and Hong Kong central banks, key industry players partook in Project Inthanon-LionRock. Thai participants include Bangkok Bank Public Company Limited, Krung Thai Bank Public Company Limited, Bank of Ayudhya Public Company Limited, Kasikornbank Public Company Limited, Siam Commercial Bank Public Company Limited, Thanachart Bank Public Company Limited, Standard Chartered Bank (Thai) Public Company Limited, and The Hongkong and Shanghai Banking Corporation Limited (Thai), while Hong Kong participants include The Hongkong and Shanghai Banking Corporation Limited (Hong Kong) and ZA Bank Limited. Together with technology partner R3, the study of a new cross-border funds transfer model is a collaborative effort between public and private sectors.

Launched in September 2019, Project Inthanon-LionRock seeks to build a proof-of-concept (PoC) where a THB-HKD cross-border corridor network is set up as a bridge between the Inthanon and the LionRock networks (DLT-based local payment network of each jurisdiction). Built on Corda, R3's blockchain platform, the corridor network is designed to allow Inthanon and LionRock networks' participants to conduct funds transfers and foreign exchange transactions on a peer-to-peer basis which helps reduce settlement layers. The cross-border funds transfer process is enhanced to enable real-time transfers and atomic PvP settlements. Leveraging smart contracts, funds transfers, and foreign exchange transactions are bundled together. The corridor network is designed to enhance banks' foreign currency liquidity management, adopted the liquidity saving mechanism for multiple currencies and incorporated compliance to local regulations where possible.

Project Inthanon-LionRock has laid a solid foundation for cooperation not only between the BOT and the HKMA, but also amongst Thai and Hong Kong commercial banks. This project has set a key milestone in preparing further collaboration amongst central banks and stakeholders to cope with the challenges of cross-border funds transfer.

Transcending all borders to

Hong Kong-Zhuhai-Macao Bridge , Hong Kong

tackle real business challenges

02 Project Overview

Project Inthanon-LionRock stems from the collaborative effort between the BOT and the HKMA, in the exploration to improve wholesale cross-border payments with a streamlined intermediation model, real-time transfers and atomic Payment-versus-Payment (PvP) settlements.

Prior to Project Inthanon-LionRock, the two central banks had embarked on their separate journeys to investigate the prospect of wholesale Central Bank Digital Currency (W-CBDC) in the local context. The HKMA led some local financial institutions in 2017 to commence Project LionRock[1] to study the benefits and risks of W-CBDC. The project included a PoC study on token-based CBDC and debt securities issued into a single DLT system. In 2018, the BOT initiated Project Inthanon[2] with local participating banks to explore the feasibility of DLT to enhance Thailand's financial infrastructure, as well as to encourage collaborative learning amongst the involved parties. Upon completion of their respective domestic projects, the next step brought together the BOT and the HKMA to explore how W-CBDC could improve efficiency in cross-border payments.

2.1 Vision

The vision of Project Inthanon-LionRock is to harness the benefits of DLT to address the pain points of cross-border transfer and settlement by enhancing process efficiency, cost effectiveness, traceability and regulatory compliance. A novel model of cross-border funds transfer was proposed with a view to minimise traditional intermediaries and improve efficiency. This project is anticipated to strengthen collaboration between central banks of the two jurisdictions as well as local banks, regarding cross-border funds transfer research and to bolster the local financial services industry's involvement in technology development.

[1]Details of Project LionRock can be found in Appendix 9.2
[2]Details of Project Inthanon can be found in Appendix 9.1

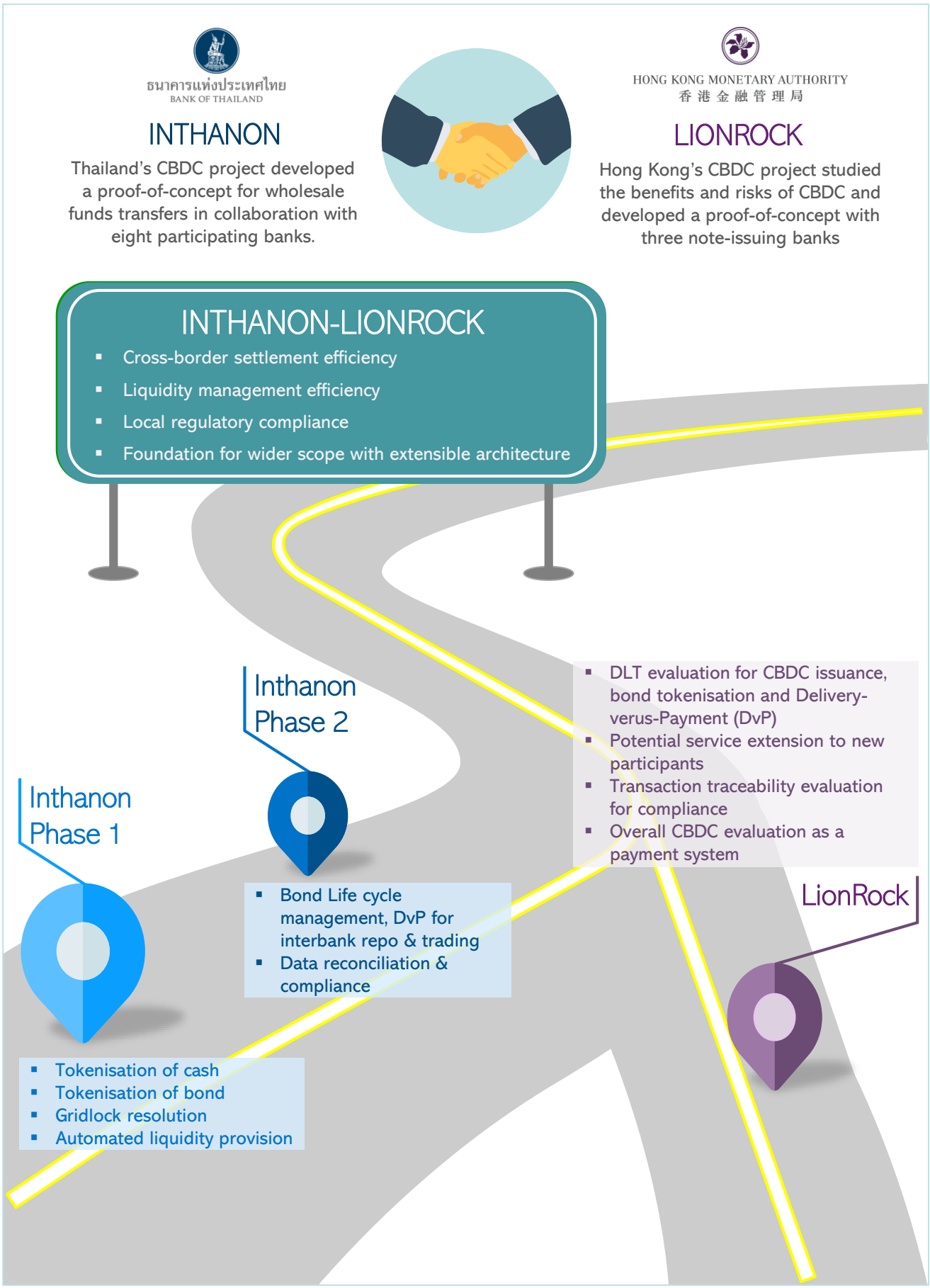


Figure 1 - Inthanon-LionRock Roadmap

2.2 Objectives

Project Inthanon-LionRock was developed to explore real-time cross-border funds transfers and FX transactions via a corridor network to achieve atomic PvP with reduced settlement layers. Four key objectives have been identified.

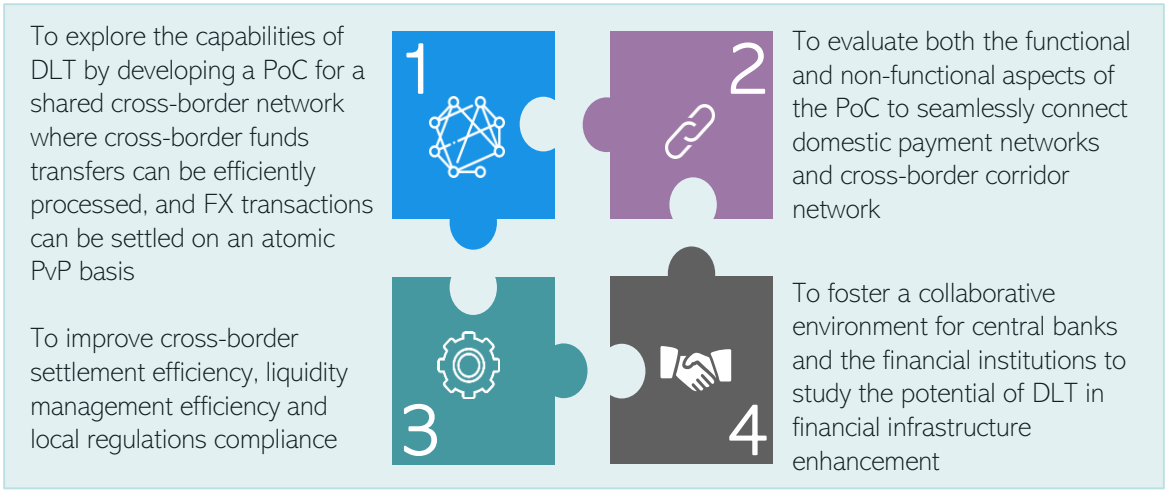
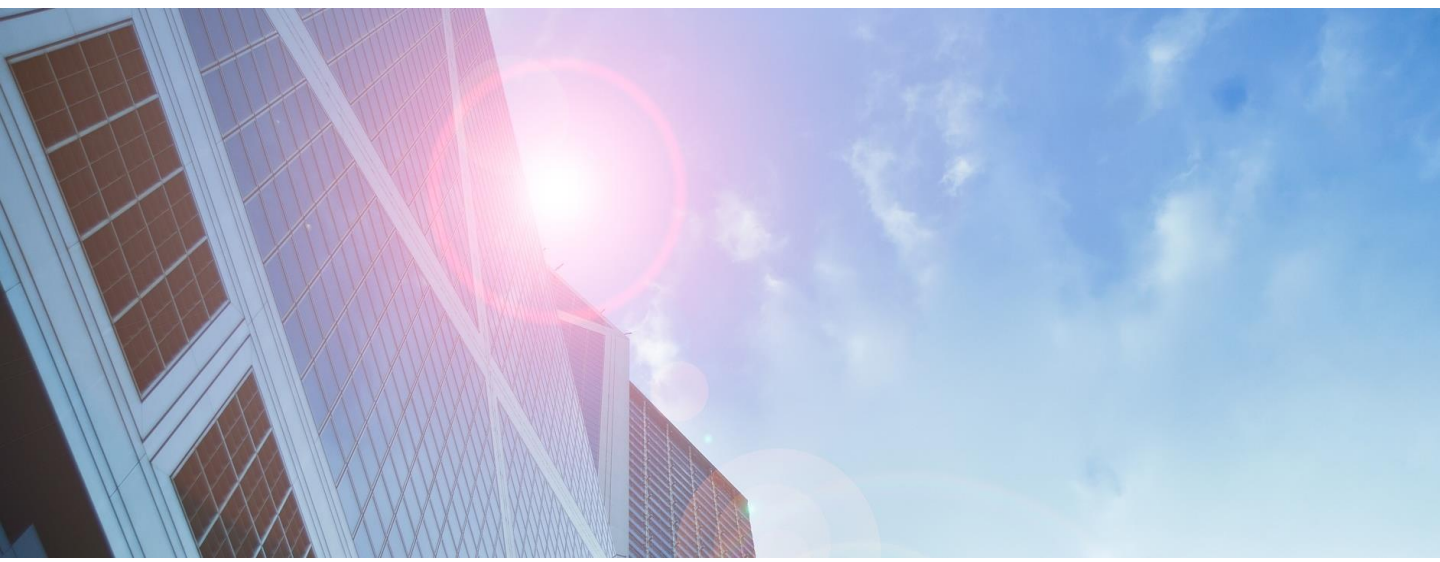


Figure 2 - Inthanon-LionRock Objectives

2.3 Scope

The THB-HKD cross-border corridor network was proposed to bridge the two domestic wholesale payment network models, Inthanon and LionRock. In the corridor network, all participating banks have their own presence and are able to directly transfer funds via CBDC tokens to each other. The functionalities in the corridor network can be grouped as follows.



Functional Scope

1 Depository Receipt conversion

- Allow Depository Receipt (DR) token conversion amongst the domestic Inthanon/LionRock networks and the cross-border corridor network
- Support automated depository receipt conversion to wholesale CBDC (W-CBDC) in the corresponding domestic networks (Sweeping process)

2 Cross-border funds transfer

- Conduct peer-to-peer and instantaneous interbank funds transfers in THB and HKD

3 Foreign Exchange (FX) execution

- Execute FX transactions by matching with the best rate available on the Board (Board Rate)
- Allow direct FX quotations for HKD/THB through Request for Quote function (RFQ) and the execution of FX transactions on agreed rate from quotes
- Settle FX transactions which are agreed bilaterally outside the corridor network (Off-corridor Arrangement)
- Ensure atomic PvP settlement of THB and HKD for FX transactions throughout the day

4 Cross-border funds transfer with embedded FX transaction

- Support cross-border funds transfer with embedded FX transactions through Board Rate or Off-corridor Arrangement

5 Liquidity management

- Provide queueing mechanism allowing participants to set priorities and manage their outgoing queues
- Activate Multi-asset Liquidity Saving Mechanism (MLSM) to resolve gridlocks[3] within transactions in queue
- Allow just-in-time liquidity through automatic local currency (LCY) W-CBDC token conversion from the domestic networks to DR in the cross-border corridor network or automatic foreign currency (FCY) DR token borrowing from the foreign currency liquidity provider, to resolve deadlocks in the cross-border corridor network

6 Regulatory compliance & enforcement

- Monitor THB and HKD wallets and transactions on a real-time basis
- Support compliance with regulations applicable to non-residents (NR) in certain areas

Non-functional Scope

A Payment atomicity

- Guarantee atomicity in all payment instructions, preventing partial database updates

B Settlement finality

- Complete all cross-border funds transfers and THB-HKD PvP with finality

C System resiliency

- Ensure that systems and transactions to remain functional despite any individual node malfunctioning in either network

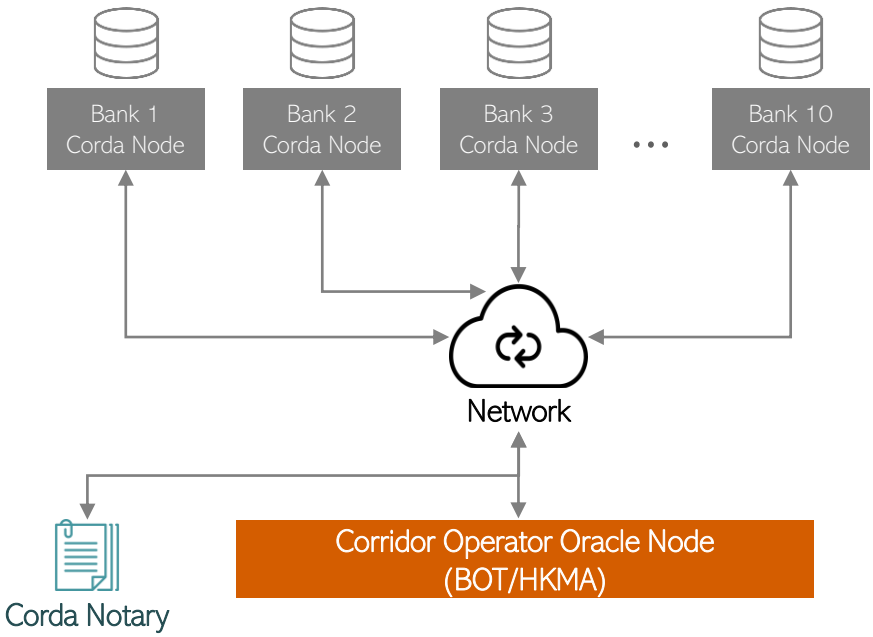
D Transaction privacy

- Establish an appropriate level of anonymity in sensitive data and maintain disclosure on a need-to-know basis

[3] Gridlock is a situation where two or more queued transactions are resolvable with one or more net payments.

2.4 Architectural Design

Overall, the corridor network acts as a bridge to connect the domestic W-CBDC payment networks of the two places. All the participating banks have their own nodes on both the local payment network and corridor network. The central banks have their own nodes in the local payment network models, and a separate node in the corridor network called the operator node, whose control is shared by the BOT and the HKMA. In principle, to facilitate the provision of foreign currency liquidity, a foreign currency liquidity provider node should exist in the corridor network. However, due to limited resources, in this PoC the operator node will operate as the foreign currency liquidity provider.



Consensus Service (Notary)
- Provides transaction finality
- Ensures a single lineage for payments & asset transfers

Participating Bank Nodes (TH & HK)
- Run regular nodes for transfer of DR tokens between each other
- Store assets in their vaults
- Run scheduler for end-of-day regulatory activities

BOT/HKMA (Central Bank)/ Oracle Node
- Creates & destroys DR tokens
- Converts between W-CBDC and DR-CBDC
- Provides MLSM
- Provides foreign currency liquidity

Figure 3 - Inthanon-LionRock Architectural Design

Collaborating to tackle cross-border challenges while preserving global financial stability

Mathee Supapongse | Deputy Governor, BOT

Bangkok, Thailand

Tsim Sha Tsui, Hong Kong

03 Corridor Network

3.1 Model Design

3.1.1 Current State & Challenges

Currently, cross-border funds transfers are costly and time-consuming. According to World Bank, the transaction processing fee for a cross-border funds transfer can cost on average 7% of a transaction[4].

In general, the current state of cross-border transactions relates closely to correspondent banking. Defined by Financial Action Task Force (FATF), correspondent banking is the provision of banking services by one bank (the "correspondent bank") to another bank (the "respondent bank"). Large international banks typically act as correspondent banks for thousands of other banks around the world. Respondent banks may be provided with a wide range of services, including cash management (e.g. interest-bearing accounts in a variety of currencies), international wire transfers, cheque clearing, payable-through accounts and foreign exchange services.

Domestic banks often rely on correspondent banks to handle transactions conducted involving foreign counterparts. This allows domestic banks to gain access to a wider scope of financial markets and extend their services abroad without the hassle of opening overseas branches.

[4] https://blogs.worldbank.org/psd/paying-across-borders-can-distributed-ledgers-bring-us-closer-together

To depict the current state clearly, a hypothetical case of a Thai Corp importing some goods from an HK Corp, which are worth HKD 1 million, is explored in this report for illustrative purpose.

The Thai Corp would like to pay the HK Corp in Hong Kong Dollar. To do so, the Thai Corp will need to convert its THB holding at Bank A in Thailand into HKD and transfer HKD to pay the HK Corp that holds an HKD account at Bank Z. On the assumption that Bank A does not hold an HKD account itself with any bank in Hong Kong, services from correspondent banks are required to complete the payment process. The whole process may proceed as follows:

1. Bank A, having an existing relationship with Bank B (another bank in Thailand with a HKD account with Bank Y in Hong Kong), informs Bank B via payment instruction that Bank B will receive a HKD fund on behalf of Bank A. Bank A would like to send that fund to a HKD account at Bank Z. Bank A consequently sources for HKD funds and HKD funds are then delivered to Bank B's HKD account at Bank Y.

2. Bank B then sends payment instruction to Bank Y informing Bank Y to send an equal amount of HKD funds in its account to the HK Corp's account at Bank Z.

3. Bank Y sends the payment instruction to inform Bank Z to credit the HK Corp's account. Bank Y transfers HKD funds to Bank Z.

4. After receiving such funds, Bank Z credits the funds to the HK Corp's account and sends a confirmation of credit to the HK Corp.

With regards to the above process, multiple hops of communication and transfers via correspondent banks are required, resulting in a lengthy process which can take several days to complete. In particular, the correspondent banking model faces the following key challenges.

Operational issues

Complications in different payment message format standards and technology pose further challenges to the correspondent banking model. Since all cross-border transactions must be settled in the currency's country of origin, regardless of the location of trading parties or currencies. Traditionally, there is a time gap between submitting the payment instruction and the actual transferral of currencies. Compounded with time zone differences, the settlement often requires a long hour window.

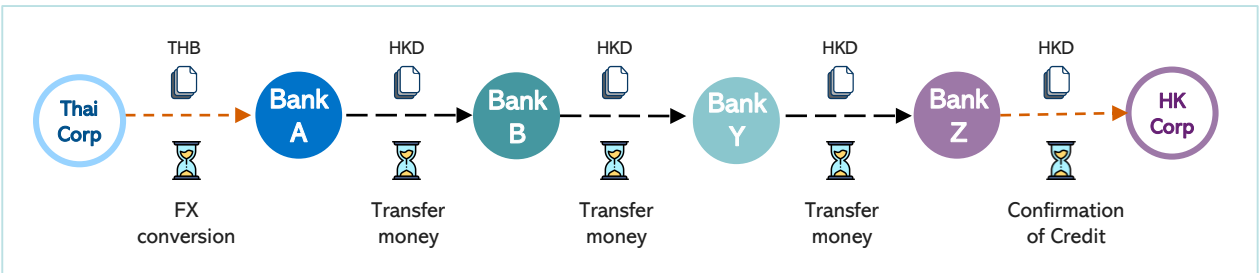


Figure 4 - Case Study (Current State)

Liquidity management in nostro account

Managing multiple nostro accounts will incur high cost in assessing and satisfying intra-day liquidity needs. As seen in McKinsey's cost breakdown of cross-border transactions below, the highest contributor is nostro-vostro liquidity.

Nostro and vostro accounts

The terms nostro and vostro express the same bank account from different perspectives. Nostro refers to a situation when a bank deposits its money with another bank (our money at your bank). While Vostro refers to an account that other banks open an account at a bank (your money at our bank).

Settlement risk

In the foreign exchange market, this is known as the Herstatt risk, which refers to the situation in which a foreign exchange trade fails to settle. It can also be associated with the insolvency, negligence of or deliberate withholding by a transacting partner. After one party delivers foreign exchange, the counterparty fails to complete the contract on its end.

Traceability

The tracking possibilities during the entire transaction process are often limited to only the initial transfer of funds and the final credit confirmation. In between those two stages, visibility is not usually available throughout the entire process flow. It is not uncommon for the processing time to take several business days until the confirmation of credit.

Furthermore, sometimes such a transaction is processed without knowing the exact intermediaries. As a result, significant latency in tracking and reconciliation of transactions can occur, and so opaque costs further add up in the transaction process.

Regulatory compliance

The compliance and regulation requirements across countries may be different. This leads to the difficulty of compliance adherence for funds transfer and FX trades that involve countries with different law governing perspectives.

Other challenges of the current correspondent banking model include changing consumer expectations and demands, and the lack of infrastructure synergy, which hinders the coping of legacy systems.

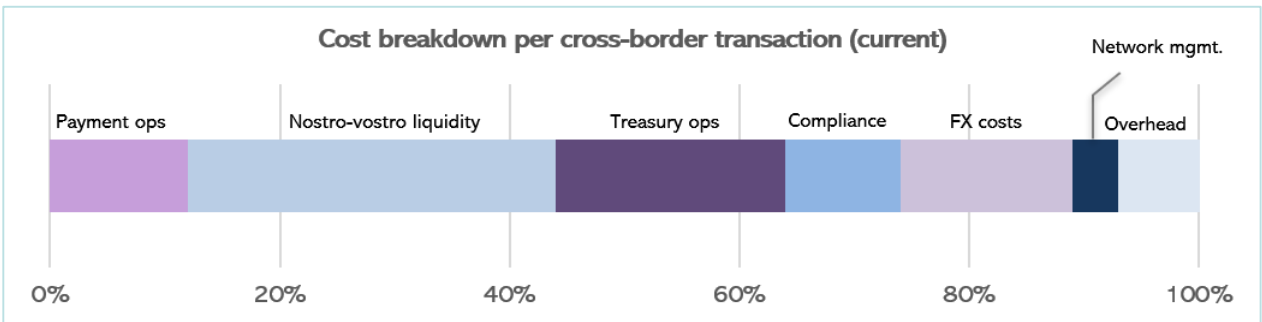


Figure 5 - Cost Breakdown per Cross–border Transaction (Current State)

3.1.2 Exploration of Different Cross-Border Models

In response to the pain points of cross-border funds transfer as mentioned in the previous section, different models have been explored in studies conducted by other central banks.

In this study, the cross-border models can be redesigned and categorised into two groups. The first category is cross-participation, where central banks open access for foreign participants to the local Real-Time Gross Settlement system (RTGS). The second category is asset expansion, where central banks allow their own currency to circulate in other jurisdictions.

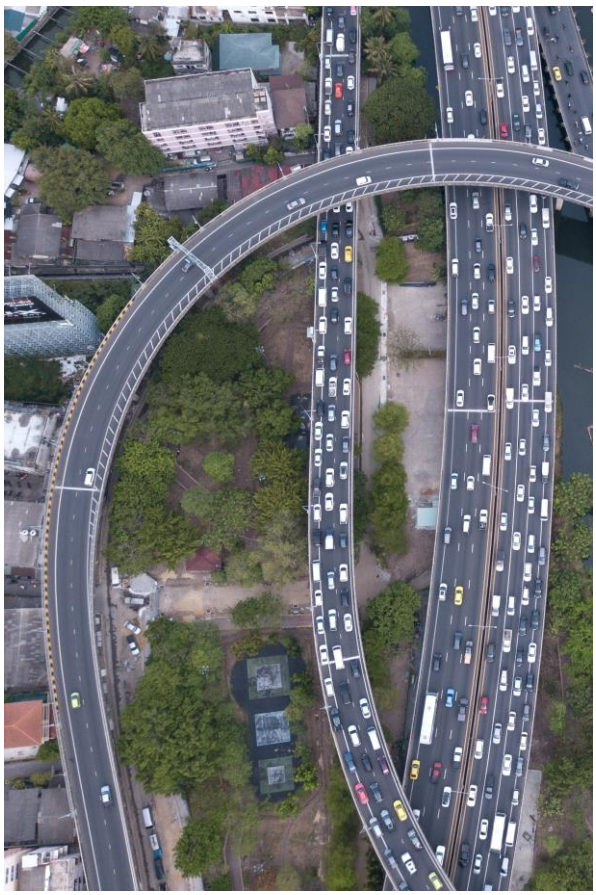
Cross-participation

This model involves a central bank as an RTGS operator allowing foreign entities' access to its local RTGS. The model's key characteristic is that the central bank still maintains control of its local currency. There are three variations in the cross-participation model, as foreign entities can vary from (i) foreign central banks, (ii) appointed settlement banks to (iii) any banks in general, subject to qualifications, to hold local currency in the local RTGS. In the first two variations the foreign entities (central banks and appointed settlement banks) with access to the local RTGS act as correspondent banks providing services to nostro accounts of other banks in its jurisdiction. For the last variation, qualified banks are provided with direct access with no correspondent bank required.

Asset expansion

The asset expansion model entails each RTGS network allowing its participants to hold and transfer foreign currencies directly. The key challenge of this model is how the central banks control money supply. Variations in this model concern the location where the foreign currency holding and transactions take place. In one case, it could be the domestic RTGS of each country being able to support settlements of transactions in both local and foreign currencies. Another case would involve the set up of a new multi-currency RTGS which serves members from all participating jurisdictions for both domestic and cross-border transactions. Lastly, a segregated corridor, which is the chosen model for this PoC, is created to serve only cross-border transactions.

A comparison of the two models, their variations and details of their designs are provided in Appendix 9.3.



	Cross-participation			Asset expansion		
Variation	Allowing foreign central banks to access local RTGS	Allowing foreign appointed settlement banks to access local RTGS	Allowing any foreign banks to access local RTGS	Domestic RTGS supporting settlements in local and foreign currencies	Multi-currency RTGS serving all transactions including domestic and cross-border	Segregated multi-currency corridor for cross-border transactions
Business Model	Correspondent bank	Correspondent bank	Direct	Direct	Direct	Direct
Atomic PvP for FX transaction settlement	Cross platform	Cross platform	Cross platform	Cross platform	Single platform	Single platform
Separation of domestic and cross-border funds transfer	Yes	Yes	Yes	Yes	No	Yes

After comparing all the models, the segregated asset expansion is highly preferred due to the reduced layers of intermediaries. Leveraging DLT in this model, FX transactions can also be settled on an atomic PvP basis in a single platform, which is favourable by the BOT and the HKMA. Since each central bank prefers to manage its own local RTGS independently, the separation of domestic and cross-border transactions in the model is desirable. However, one limitation of this model, money supply, poses a crucial question for central banks to consider. The fact that under this model, a jurisdiction's currency can circulate out of its jurisdiction may weaken the central bank's ability, if applicable, to control its money supply. Possible mitigation measures include control of amount or holding period by non-resident entities. The proposal model in this study has taken into account these considerations, and is explained in the next section.

HTLC (Hash Time Locked Contracts), which is required for FX PvP in some cross-participation models, is not an area of exploration in this study as the proposed model does not require HTLC. The chosen corridor network model has no escrow agent holding assets for release to bear settlement and credit risk. Instead the model depends on the set-up of a structure corridor where participating banks can settle directly through their own wallets. With atomic swaps occurring on the same platform, HTLC is not required.

3.1.3 Proposed Model

The proposed model in this PoC is designed with the following characteristics:

- The central bank is the sole issuer of its currency, equivalent to W-CBDC. The W-CBDC is only tokenised and redeemed against the issuing central bank.

- The domestic settlement networks (i.e. Inthanon network and LionRock network) are separated from cross-border transactions. Non-resident banks are not allowed to access the domestic network and hold respective W-CBDC.

- The "corridor network" is introduced particularly for cross-border settlement. Participants in the corridor network are participating banks from Inthanon network and LionRock network. To settle transactions in the corridor network, a special vehicle called Depository Receipt (DR) is needed for transferring value amongst all participants in the corridor network.

- In the corridor network, participating banks may hold DR-THB and DR-HKD for cross-border funds transfer and FX PvP transactions, which are performed on a peer-to-peer basis with finality.

- Liquidity management processes (which includes Queueing Mechanism, Gridlock Resolution and Liquidity Provisioning) are also introduced on the corridor network in both local and foreign currencies. Compliance to local regulations is taken into account where possible.

Corridor network parties and their roles

In the proposed corridor network, the parties involved are the corridor operator node, the participating bank nodes and the foreign currency liquidity providers.

The corridor operator node is a joint BOT-HKMA body responsible to:

- Issue and destroy DR-THB and DR-HKD in response to DR conversion request by participating banks
- Provide gridlock resolution service
- Ensure regulations are complied with

Participating bank nodes in the corridor network (that are independent of Inthanon/LionRock):

- Initiate and settle cross-border payments and HKD/THB FX transactions (between the participating banks in the corridor network)
- Manage their own liquidity in both local and foreign currencies

The foreign currency liquidity providers:

- Provide foreign currency liquidity when deadlock occurs

In parallel with the corridor network, each central bank plays a role in its respective domestic settlement network to facilitate the conversion of W-CBDC to DR nominated in its domestic currency and vice versa.

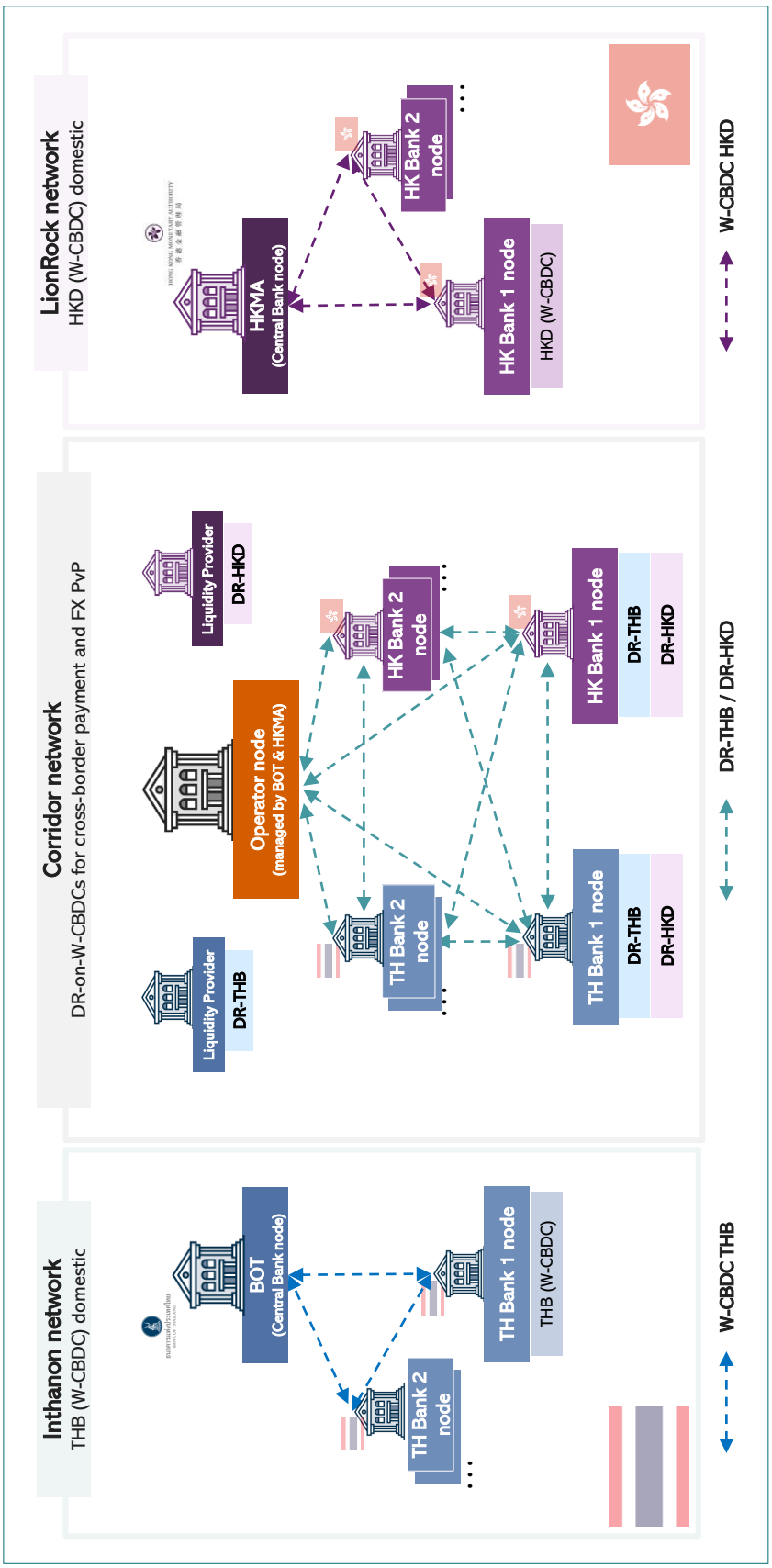


Figure 6 - Proposed Model

Central, Hong Kong

3.2 Key Functionalities

Aiming to enhance the efficiency of cross-border funds transfers and FX transactions, the proposed corridor network is designed to provide six key functionalities. They will be explained in detail in this section.

3.2.1 Depository Receipt Conversion

Token conversion from W-CBDC in domestic settlement networks to DR in the corridor network and vice versa is an on-demand process for banks to manage their local currency liquidity in the corridor network. To obtain DR, participating banks are required to convert W-CBDC into DR. The conversion process begins with the user (a bank) requesting a number of tokens to be converted from W-CBDC to DR in the corridor network. The request will then be validated. The token conversion will be carried out if the bank has sufficient W-CBDC in the domestic settlement network. For example, when a bank in Hong Kong wants to have more HKD liquidity in the corridor network, it can submit a request to convert W-CBDC HKD from the LionRock network to DR-HKD available in the corridor network.

The central bank node in each domestic network acts as a corridor gateway in which W-CBDC and DR are destroyed and issued respectively. The role of the central bank nodes is to ensure that the amount of DR available in the corridor network always equals that of W-CBDC which is destroyed in the domestic network. The conversion from DR back to W-CBDC is also possible in the same manner (i.e. destroying DR in the corridor network and issuing W-CBDC in an equivalent amount in a domestic settlement network).

If banks have an outstanding balance of DR at the end of the day, banks may perform token conversion from DR to W-CBDC to reduce their DR balances and move them back to their respective domestic settlement networks. For example, when a Thai bank has an outstanding DR-THB on the corridor network, the DR-THB balance is automatically swept to W-CBDC-THB in the Inthanon network at a specified time.

3.2.2 Cross-Border Funds Transfer

Cross-border funds transfer is simply a one-way payment from one bank to another in the corridor network. This involves a sending bank submitting instructions to transfer funds in either local or foreign currency (DR-LCY/DR-FCY) to a receiving bank.

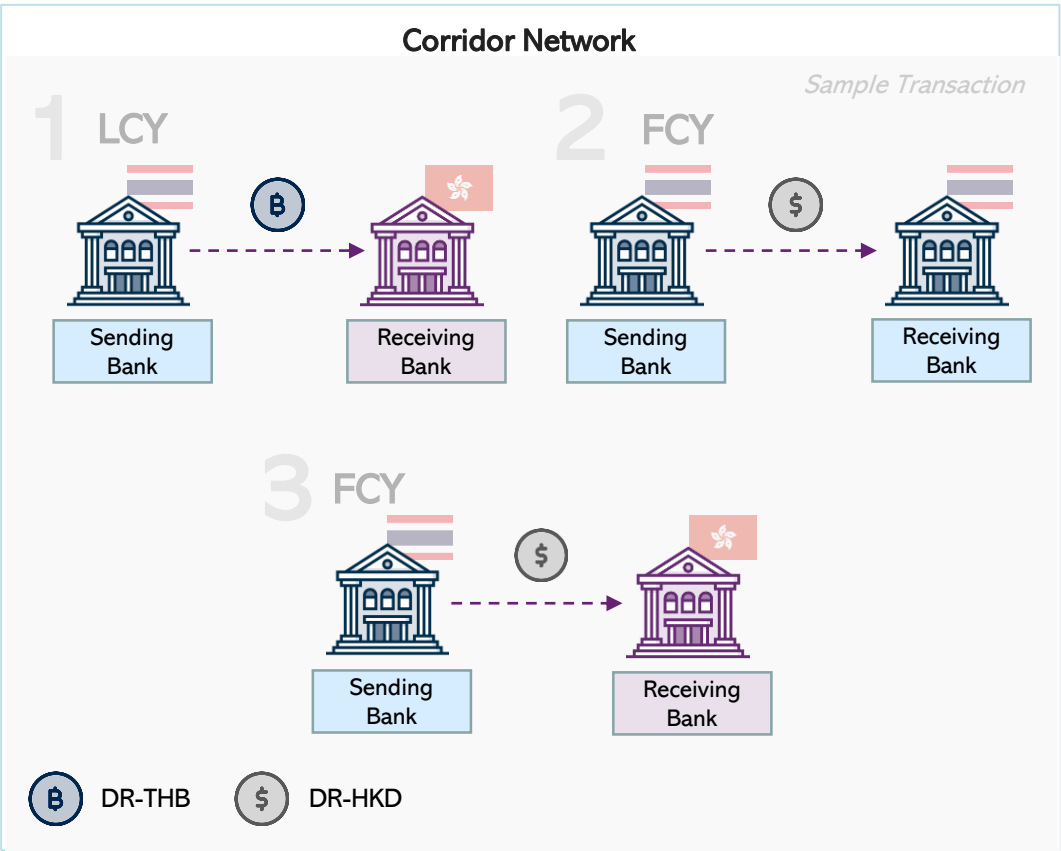


Figure 7 - Variations of Cross-border Payments

As payments in both DR-LCY and DR-FCY are allowed in the corridor network, banks are able to transfer DR tokens to other banks in 3 possible scenarios.

1. Sending DR-LCY funds to a foreign bank:
   - A Hong Kong bank sends DR-HKD to a Thai bank
   - A Thai bank sends DR-THB to a Hong Kong bank

2. Sending DR-FCY funds to another local bank:
   - A Hong Kong bank sends DR-THB to another Hong Kong bank
   - A Thai bank sends DR-HKD to another Thai bank

3. Sending DR-FCY funds to a foreign bank:
   - A Hong Kong bank sends DR-THB to a Thai bank
   - A Thai bank sends DR-HKD to a Hong Kong bank

The only scenario which has been excluded is the sending of DR-LCY funds to a local bank as this scenario is supposed to be executed in the domestic settlement network.

A sending bank can input a cross-border payment instruction with the required details such as the receiving bank's name, amount, currency and transaction purpose. Once submitted, the transactions will be settled simultaneously (if there are sufficient funds) or be placed in a queue and settled when liquidity is sufficient (if there are insufficient funds).

3.2.3 Foreign Exchange (FX) Execution

When a bank in the corridor network wants to do an FX transaction, there are three different ways of doing so: Board Rate, Request for Quote and Off-corridor Arrangement. All FX transactions are settled in an atomic PvP fashion.

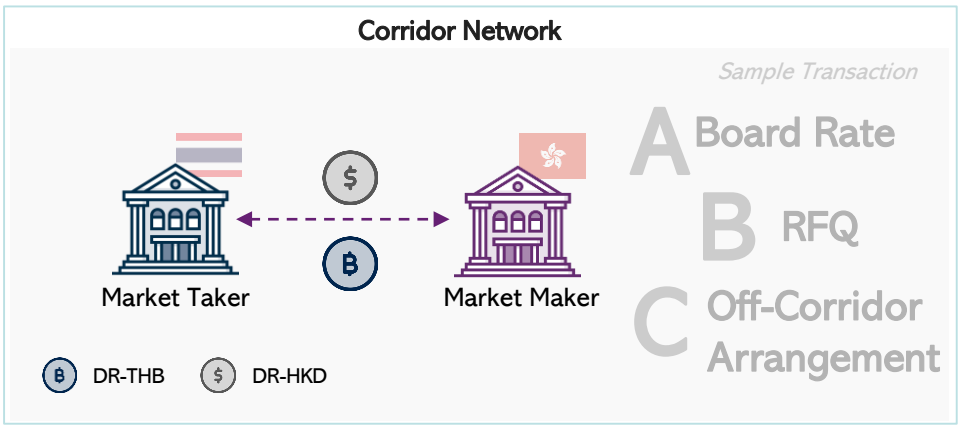


Figure 8 - FX Execution and Settlement

A. Board Rate

Board rate is one of the options that allows banks to seek the best bid and offer FX rate from other participants in the corridor network. A bank choosing to conduct an FX transaction via the board rate method can obtain HKD/THB rates published by market maker banks. The system takes the best board rate available into the FX transaction. The bank, as a market taker, will get the best rate amongst rates submitted by market maker banks.

To publish the rates, the market maker banks input the HKD/THB quote into the system. The system requires three details to be filled out: (1) type of board rate, whether bid or ask, (2) available amount, and (3) the quoted rate. Inputted quotes can be updated at any time.

For the market taker looking for a board rate, the system will automatically match the market taker's board rate request with the best available board rate and book the FX transaction. Once matched, the market maker's available amount will reduce accordingly.

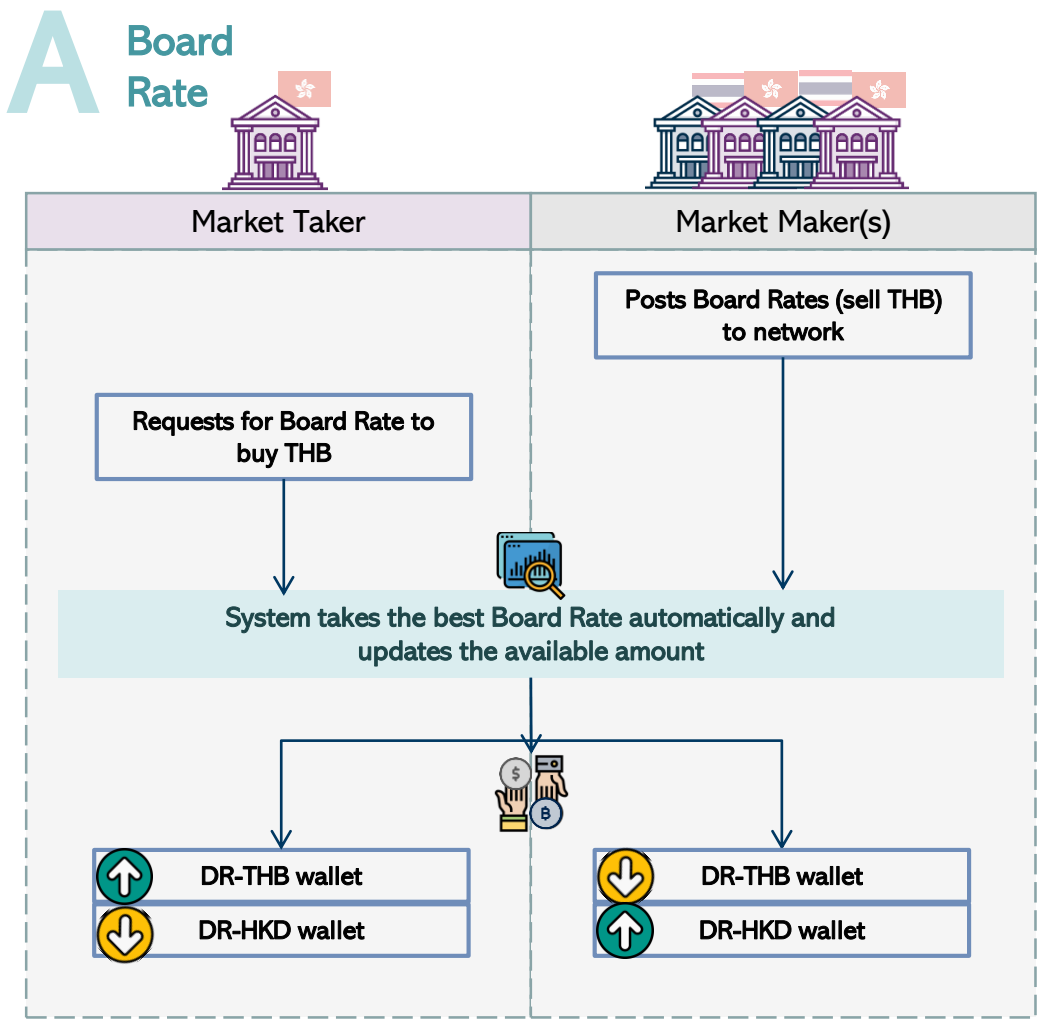


Figure 9 - FX Execution and Settlement with Board Rate Workflow

B. Request for Quote (RFQ)

The request for quote provides banks with the option of selecting specific counterparties within the corridor network. The bank, as a market taker, asks for a quote directly from a market maker bank in the corridor network. To request for a quote, the market taker bank inputs the settlement details which are the required amount, currency, preferred counterparty, and option of quoting an FX rate from one or multiple market makers. Once the market makers respond, the market taker then reviews and confirms which quoted rate it wants to execute.

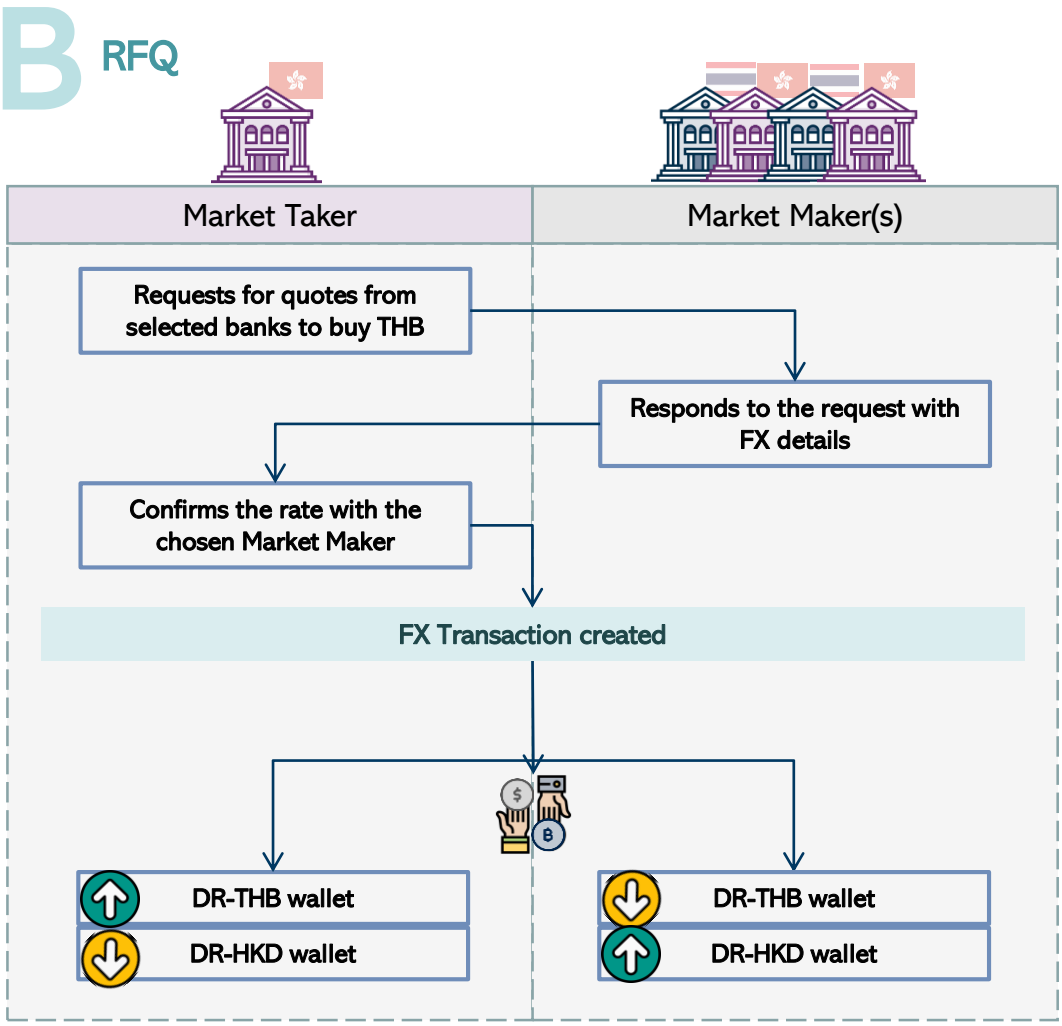


Figure 10 - FX Execution and Settlement with RFQ Workflow

C. Off-Corridor Arrangement

The off-corridor arrangement option provides an alternative way of FX dealing outside the corridor network between participating banks in the network and non-participating banks. Once the FX rate has been agreed upon, the transaction can be settled via a participating representative bank of the non-participating banks in the corridor network.

The representative bank and the counterparty bank both input the transaction details in the system to settle the transaction. The two transactions entered by the two transacting parties must be matched using the same reference number and transaction details. The matched transaction then proceeds to settlement. If the transaction details do not match, the deal is rejected.

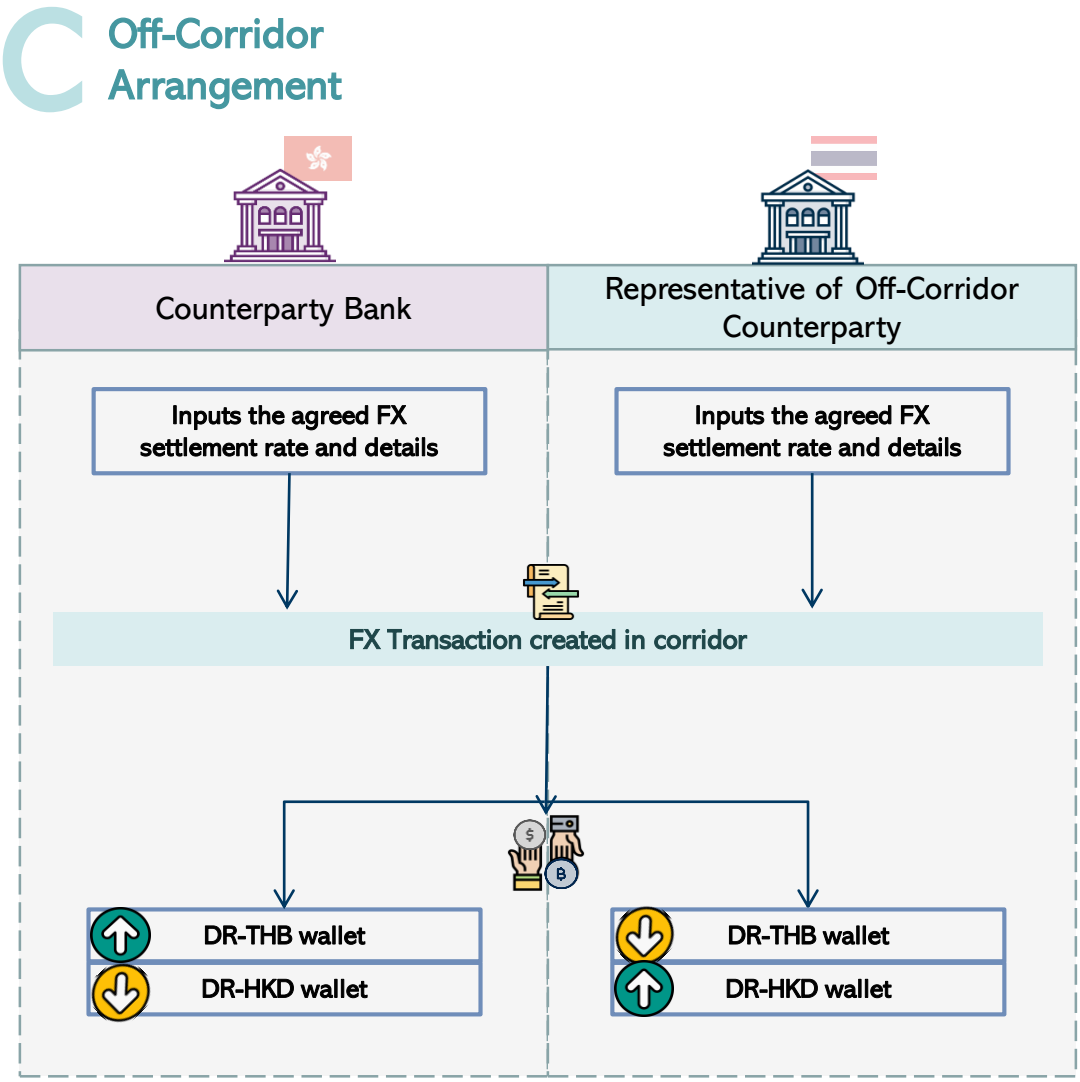


Figure 11 - FX Execution and Settlement with Off-corridor arrangement

3.2.4 Cross-Border Funds Transfer with Embedded FX Execution

To maximise the benefit of having both functions of funds transfer and FX transaction in the same system, the corridor network offers a solution for banks to manage their foreign currency liquidity.

The funds transfer function is bundled with an FX transaction to provide on-demand foreign currency funds for instant cross-border foreign currency funds transfers. This benefits banks needing to transfer foreign currency at short notice as the system will source foreign currency funds by either buying foreign currency through board rate or off-corridor arrangement. With these settlements occurring PvP, the foreign currency exchange occurs and funds the wallet just-in-time for the settlement of the outgoing payment.

A. Funds Transfer with embedded FX transaction via Board Rate

A bank can submit a cross-border payment instruction with embedded FX board rate by simply inputting transaction instruction details such as the receiving bank name, sending amount and its currency, and transaction purpose. Once the request is submitted, the bank executes FX transaction at the best available board rate. When both FX trading parties have sufficient funds, only then can the cross-border payment and FX transaction be settled instantaneously.

B. Funds Transfer with embedded FX transaction via Off-Corridor Arrangement

Following the basic principle of embedded FX transaction via board rate, the funds transfer with embedded FX transaction via off-corridor arrangement differs in that the FX transaction is agreed off-corridor instead of opting for board rate.

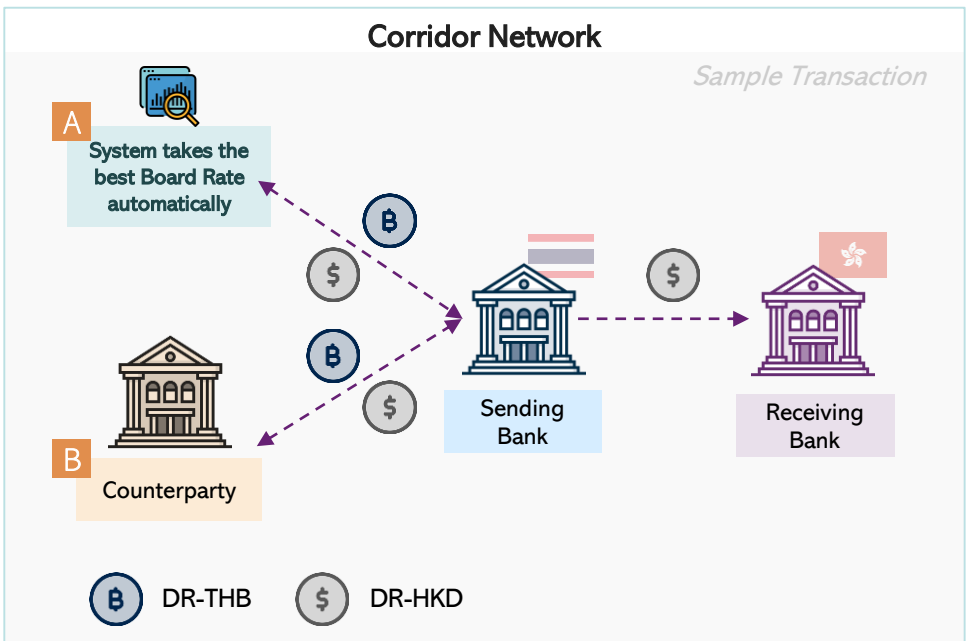


Figure 12 - Funds Transfer with embedded FX Transaction

A Board Rate

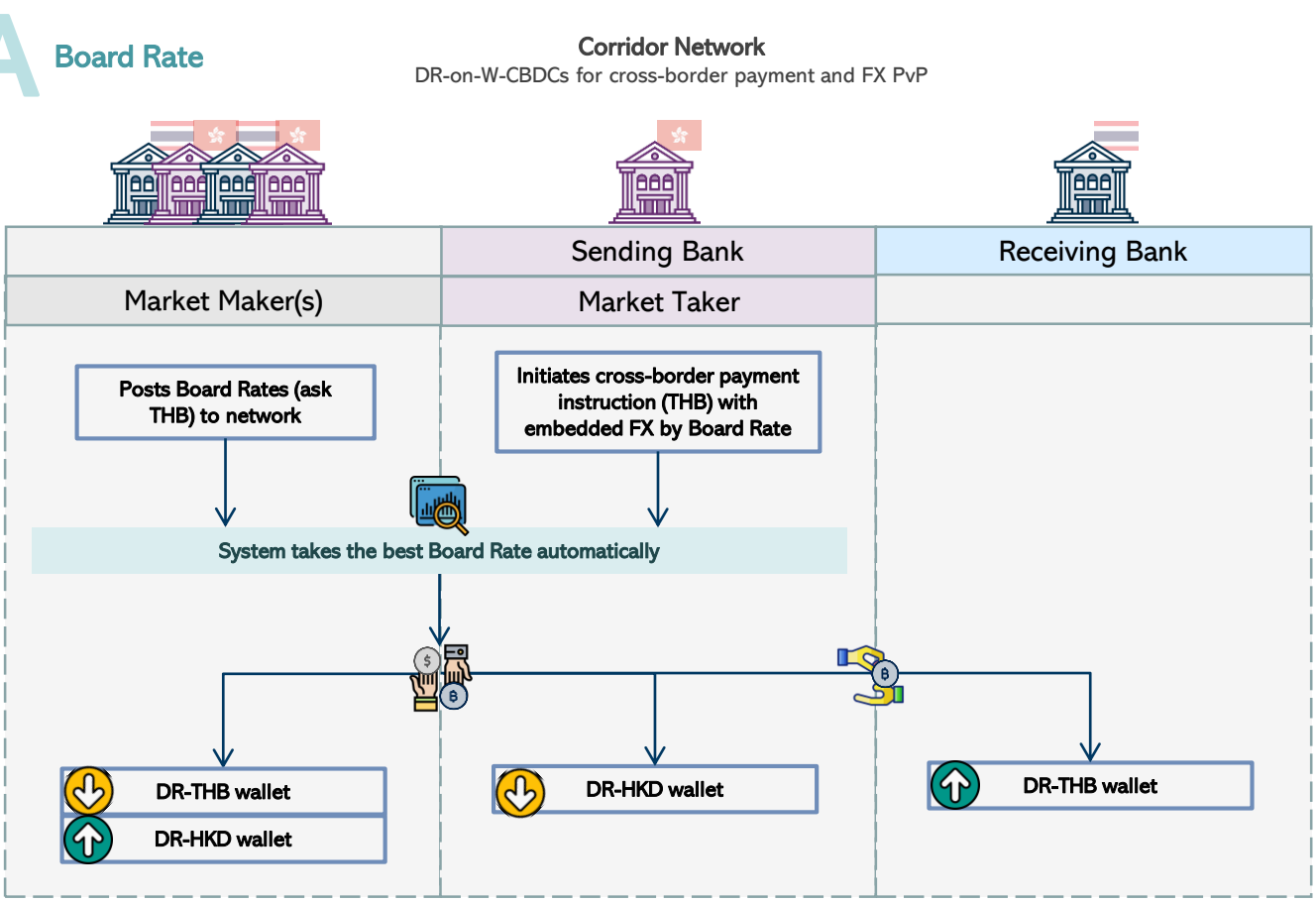


Figure 13 - Funds Transfer with embedded FX Transaction Workflow

B Off-Corridor Arrangement

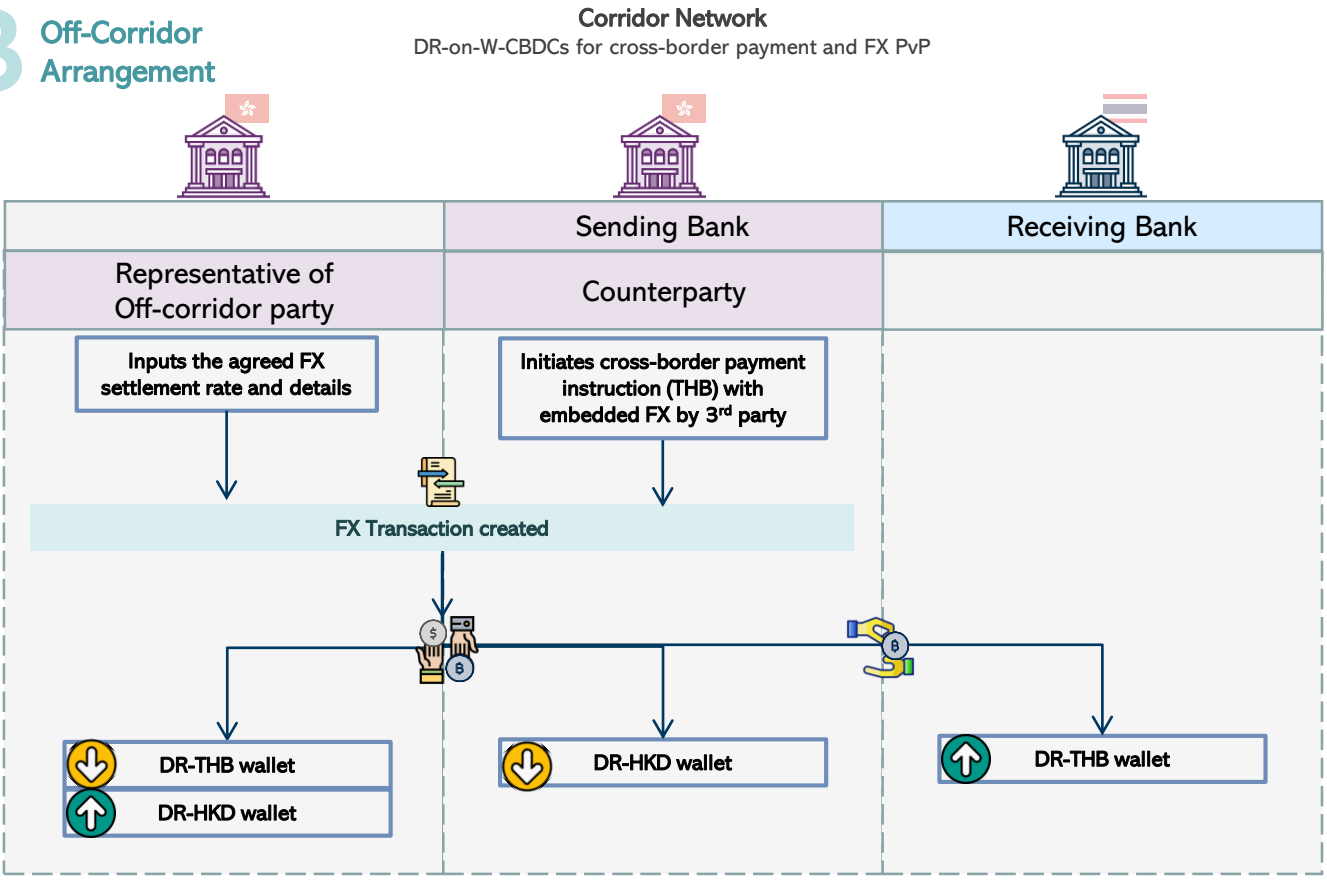


Figure 14 - Funds Transfer with embedded FX Transaction Workflow

3.2.5 Liquidity Management

To manage liquidity of DR-FCY and DR-LCY in the corridor network, the following mechanisms are put in place.

Queueing Mechanism

The queueing mechanism is adopted in the corridor network. In case a bank faces temporary liquidity insufficiency, transactions initiated will be placed into a queue with specified priority, so that when the liquidity of the bank's wallet becomes available, transactions in queue will be settled sequentially from higher priority ones.

Multi-asset Liquidity Saving Mechanism (MLSM)

The MLSM from the previous study is also adopted in this PoC. The gridlock resolution is enhanced to serve in a multi-currency settlement environment.

The objective of MLSM is to find a netting solution in case of a gridlock and is triggered periodically in the corridor network. The gridlock solution is iterated sequentially for each currency which takes into account both single-leg payment transactions and atomic PvP transactions.

Allow Just-in-Time Liquidity to Resolve Deadlock

When a deadlock arises in the MLSM, it means there is no netting solution available unless a bank with a negative position adds more liquidity. Such a deadlock necessitates the bank an Automated Liquidity Provisioning (ALP) facility to provide just-in-time liquidity. If the bank requires local currency liquidity, automatic token conversion will take place, converting W-CBDC from a domestic settlement network into DR in the corridor network. If the bank requires foreign currency liquidity, the ALP will automatically borrow foreign currency from the foreign currency liquidity provider to resolve the deadlock. The borrowed amount should be returned within the cut-off time of the same day.

Token Conversion for Liquidity Management

Liquidity management is made available to banks by the DR token conversion functionality, through which a bank can input instructions for the number of tokens to be converted into its domestic settlement network and vice versa. This conversion mechanism from DR to W-CBDC allows banks to manage their local currency wallet liquidity effectively in both the domestic and the corridor networks.

3.2.6 Regulatory Compliance and Enforcement

One of central bank's mandates is to perform surveillance activities in financial markets. This PoC, therefore, aims to improve the visibility of transactions occurring in the corridor network to the central banks. In addition, this PoC also takes into account the regulatory compliance and reporting requirements, especially those related to Thailand's foreign exchange regulations or specifically the Measures to Prevent Speculation on Thai Baht, where possible.

Real-time Monitoring

Cross-border funds transfers and FX transactions

In the corridor network, the central banks can observe life cycles of transactions. This helps meet and validate some regional regulatory compliance and reporting requirements.

Each central bank can monitor all cross-border transactions including all LCY cross-border transactions flows between all nodes in the corridor network and all FCY cross-border transactions involving local bank nodes in real-time, as well as all FX transactions and settlements.

The system is designed to provide real-time reporting for all transaction types, which are (1) cross-border funds transfers (one-way), (2) FX transactions, and (3) cross-border funds transfers with embedded FX transactions.

Board rate

Each central bank can monitor all real-time HKD/THB quotes posted on the board (board rates). The information shown on the board also includes the banks' latest bid-ask rates and corresponding available amounts. This enables the central bank to follow market development on a real-time basis.

DR conversion

The central banks can also oversee banks' activities in DR conversion. Real-time records show the amount of W-CBDC converted to DR-LCY in the corridor network, and vice versa. In other words, the BOT oversees the flows between W-CBDC-THB in the Inthanon network and DR-THB in the corridor network and the HKMA oversees flows between W-CBDC-HKD in the LionRock network and DR-HKD in the corridor network. Furthermore, the central banks are able to check and reconcile domestic network tokens and DR-LCY at all times.

Banks' borrowing activities

Borrowing transactions between banks and liquidity providing agencies, arising from deadlocks, are kept on an intraday basis. Central banks can oversee all borrowing transactions' details and their statuses. The status indicates whether or not the return of funds has been completed within the cut-off time of each day.

Regulatory Compliance with THB Specific Regulation

The purpose of regulation specific to Thai Baht is to maintain the stability of the exchange rate and reduce volatility of the Thai Baht from speculation.

Non-Residents Thai Baht Accounts

Under Thailand's current foreign exchange regulation, non-residents (NRs) are allowed to open two types of THB account, i.e. Non-Resident Baht Account (NRBA) and Non-Resident Baht Account for Securities (NRBS). NRBS shall be used solely for investment activities in financial instruments in Thailand, such as equity and debt securities, whereas NRBA shall be used for other purposes such as trade, services, lending or direct investment activities in Thailand. A daily ending balance limit and overdraft outstanding limit are applicable to both NRBA and NRBS.

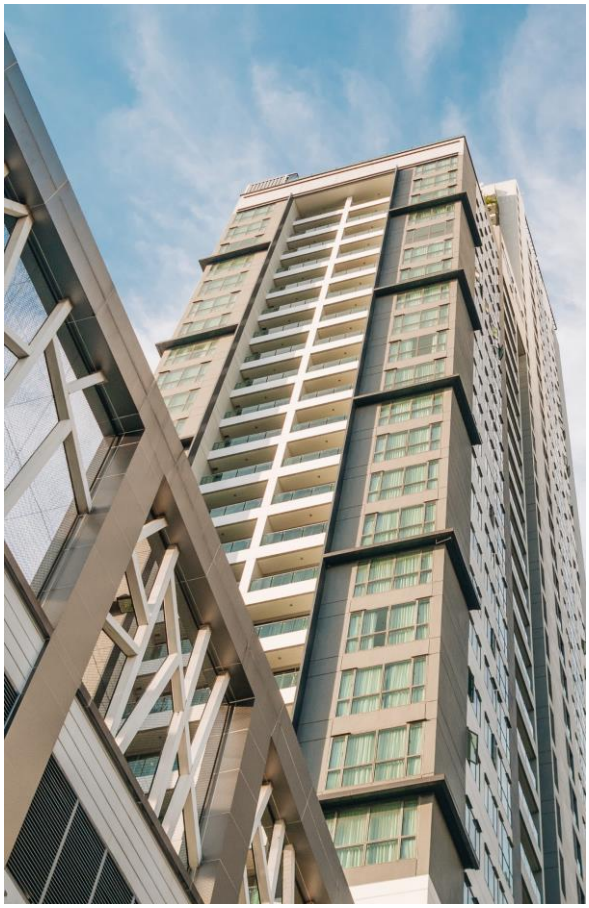
As this project focuses solely on cash transactions for general purposes other than investment in securities, it is assumed that HK banks' THB wallets within the corridor network are equivalent to NRBA. NRBS is not included in this PoC's scope.

Daily Outstanding Balance Limit

NRs are prohibited from having an aggregated ending balance in NRBA/NRBS exceeding THB 200 million per NR entity, across all financial institutions in Thailand. If an NR breaches the NRBA/NRBS outstanding limit, banks are required to notify the NR to sell the excess THB at a rate specified by the BOT.

The PoC takes into account this daily outstanding balance limit requirements to the maximum extent possible, with some limitations[5].

In addition, NRs are required to comply with borrowing and lending limits when transacting in Thai baht[6] or undertaking FX/THB transactions comparable to borrowing or lending Thai baht. However, compliance with these limits inside the corridor network is beyond the scope of this PoC.



The following describes the implementation in the PoC with respect to Thai regulations applicable to Hong Kong banks operating in the corridor network.

Surveillance on HK banks' THB outstanding balance

According to the current regulations, the BOT governs compliance enforcement on NR's THB cash holdings, which should not exceed THB 200 million at the end of each day. This applies to HK banks' outstanding DR-THB balance in the corridor as well as off-corridor THB held in NRBA/NRBS opened with banks in Thailand.

To take this into account, any off-corridor THB must be recorded into the system at the end of each day to verify that the HK banks' total outstanding balance indeed does not exceed THB 200 million. At the cut-off time, the system will then aggregate the amount of on-corridor DR-THB and off-corridor THB. If the aggregated amount exceeds THB 200 million, this amount will be displayed in red. In addition, if at any given time a HK bank's DR-THB wallet exceeds THB 200 million, the amount will also be displayed in red, so that the bank will be aware that they will need to manage the excess amount.

Auto-reduction of HK banks' DR-THB in the corridor when exceeding THB 200 million

The system is designed to perform automatic reduction from HK banks' THB wallets at the cut-off time in the case that their aggregated balance of DR-THB wallet and off-corridor THB exceeds THB 200 million. The exceeding THB amount will be sold to the operator node at a specified exchange rate.

For example, should an HK bank have an off-corridor NRBA balance of THB 200 million and DR-THB 100 million, totalling THB 300 million, auto reduction occurs to the DR-THB balance of 100 million and resulting in reduction of the total THB balance to 200 million.

In the second example, should an HK bank have an off-corridor NRBA balance of THB 300 million and DR-THB 200 million, totalling THB 500 million, auto reduction occurs to the DR-THB 200 million so the total THB balance becomes 300 million. In addition, the HK bank will also need to sell the THB 100 million cash outside of the corridor network at a specified exchange rate to reduce the aggregated outstanding balance to THB 200 million.

While the mechanisms in the Inthanon-LionRock model are geared towards facilitating greater efficiency in atomic real-time settlement of cross-border transactions, such mechanisms pose compliance challenges given the existence of foreign exchange regulations in Thailand, which require banks to monitor outstanding THB holdings by NRs and check for proof of underlying business activities before undertaking any FX/THB transactions, other than Spot (T+2) transactions. If not, such FX/THB transactions without any underlying business activities will be subject to outstanding limits. Therefore, the current design of the cross-border model may need to be modified to cater to existing regulations, trading off some level of efficiency for regulatory compliance. Otherwise, to release the full potential of DLT in facilitating cross-border transactions, monitoring approaches will need to be changed or existing foreign exchange regulations will need to be amended to better suit the dynamic nature of transactions to be undertaken within the corridor.

[5]Thailand's Measures to Prevent Thai Baht Speculation stipulate that NRs are allowed to maintain an outstanding balance at the end of each day in NRBA and NRBS accounts not exceeding THB 200 million. One exemption to this rule is that NRs are allowed to maintain an ending balance exceeding 200 million, only if they have an obligation to use the amount towards trade or investment in Thailand in the following business day. In this case, the domestic financial institutions with which the NRBA/NRBS accounts is held will check the NR's underlying documents and submit a report to the BOT. The PoC will not take into account this exception since it will be difficult for banks to check the DR-THB held by HK banks for proof of underlying.

[6]In addition, the Measures also stipulate that, other than FX/THB Spot (T+2) transactions, groups of NR are allowed to borrow Thai Baht (or undertake FX/THB transactions comparable to borrowing Thai Baht) up to THB 600 million and lend Thai Baht (or undertake FX/THB transactions comparable to lending Thai Baht) up to THB 10 million from and to domestic financial institutions, respectively, if they do not have any underlying obligations. HK banks, as NRs, transacting with domestic banks should comply with this measures. However, the PoC which includes FX trading (not only cross-border funds transfers) does not take into account this measure, as it is difficult to effectively monitor and aggregate the outstanding amount that HK banks have transacted with domestic banks both on and off the corridor. It is also not possible to pre-check for proof of underlying before undertaking FX trading under this atomic real-time environment.

LionRock Mountain, Hong Kong

04 Technical Design & Findings

4.1 System Architecture

This PoC considers the scenario of three heterogeneous, independently operated Corda networks, each running a different doorman and notary service. The three networks are Inthanon network, LionRock network, and the newly developed cross-border corridor network. In order to provide a certain degree of interoperability between the networks without compromising the independent operation, token conversion facilities are provided by placing trust on the central bank of each domestic network and the operator of the corridor network. Each central bank operates a token conversion service that coordinates DR token conversion requests between its domestic node and the corridor node.

Other bank participants are assumed to participate in both their domestic networks and the corridor network. As a result, each of them operates 2 Corda nodes with a single application programming interface (API) service and a user interface (UI) client. To align with the existing practices in setting up a secure infrastructure, all components are placed behind a firewall with only the necessary ports for DLT operations whitelisted.

Each bank participant operates the following components as the solution stack of the PoC[7].

Corda Node in the Corridor Network

Each participating bank hosts one Corda node on the corridor network, while the central banks co-manage the operator node of the network. CorDapps installed on nodes in the corridor network provide cross-border payment, FX related transaction and project core features, which are much focused on in this PoC.

Corda Node in the Domestic Network

Each participating bank and central bank hosts one Corda node on its respective domestic network. The central bank node in the domestic network is responsible for tokenisation and regulatory monitoring in its domestic networks. CorDapps installed on nodes in the domestic networks are taken from Project Inthanon and Project LionRock with an additional CorDapp providing token conversion features.

[7]Additional Technical Information can be found in Appendix 9.4

Application Programming Interface (API) Service

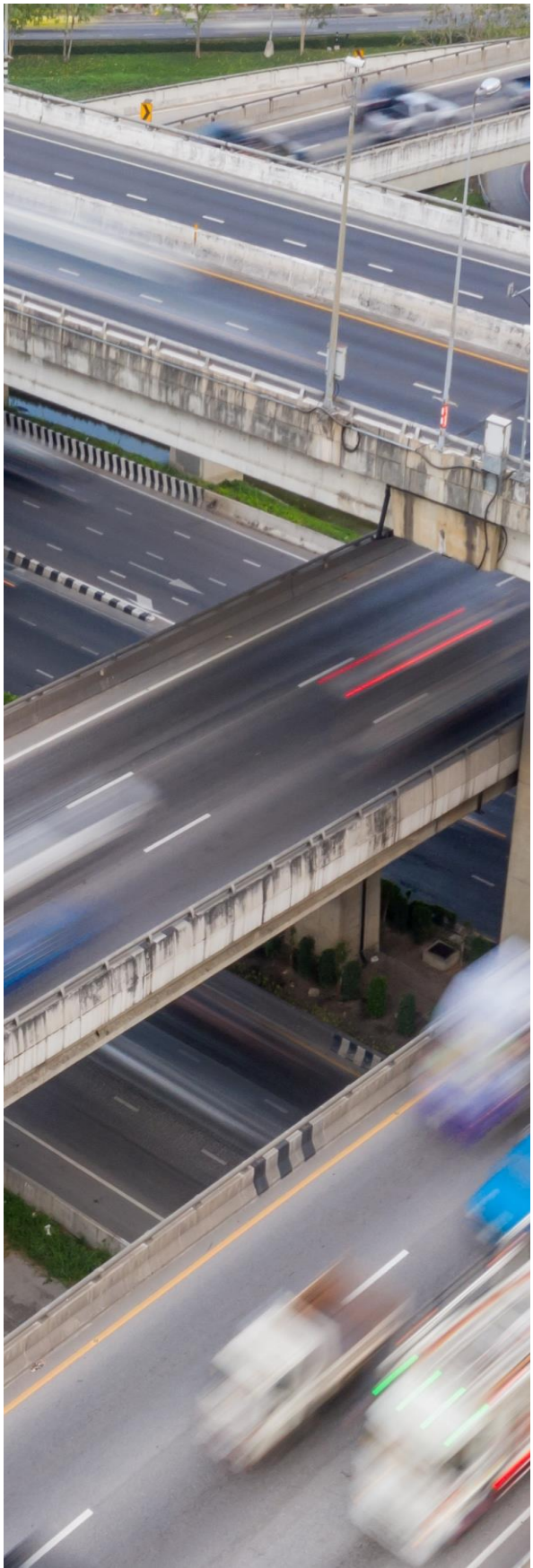
The API Service is run by all participating banks and central banks as a middleware between the DLT layer, i.e. the Corda nodes on domestic networks and cross-border corridor network, and the web clients. The central banks' API services connect to their own domestic Corda nodes and the co-managed operator node on the corridor network.

A RESTful API built with Spring Boot framework is designed to be used by the downstream clients, whereas communication with Corda nodes is done through Remote Procedure Calls (RPC).

The API Service manages to route domestic and cross-border instructions to Corda node in the corresponding domestic network and the cross-border corridor network. It also manages internal data (as opposed to on-ledger data most likely shared with at least one counterparty), provides authentication to and authorisation of end users.

User Interface (UI)

The UI client is built with the Angular web framework to provide to the end users, e.g. participating banks' and central banks' operators, with a web-based graphical UI to perform business actions in both the domestic and the corridor networks. The UI client sends requests to the API service for these actions.



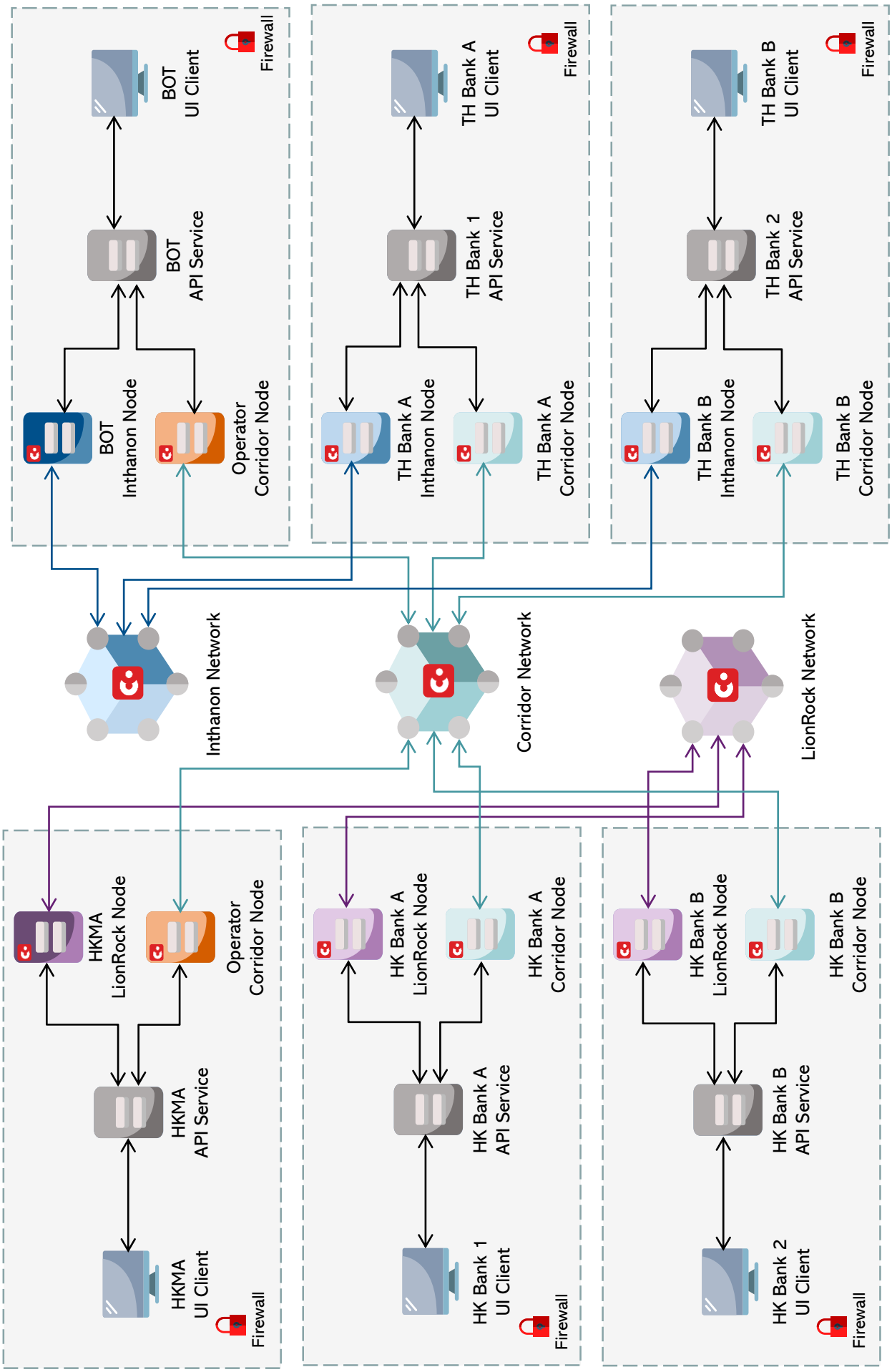


Figure 15 - Inthanon-LionRock Technical Design (Conceptual)
(The Operator Node indicated in red colour is a Corda Node co-managed by HKMA and BOT)

4.2 Corridor Network Application Architecture

Modules

Project Core and Project Plugins

In the PoC of Project Inthanon-LionRock, the Project Core and Project Plugins module are inherited from the BOT's Project Inthanon. These modules provide the general financial asset modelling, core settlement and configurable components to support gross and net settlements. Multi-asset Liquidity Saving Mechanism (MLSM) has been enhanced to support FX instructions with currency pair using the reference currency equivalent value conversion.

Corridor Services

The corridor network relies on the presence of several services:

- Network-network token conversion
- Regulatory monitoring
- Liquidity provisioning
- FX board rate broadcasting

Each service can be hosted on one Corda node and owned by institutions other than the central banks. For example, FX board rate broadcasting service is typically provided by exchanges. For simplicity in the PoC, all services are delegated to the operator node.

Cross-Border Payment

The cross-border payment module models the cross-border payment transactions as smart contracts and performs settlement via the project core. It also allows embedded FX transactions, where the settlement for the payment and the FX transaction are settled instantaneously within one DLT transaction.

FX transaction

One of the core features of the corridor network is to model multiple fiat currencies and enable foreign currency exchange capabilities between participating banks. In this PoC, two major FX associated transactions are developed: FX transactions and cross-border payment with embedded FX transaction.

There are three methods to execute an FX transaction: Board Rate, Request for Quote (RFQ), and Off-corridor Arrangement. Each differs mainly on how the FX rates are agreed upon. Smart contracts are developed to model the workflows of these methods and once a trade is agreed upon, a separate smart contract is issued to track the settlement process of the trade. The FX settlement process is monitored for regulatory purposes.

Liquidity Provider

When a gridlock occurs during MLSM, injecting liquidity to the participating banks increases the chance of finding a solution to settlement. This process is commonly referred to as Automated Liquidity Provisioning (ALP).

In the corridor network of Project Inthanon-LionRock, instead of provisioning liquidity from pledging bond holdings as collaterals as in the domestic settlement networks explored in both Project Inthanon and Project LionRock, participants can borrow foreign currency funds from the foreign currency liquidity provider or perform token conversion from W-CBDC to DR-CBDC, thus increasing the banks' liquidity available in the corridor network.

The liquidity provider is an interface for different sources of ALP to be plugged in to the Corda nodes. Leveraging system automation, the provisioning of liquidity is executed in real-time. In the case when borrowing is triggered, the borrowing bank would have to return the borrowed funds through functionalities on the web UI.

Token Conversion

Token conversion refers to the process of converting tokens belonging to a requester in the domestic network to depository receipt tokens belonging to the same requester in the corridor network, and vice versa. This differs from a transfer because the requester retains ownership of all converted tokens, and the tokens themselves are moved to another network.

Naturally, token conversion involves making changes to two ledgers on two separate networks. Not only does it require cooperating smart contracts on each network, but also an orchestration mechanism maintaining the operation across the two ledgers. By placing centralised trust on the central banks, an algorithm was developed and ran by the central banks to handle the token conversion requests for the issuance and redemption between W-CBDC and DR-CBDC.

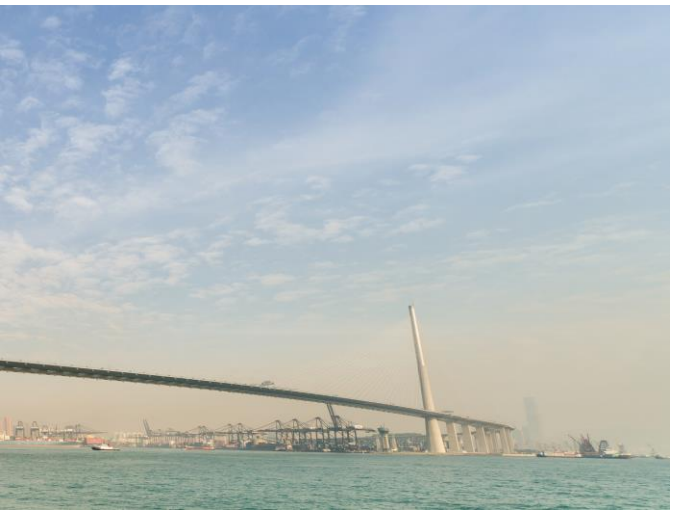
Data Architecture

Data Relevant to Domestic Transactions

Data relevant to domestic interbank transactions are represented as Corda states broadcast only within the domestic Corda settlement network in accordance with the contract and flows defined. These transactions include details of various agreements for local domestic payments and bond trades modelled from Project Inthanon and Project LionRock.

Data Relevant to Cross-border Transactions

Data relevant to cross-border payments and FX transactions are presented as Corda states over the corridor network. These transactions include the new agreements which are built in Project Inthanon-LionRock.



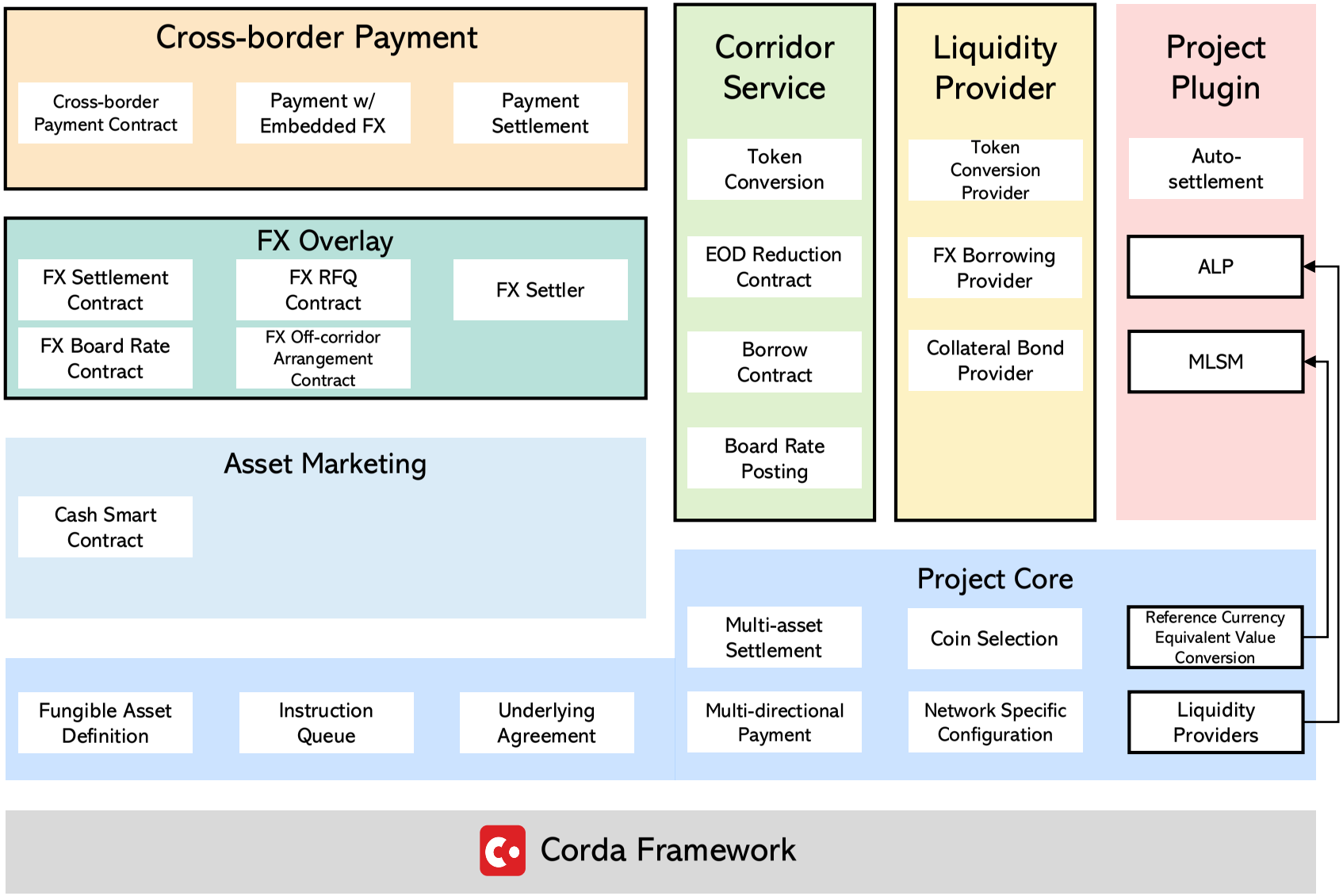


Figure 16: Inthanon-LionRock Technical Design

4.3 Non-functional Findings

Atomicity

The project successfully demonstrated the ability of the Corda network to perform atomic PvP for FX transactions by leveraging on smart contracts. An FX transaction either entirely succeeds or completely fails. No situation exists where a bank delivers foreign currency while the counterparty fails to deliver its part. Settlement risk is mitigated with the use of smart contracts.

Settlement Finality

Finality describes the way a system reaches a consensus on the state of an event or fact. In the case of digital cash or digital asset, it typically represents the time when a change of ownership occurs. In Corda, there is a notary service committing to settlement finality and irrevocability by providing a signature for all transactions. This PoC has technically demonstrated that the system is able to provide settlement finality for PvP transactions involving different currencies and token conversion between two networks.

Resiliency

Token Conversion Recovery

Working with two networks may increase the possibility of failure, so the token conversion mechanism is designed to be resilient against insufficient balance, system outage and network failure. This means that the central banks can recover the conversion automatically after a failure is resolved.

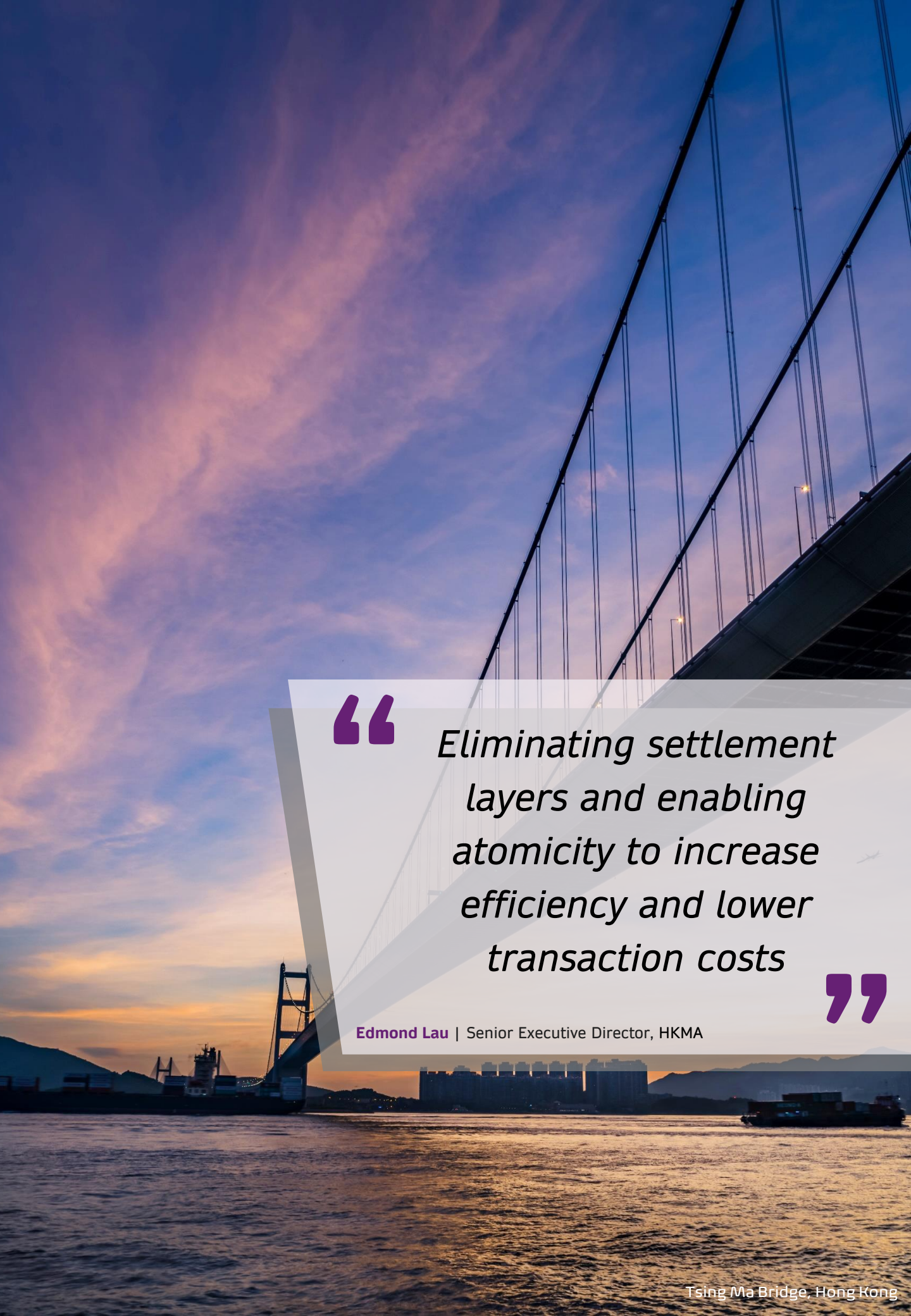
Resilience in Corda

Resilience in Corda guarantees the continuity of flows throughout any disruption and protects nodes from loss, corruption or duplication of data on the ledger due to system outages.

Privacy

In this project, data privacy features from the previous projects are retained. The first feature is that transactions are broadcasted only on a need-to-know basis. Another feature is the use of confidential identities to ensure anonymity amongst transacting parties in MLSM.

In the board rate broadcasting process, the operator retrieves quote details from the market makers. The market takers then obtain the best quote from the operator without knowing the identity of other market takers and deal with the market maker directly on a peer-to-peer basis.



> *Eliminating settlement layers and enabling atomicity to increase efficiency and lower transaction costs*

Edmond Lau | Senior Executive Director, HKMA

Tsing Ma Bridge, Hong Kong

Bangkok, Thailand

05 Business Benefits

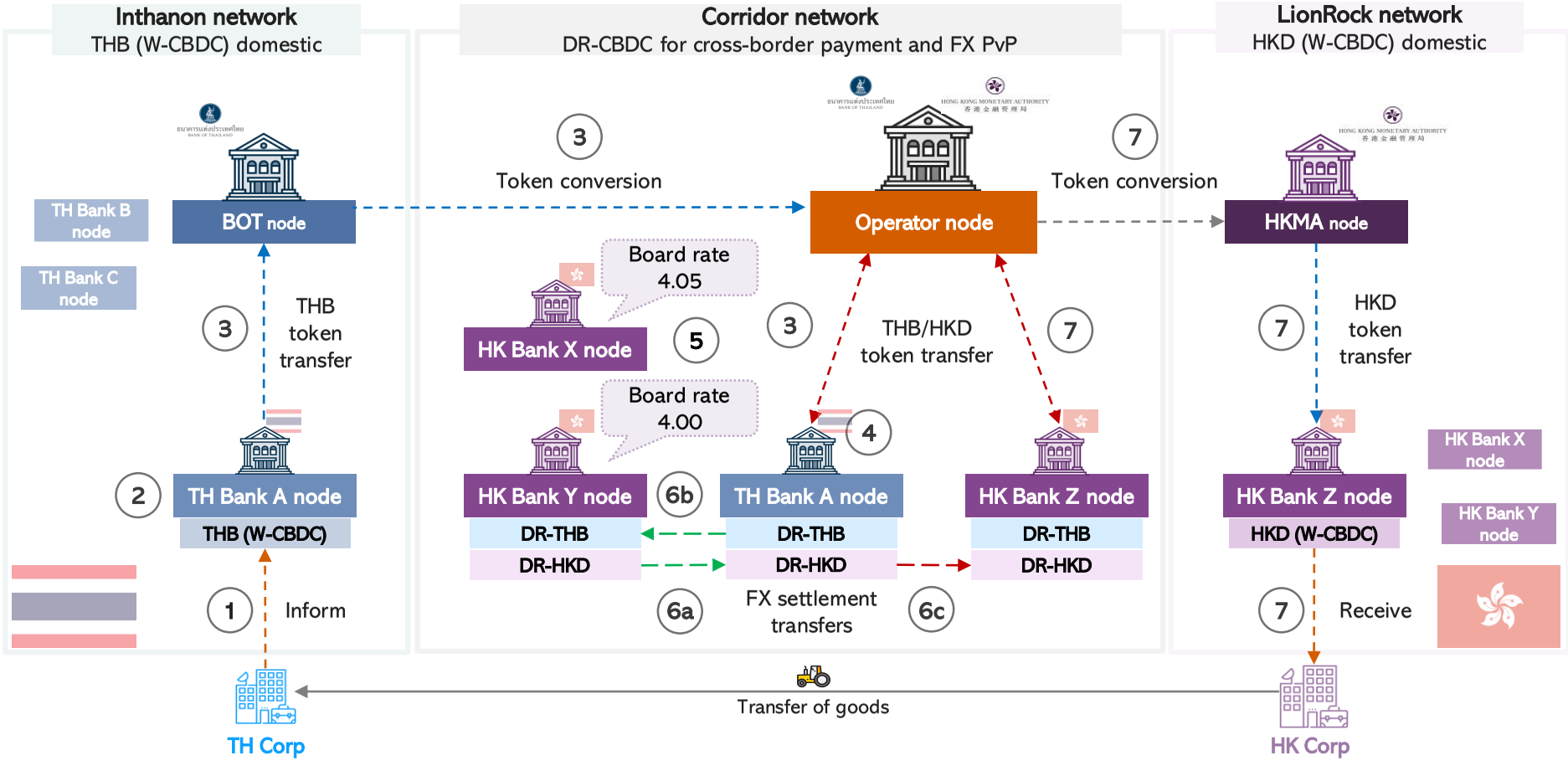
The case study presented in Section 3.1 helped further illustrate the business benefits of a corridor network in a real-world scenario. As a refresher, the case study demonstrates trade-related exchanges between a Thai and Hong Kong corporation ("Corp"). In lieu of utilising existing cross-border transfer infrastructure, the proposed corridor network provides means to increase transaction speed and transparency.

With the case study at hand, a hypothetical payment situation is explored below involving a Thai Corp importing goods from its vendor, HK Corp.

A payment situation occurs when the Thai Corp wants to pay HKD 1million to the HK Corp through Thai Bank A via CBDC. Utilising CBDC and the connection of the Inthanon, LionRock and the corridor networks, this cross-border payment process can be completed within seconds[8].

The following describes the case study roles and procedures in adherence to the proposed model.

[8]Given that the sending bank (i.e. Bank A in this case) has sufficient DR-HKD liquidity in the corridor network, so that payments can be sent to the receiving bank (i.e. Bank Z in this case) instantly.



1. The Thai Corp informs Bank A to transfer HKD 1million to the HK Corp's account at Bank Z in Hong Kong.
2. Bank A checks whether Bank Z is also a member of the corridor network. The result is positive.
3. Bank A converts THB 4 million worth of W-CBDC-THB from the domestic network into DR-THB in the corridor network.
4. Bank A decides to process this transfer via the "funds transfer with embedded FX transaction via board rate" method knowing roughly the market exchange rate.
5. The system searches and discovers that Bank Y offers the best board rate available in the corridor network at 1 DR-HKD for 4 DR-THB.
6. The settlement of the transaction occurs, which comprises (a) Bank A receives DR-HKD 1million from Bank Y, (b) Bank A delivers DR-THB 4 million to Bank Y, and (c) Bank A transfers DR-HKD 1 million to Bank Z, (a), (b) and (c) happen simultaneously and instantaneously.
7. Bank Z confirms it has received the funds and credits HKD 1million to the HK Corp's account.

Figure 17 - Case Study Model (Proposed Model)

This case study shows the potential benefits of the PoC ameliorating the pain points of the existing cross-border model as follows.

01 Improve settlement efficiency

With real-time gross settlement of cross-border funds transfers and real-time PvP of FX settlement, efficiency is enhanced. By using token transfers between the corridor network and Inthanon/LionRock networks, cross-border transaction can occur real-time without intermediaries or settlement layers.

02 Enhance liquidity efficiency

Liquidity efficiency is maximised through multi-currency liquidity saving mechanisms. FX transactions are made available on the corridor network supporting foreign currency liquidity. W-CBDC tokens replace nostro accounts while liquidity providing agents offer intra-day liquidity provision for foreign currency.

03 Comply better with regulations & improve reporting ability

All transactions are reported in real-time, reducing the post-trade reporting effort of banks. The system generates an alert for the enforcement of regulations, leading to better regulatory compliance; especially with Thailand's non-resident requirements.

04 Allow for wider scope with extensible architecture

Although the current project only tests a THB-HKD corridor with 10 participating banks from Thailand and Hong Kong, the model can be further extended to embrace the global financial market's needs. The outcomes of Project Inthanon-LionRock will help determine the ease and feasibility of extending to other markets while enhancing functionalities linked to the corridor network.

Bangkok, Thailand

06 Future Considerations

As the PoC of Project Inthanon-LionRock is successfully completed, it is pivotal to underline areas of potential development in preparation towards the next stage of the study, e.g. a full production-grade system in a sandbox environment. The following aspects, non-exhaustively, cover legal, operational and technical considerations which the central banks may elaborate on.

6.1 Legal and Regulatory Considerations

Further Regulatory Review and Implementation

The PoC, as a preliminary attempt to trial compliance with partial local regulations, is expected to extend its potential to fully encompass the regulations despite the complexities of fulfilling multi-regional cross-border policies. The future build-out shall scrutinise the onboarding of new regulations and continue periodic revision of existing regulations to adapt with the ever-changing regulatory environment (including Thai, Hong Kong and global regulations). Any change in the regulatory environment will result in a compliance consideration in the proposed DLT system. Thus, it is vital to consider the harmonisation of disparate cross-jurisdiction regulatory frameworks - both on paper and in execution. Besides, legal claims to central banks and financial data privacy concerns should also be included to outline escalation and remediation protocols for such claims and issues.

Anti-Money Laundering (AML) Accordance

AML accordance is a regulatory requirement imposed internationally and constitutes a pillar in the global effort in policing financial crime. In view of this, the system should support AML practices to enhance the efficiency in overseeing suspicious transactions. Therefore, the design of integrating relevant agencies such as Anti-Money Laundering Office (AMLO) should be considered to ensure a smooth-running business.

Settlement Finality

As the PoC proposes a DLT-based payment system for cross-border transactions, another legal dimension to consider is settlement finality. Settlement finality guarantees transaction completion indefinitely and revokes any potential reversal (should any transaction party fail or enter bankruptcy). Accordingly, prior to rolling out the PoC into production, settlement finality should be clearly defined in the legal and operational sense.

6.2 Operational Considerations

Governance, Roles, and Responsibilities

Currently, the multi-currency DR issuing node in the corridor network is shared equally between the BOT and the HKMA. A follow-up question arises when the network extends its architecture to include other foreign currencies or central banks. There will be governance issues of how to set up the multi-currency DR issuing node's entity in terms of governing law, data privacy, and node's location. In addition to the governance structure, roles and responsibilities may also need to be further deliberated. As an example, it is assumed that there is a liquidity providing agency in the PoC. Corresponding changes in roles and responsibilities may further allude to new functionalities development such as cross-currency repo facility provided by central banks. A repo facility function offers an additional option for liquidity management, should participating banks need further collateralised liquidity injection.

Integration of the corridor network in the PoC with existing real-world systems or other CBDC networks remains critical in achieving global financial industry synergy. The proposed corridor network model allows flexible expansion and operation of cross-border transactions, equipped with liquidity management functions such as the just-in-time liquidity provision. Feasible integration models from technical and operational perspectives will need to be explored for connecting the corridor network to other systems.

6.3 Technical Considerations

Performance and Scalability

Performance and scalability are the key concerns for facilitating real-time payments and onboarding of new participating members. Under the PoC testing scenario, it was found that if a bank holding a certain amount of cash tokens would need to make a payment to a different receiving bank at the same time, the payment transaction would occur in a sequential order in which one transaction chain must be finished before performing another transaction. It is worth exploring further on facilitation of parallel computing and optimisation of the way cash tokens can be distributed without order dependency.

Security is another area which needs to be addressed. DLT-related controls must be implemented to mitigate risk. For example, DLT keys, which are generated by the Doorman and stored in DLT nodes to identify nodes and sign transactions, should be integrated with the Hardware Security Module (HSM) and managed properly to avoid being compromised.

Production Resilience

High availability (HA) is related to the capability for disaster recovery, which requires the presence of a procedure to handle different degrees of system component failures. Corda is built on tried and tested technologies such as Java Virtual Machine and Structured Query Language (SQL), which support the use of commercial Relational Database Management Systems (RDBMs) and Cloud. This enables the utilisation of existing technology capabilities and industry best practice to reduce the frequency and impacts of system failures. At present, Corda HA is achieved through a hot-cold setup, while ledgers can also be supported through HA relational databases. Future work may include exploration of new HA deployment configuration options for the Corda nodes and capability to monitor running flows in Corda.

Inthanon Mountain, Thailand

07 Conclusion

In an attempt to explore improvements to international payments, the BOT and the HKMA have come together to put forward a Distributed Ledger Technology (DLT) system allowing real-time atomic cross-border transactions. Alongside the two central banks are eight Thai banks, two Hong Kong banks, and technology partner R3. The Project Inthanon-LionRock Proof-of-Concept (PoC) made good progress in achieving intended functional and non-functional objectives.

Project Inthanon-LionRock PoC discusses how the corridor network model, which incorporates liquidity management and regulatory compliance, addresses current key pain points and promotes better cross-border settlement efficiency. The key functionalities to support cross-border transactions in the corridor have been developed with participants in an attempt to incorporate practical business requirements. However, some challenges, namely legal and regulations, operational issues, and technical limitations may need to be further explored in the next stage of the project.

The project is achieved by a fruitful collaboration including valuable contributions from participating banks, technology partners and development teams reflecting the shared urgency to shape the application of DLT to prevail over existing pain points in cross-border transfers.

Suggestions for the way forward include adapting the model to match existing regulations as well as refining the model so that it complies with global standards and can create synergies with other internal or external systems of other currencies.

To conclude, Project Inthanon-LionRock represents an important step forward in the realm of CBDC initiatives, especially in the advancement of cross-border transactions. With a committed team behind the platform, the PoC represents one of many future potential DLT advancements between Hong Kong and Thailand. While the journey ahead may be filled with its own set of challenges, we must face them head on and continue leaving our mark in the continuous development of DLT applicability in the global financial market.

Bangkok, Thailand

08 Glossary

Term	Definition
Atomicity	It is one of the ACID (Atomicity, Consistency, Isolation, Durability) transaction properties. It measures whether the updates of data from a series of database operations are fully completed.
ALP	Automated Liquidity Provision
AML	Anti-Money Laundering
BOT	Bank of Thailand
CBDC	Central Bank Digital Currency
Corp	Corporation
Corridor Network	A segregated cross-border transactions settlement network
Deadlock	Deadlock arises when a potential netting solution results in a negative net liquidity across participants, where no resolution is possible unless additional liquidity is provided to one or more participants.
DLT	Distributed Ledger Technology
DR	Depository Receipt
DvP	Delivery versus Payment
FCY	Foreign Currency
GR	Gridlock Resolution is an optimisation process to help resolve a gridlock situation. The system searches for a combination of obligations that can be netted, in which these obligations are executed simultaneously.
HKD	Hong Kong Dollar

Term	Definition
HKMA	Hong Kong Monetary Authority
LCY	Local currency
LSM	Liquidity Saving Mechanism
Market Maker	A market participant who sets both the bid and ask prices for FX on its system, these prices will be displayed publicly on the quote screens. The market maker will stand prepared to make transactions at the prices committed in the system and provide FX liquidity to the market.
Market Taker	A market participant who agrees with the listed prices on the screen system quoted by a market maker.
Nostro	Nostro account signifies when a bank possesses foreign currency amounts in another bank.
NRBA	Non-Resident Baht Account
NRBS	Non-Resident Baht Account for Securities
PoC	Proof-of-Concept
PvP	Payment-versus-Payment
Repo	A sale-and-repurchase agreement. For example, in Inthanon's case, the BOT is the lender of cash against assets provided by other banks.
RTGS	Real-Time Gross Settlement
THB	Thai Baht
Vostro	A vostro account denotes when a bank's correspondent bank holds one of their domestic currency accounts.
W-CBDC	Wholesale Central Bank Digital Currency

09 Appendix

9.1 Project Inthanon

Project Inthanon is a CBDC project, envisioning two goals; to establish a collaborative environment for the financial industry to gain a deeper understanding of DLT and to explore the feasibility of DLT and its resiliency and efficiency features as a financial market Real Time Gross Settlement (RTGS) infrastructure. These two goals allow for a cultivation of innovation within the global financial services industry as the project aims to pioneer a decentralised RTGS for an interbank payment system.

In partnership with R3, the BOT, the HKMA and a consortium of Thai and Hong Kong financial institutions, Project Inthanon-LionRock aims to build a proof-of-concept on R3's Corda platform to explore the capacity of DLT for cross-border payment. Prior to this project, Project Inthanon solely covered the Thai financial services industry. With a global perspective in mind, the Hong Kong market was quickly introduced to help transform the cross-border funds transfer model.

Phase 1: Build the Fundamentals

- Built PoC for a DLT-based RTGS utilising W-CBDC interbank settlement
- Developed gridlock architecture with ALP functionality to tackle privacy and atomicity concerns
- Designed tokenisation of cash and bonds

Phase 2: Enhanced Functionalities

- Amplified Phase 1 PoC functions to manage DvP settlement for bond life cycle events including repo and trading, to reconcile data and meet Thailand's Non-Resident (NR) regulatory requirements for third-party funds transfer
- Recognised DLT operability in achieving real-time DvP through provisional MLSM

9.1.1 Inthanon Phase I PoC Highlights

Inthanon Phase 1, started in August 2018, encompassed designing and building a decentralised interbank payment system with enhanced GR architecture, bond tokenisation and ALP. The resulting PoC allows evaluation of blockchain, proving DLT's ability to alleviate current infrastructure issues and inefficiencies within the Thai financial market.

Phase 1 Overview

Functional Capabilities

1. Tokenisation of Cash: The BOT central bank node has the exclusive capability to issue and recall THB cash tokens on the network.
2. Decentralised Bilateral Transfers: The network allows participating nodes to make payments via cash token transfers.
3. Queuing Mechanism: Participating nodes may set priorities to their outgoing queues when lacking liquidity.
4. Gridlock Resolution: LSM oracle node executes centralised GR calculation while participating nodes execute settlement in a decentralised practice.
5. Tokenisation of Bond: Participating nodes may convert TSD bonds into bond tokens on the DL system for ALP when required.
6. Automated Liquidity Provisioning: Participating nodes can obtain additional liquidity to resolve urgent pending transactions and clear deadlocks.

Non-Functional Capabilities

1. Settlement Finality: The network shall maintain clear ownership status of funds or an asset and irrevocability in transactions.
2. Transaction Privacy: All transaction details must only be visible to relevant counterparties.
3. System Resiliency: With a decentralised approach, the promise of system resiliency is kept under all circumstances.

9.1.2 Inthanon Phase 2 PoC Highlights

Building on the successful completion of Phase 1, the focus shifted to exploring the applicability of smart contracts for automating bond life cycle events and enhancing the monitoring of regulatory compliance activities. Phase 2 sought to address process rigidity within financial systems and increase efficiency for regulatory practices.

Phase 2 Overview

Functional Capabilities

1. DvP for Interbank Repo & Bond Trading: The PoC demonstrates smart contracts' flexibility for codifying complex product structures and interdependencies. Smart contracts support various events around bond life cycle including auto-triggered coupon and principal payment, as well as, disbursement using auto-generated cash token transfer transactions.
2. Third-Party Payment Integration & Regulatory Compliance: The DLT-based platform provides standardised end-to-end payment and control processes with key characteristics including single platform design, openness for integration and ability to implement proactive compliance. Stringent compliance with regulations where all non-resident accounts (NRBA/NRBS) must comply with limits on the daily outstanding balance, overdraft amount, and types of transfer.

Non-Functional Capabilities

1. Settlement Finality: The tried-and-tested system provides technical settlement finality of exchange between cash and bond tokens. In Corda, finality occurs when notary signs against a transaction.
2. Transaction Privacy: Transactions are disseminated on a need-to-know basis and transaction parties' identities are maintained with multiple confidential identities generated by Corda node. Prior to disseminating the transaction, sensitive information is separated from instruction as part of the partial data visibility protocol.
3. System Resiliency: Under the Inthanon system, a scheduler is adopted to help automate key system's functionalities which will be automatically triggered at a predefined time by all involved nodes in the system.

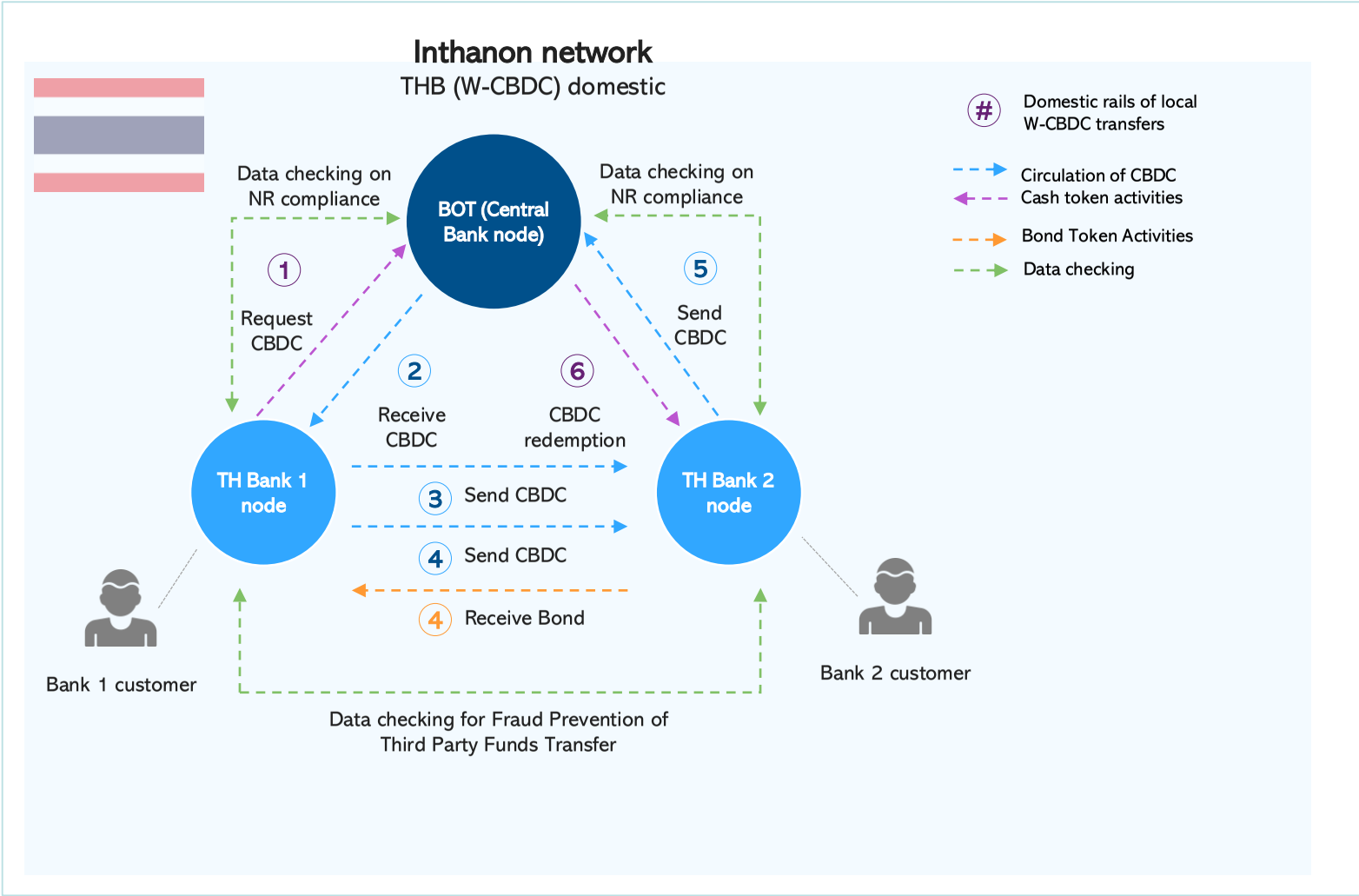


Figure 18 - Inthanon Network

9.2 Project LionRock

Notwithstanding the hypothesised benefits of wholesale CBDC applications, the industry would require answers to the perceived technical challenges of achieving proven scalability and efficiency, appropriate level of privacy, interoperability between platforms and successive generations, and forward compatibility of current designs with future platform upgrades.

Against this backdrop, the HKMA initiated Project LionRock as a proof-of-concept (PoC) study to carry out the research and validate the hypothesis, and to better understand the potential benefits and challenges of DLT towards reality through evaluations across technology factors, including:

1. How DLT compares with existing technology capabilities and what additional benefits it can bring to the financial ecosystem;
2. What significant advantages DLT capabilities can provide to financial use cases in comparison with prevalent existing technologies;
3. What are the key impediments to be addressed before the benefits of DLT can be realised for the financial market infrastructure.

9.2.1 Design Considerations of the CBDC Prototype

Issuance of CBDC could be accompanied with undesirable impacts on monetary and financial stability, thus demanding careful considerations to be made in designing the modalities of CBDC and its issuance mechanism. In order to balance between the benefits and risks, the PoC study is designed with a confined scope of application and eligible participants in mind, as reflected in the modalities of the CBDC prototype summarised in the table.

Modality	Features
Access	▪ Wholesale-focused: banks, non-bank financial institutions (NBFIs), large corporates
Remuneration	▪ zero interest
User anonymity	▪ user identities known ▪ transaction details known to transacting parties only
Continuity	▪ CBDC issuance and redemption at central bank limited to RTGS operating hours ▪ Transfer and payment settlement on a 24/7 basis
Quantitative limits	▪ Individual limits possibly imposed by banks
Technologies	▪ distributed ledger technology

The PoC study focuses on CBDC purely as a payment instrument for potential applications in securities settlement and cross-border payments, covering only wholesale participants (such as banks, non-bank financial institutions and large corporates), which fall into one of the two categories, namely banks which are existing participants of the RTGS, and non-banks which do not hold an account with the RTGS but are customers of the banks. The non-banks are registered as sponsored participants of the banks in the CBDC ecosystem, thereby retaining banks' role in serving their customers, doing KYC, and implementing features such as individual quantitative limits.

The prototype aims to serve as a foundation to assess the technical feasibility and implications of DLT for issuance and transfers of CBDC and other digital tokens, and to identify the elements required for further enhancements. Specifically, it builds a proposal for the CBDC and tokenised debt securities lifecycle models, including issuance, transfer/settlement and redemption of the two assets over the same DLT network. In other words, the prototype focuses on a value-based implementation of CBDC for it could achieve the aforementioned benefits (such as direct, real-time settlement) more directly and effectively. In addition, the prototype should demonstrate the feasibility of implementing a number of useful features on DLT, which include:

- Transaction-level DvP (delivery-versus-payment) settlement of the two assets (CBDC and tokenized debt securities) through which the two assets can be exchanged in a single DLT transaction;
- Coupon payment in CBDC for the tokenised CMU securities on DLT;
- Intraday repurchase agreements (repo) which allows CBDC issuance against EFBNs (Exchange Fund Bills and Notes which are Hong Kong dollar debt securities issued by the HKMA) held by a bank whenever the bank needs additional CBDC for inter-bank payment or fulfilment of customer requests;
- ISO 20022 messages embedded in transactions to enable better traceability of transactions and provide richer information for banks for better regulatory compliance.

9.2.2 Key Findings

Project LionRock consisted of two phases conducted in a successive manner. Phase A focused on assessing the potential benefits and challenges in CBDC issuance and the technical viability of DLT. Key findings of phase A include the following.

- Proved technical feasibility to interface DLT-based CBDC with RTGS safely
- Proved possible extension of access of central bank money to corporates without opening up access to RTGS
- Demonstrated benefits brought by DLT to CBDC include transaction traceability, security and resilience, and enablement of direct settlement on CB money between customers
- Revealed challenges concerning scalability and privacy issues

Phase B further evaluated the technical feasibility and suitability of implementing the lifecycle of EFBN and Hong Kong government bonds on the DLT network. Key findings of phase B include the following.

- Proved technically feasibility to tokenise EFBN and government bonds
- Validated operational benefits in automated intraday repo
- Discovered challenges in carrying out some corporate actions, e.g. coupon payments

Project LionRock has proven the feasibility of utilising DLT to conduct CBDC issuance and its atomic DvP transactions. The PoC shows that CBDC has the potential to reduce intermediaries and settlement layers in comparison to the traditional banking payments system. For example, payers can directly and immediately settle payments with their payees via CBDC in a DLT network as opposed to going through via RTGS intermediaries, including banks, involving multiple debit and credit account entries. The infrastructure for these direct payments further prevents double-spending with temporal transaction orders in place..

9.2.3 Way Forward

Last but not least, the study has identified that there are some potential benefits of applying DLT to CBDC in the area of cross-border payments. As a result, the HKMA then decided to take a next step to further explore expanding the functionalities of the PoC to include cross-border transactions and FX settlements.

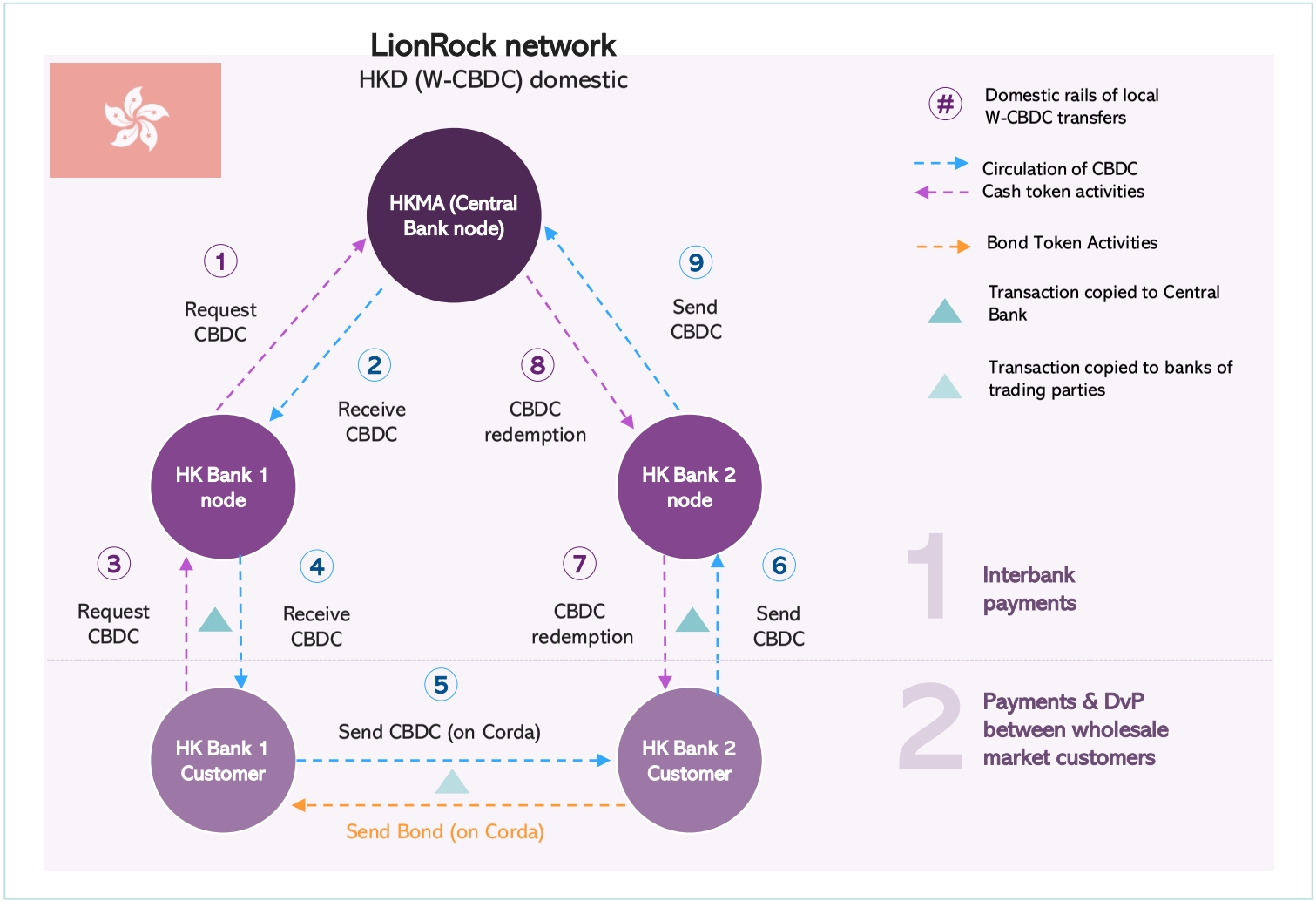


Figure 19 - LionRock Network

9.3 Cross-Border Models

9.3.1 Cross-participation models

Super-correspondent (via central banks)

- Each central bank has its own foreign account in the foreign RTGS network
- Each central bank acts as a correspondent bank to its RTGS member banks
- Member banks, which have a foreign currency account with the central bank, submit transaction instructions to their respective central bank when they need to transfer foreign funds in the foreign RTGS network
- The central bank in the foreign RTGS network will then carry out the transaction instructions

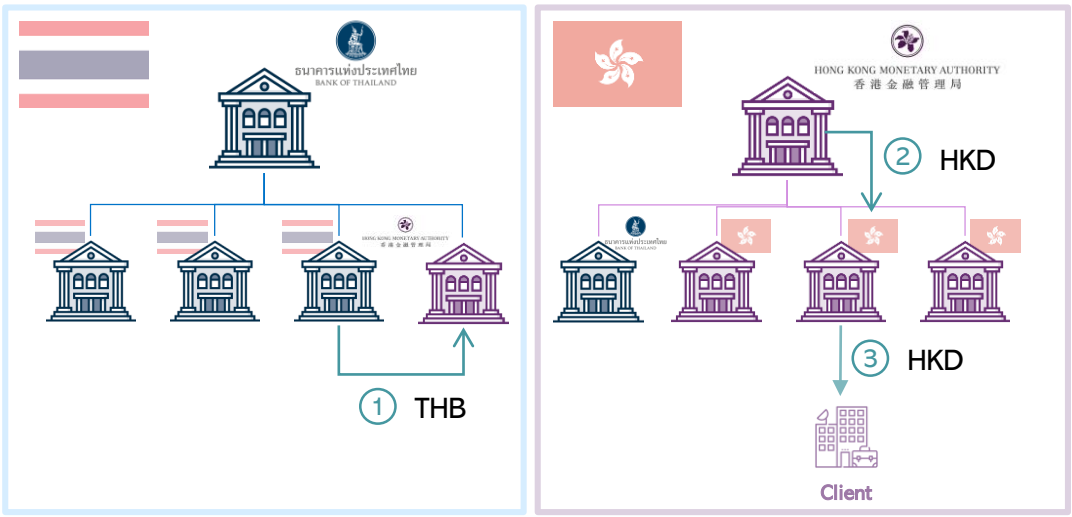


Figure 20 - Super-correspondent (via central banks) Model

Super-correspondent bank (via appointed commercial banks)

- An appointed commercial bank represents as the sole correspondent bank which has an account in the foreign RTGS network
- Member banks, which have a foreign currency account with the appointed bank, submit transaction instructions to their respective appointed bank when they need to transfer foreign funds in the foreign RTGS network
- The appointed bank in the foreign RTGS network will then carry out the transaction instructions

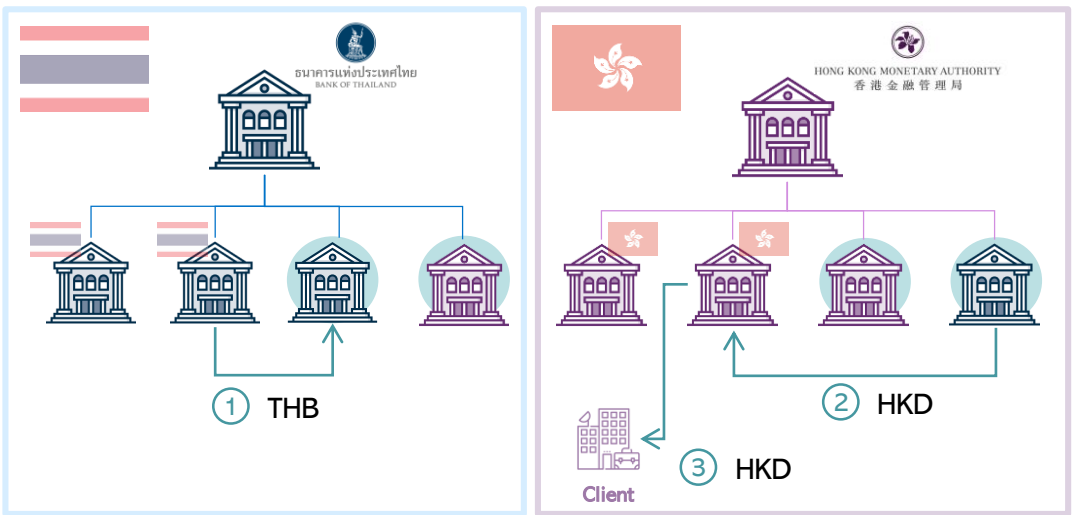


Figure 21 - Super-correspondent Bank (via appointed commercial banks) Model

Cross-participation

- Each and every RTGS allows qualified foreign banks to directly carry out transactions on a peer-to-peer basis without the need for a correspondent bank

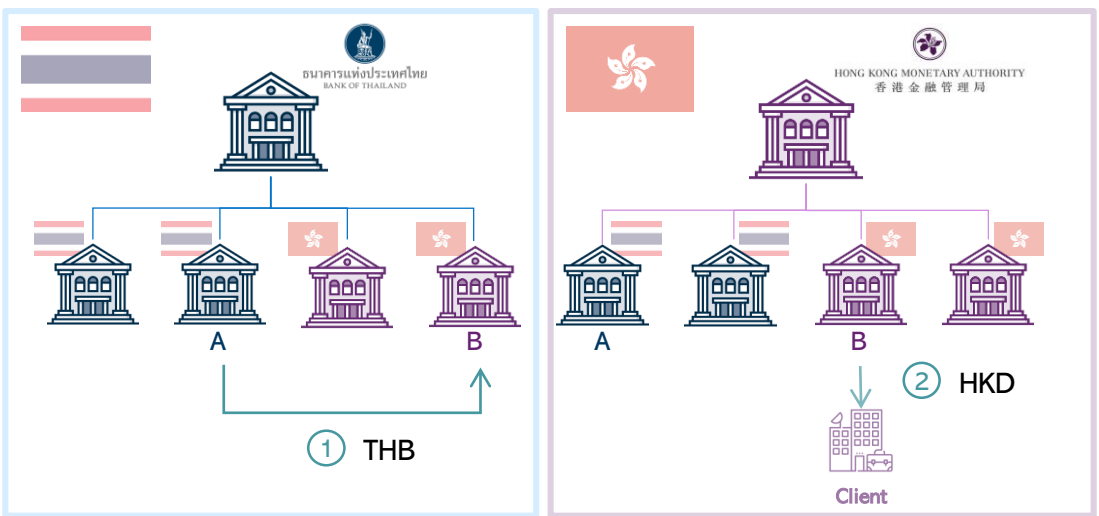


Figure 22 - Cross-participation Model

9.3.2 Asset expansion based models

Credit-based asset expansion

- Two central banks have mutual agreements enabling their RTGS members to hold and settle local and foreign currencies.
- To obtain foreign currency, the central banks will conduct the transactions through credit line or currency swap arrangements by having their local currencies serve as collaterals at the foreign central banks.
- With the connectivity of two RTGS, member banks can conduct foreign currency transactions via the local RTGS.

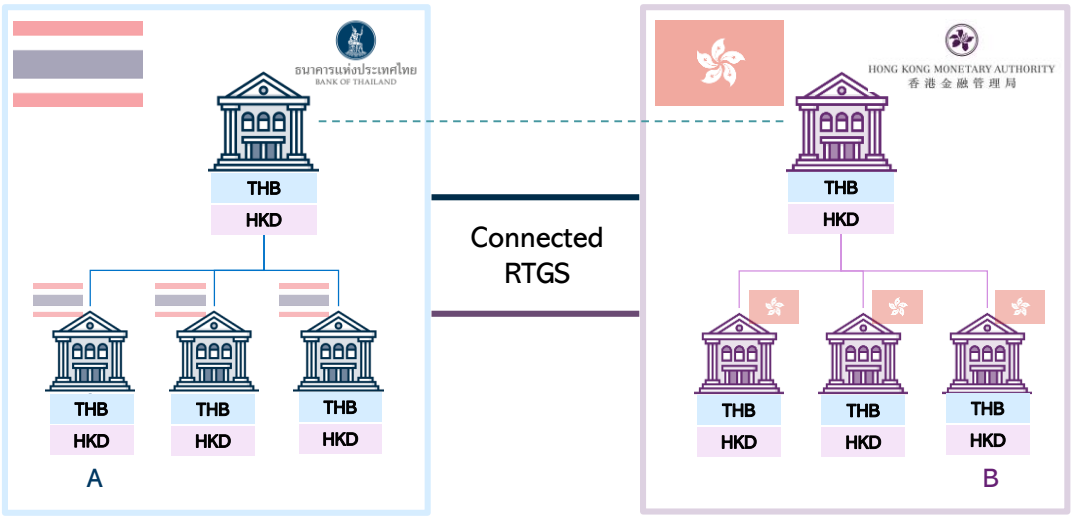


Figure 23 - Credit-based Asset Expansion Model

Full asset expansion

- All central banks agree to share one single RTGS platform where the settlement agent is an operator and all commercial banks are members.
- The platform is able to settle all currencies.
- The central banks act only as local currency issuers and do not conduct RTGS operations.
- Participating banks can conduct transactions in both local and foreign currencies.

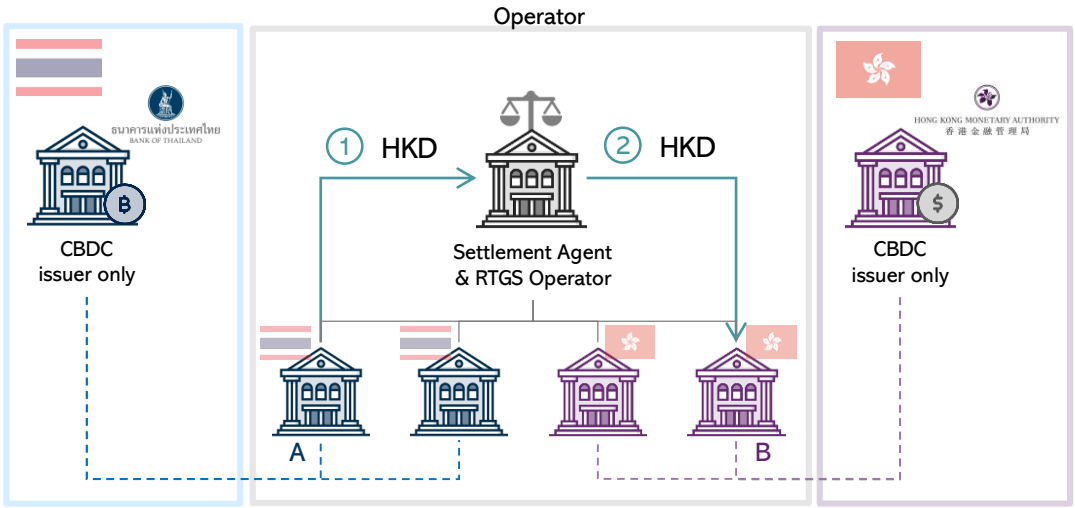


Figure 24 - Full Asset Expansion Model

Separated asset expansion

- Each central bank is an operator of its respective local RTGS in which local transactions are conducted.
- A segregated corridor is linked with each participating RTGS in order to conduct cross-border transactions.
- The settlement agent acts as the corridor operator.

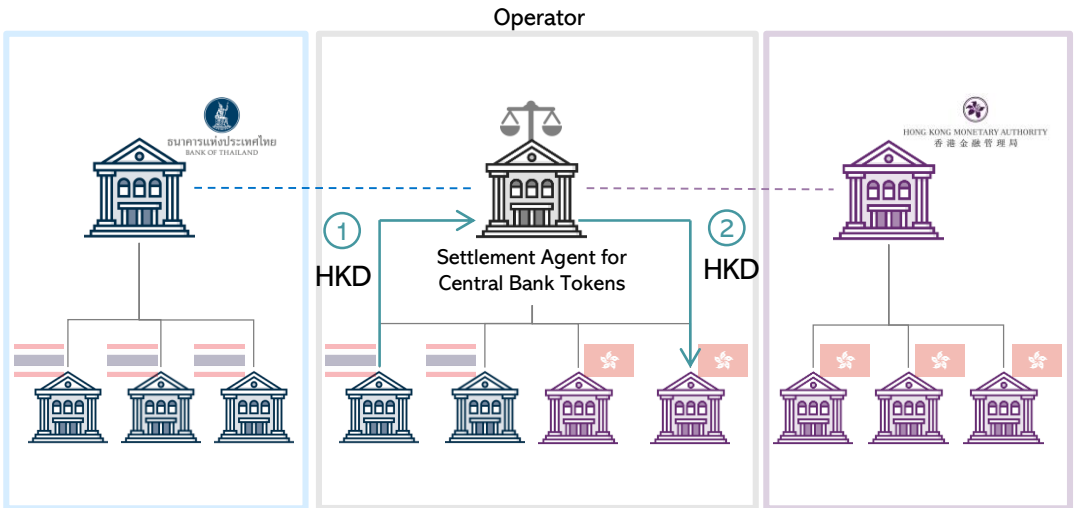


Figure 25 - Separated Asset Expansion Model

9.4 Additional Technical Information

9.4.1 Key Assumptions

- The segregated DLT-platform and corridor network is used strictly for cross-border and FX payments. It is completely independent of the domestic (i.e. the Inthanon and LionRock networks) in terms of payment processing scope. This is to align with the separation of domestic payment networks constraint.

- The corridor network is a DLT-based solution using Corda.

- Participation in the corridor network is technically independent from participation in the Inthanon and LionRock networks. Participating banks will run independent nodes on the corridor network, which are separated from those running on the domestic payment networks. While technically independent, in practice or by policy, participants in the corridor network should also participate in the domestic Inthanon or LionRock networks.

- Indirect access to CBDC tokens in the domestic Inthanon and LionRock networks is done through a special vehicle, namely depository receipt tokens (which represent claims against W-CBDC tokens on a domestic network), issued in the corridor network, so as to align with the no expansion of circulation constraint. Synchronisation between the corridor network and the domestic networks occurs through dedicated communication links between the operator node in the corridor network and the respective central bank nodes in the Inthanon and LionRock networks.

- All participants in the corridor network settle transactions in different currencies using DR-CBDC tokens directly and atomically, as well as to achieve FX settlements on a Payment-versus-Payment (PvP) basis. As such, existing challenges in the correspondent banking's nostro-vostro model could be addressed.

9.4.2 Technology Stacks for Central Bank and Participating Bank

The following diagram describes the technologies used for Inthanon-LionRock. Components in green can be replaced by more performant counterparts if necessary. The architecture is built on top of Project Inthanon by adding a new Corridor CorDapp and a new Token Conversion Orchestration module.

Technology Stack (Central Bank)

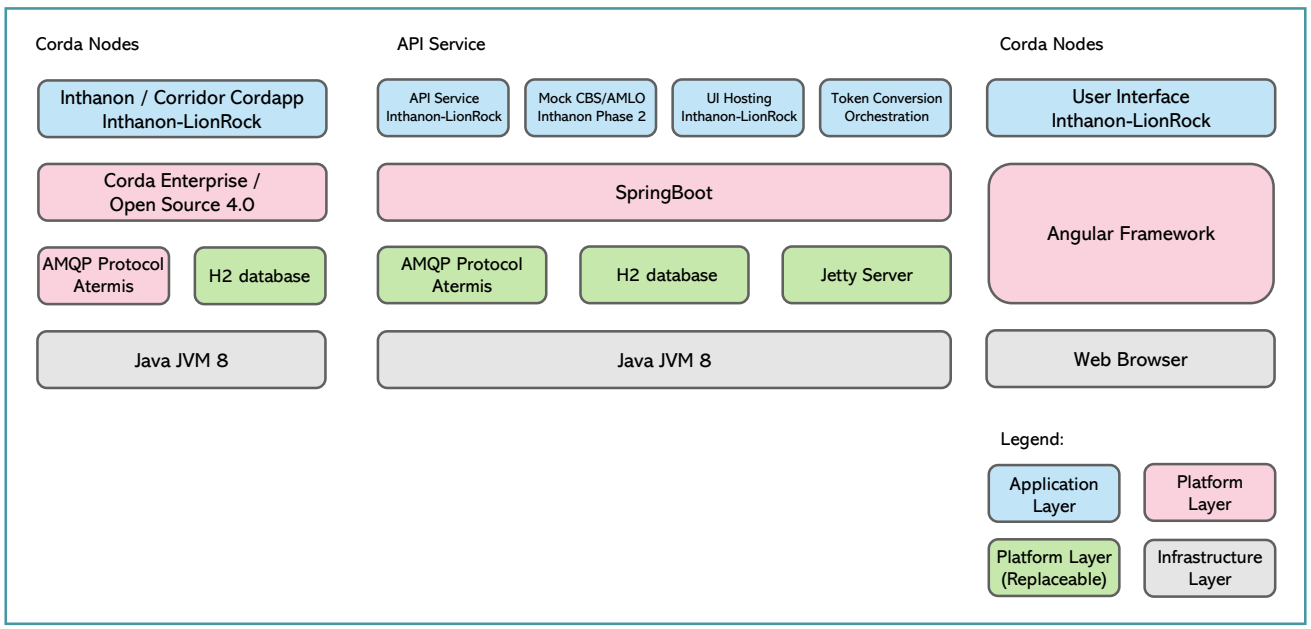


Figure 26 - Technology Stack (central bank)

The Corridor CorDapp is a new CorDapp which includes the smart contract and workflow for cross-border transfers and FX Overlay functionalities.

The Token Conversion Orchestration is a new API module for the central banks to coordinate the flow of converting a domestic wholesale Central Bank Digital Currency (i.e. W-CDBC) token to a depository receipt (i.e. DR-CBDC) token.

Technology Stack (Participating Bank)

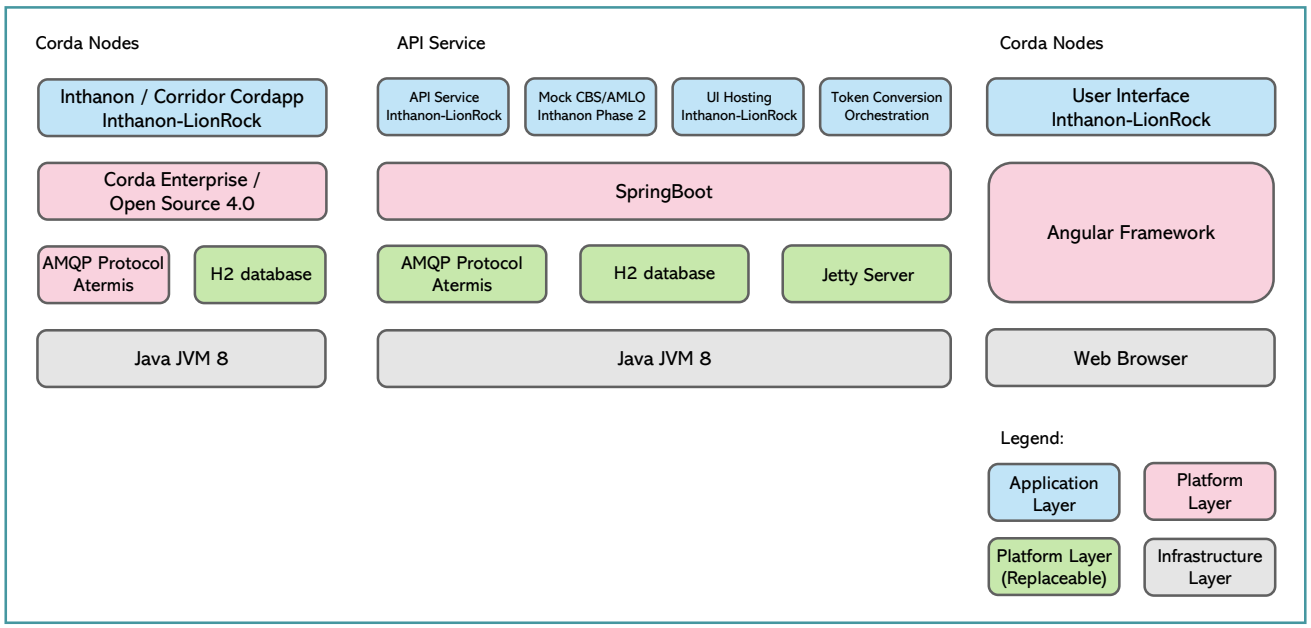


Figure 27 - Technology Stack (participating bank)

The Corridor CorDapp is a new CorDapp which includes the smart contract and workflow for cross-border transfers and FX Overlay functionalities.

The token conversion request is handled by the API service. The API will trigger the Corda flow to request for token conversion by the central bank nodes.

9.4.3 Cross-Border Payment with Embedded FX Execution

FX Overlay enables the overlaying of FX trades over cross-border transfers to achieve PvP, in where one can only be settled if and only if another also settles. Such transfers can be coupled with FX trades from Board Rate and 3rd Party Agreements.

The overlay is represented by three respective smart contracts: Cross-border Payment, FX Trading and the chosen FX trade method. Three parties are involved in this trade: sender of transfer, receiver of transfer and provider of FX. When both paying ends have sufficient funds, the smart contracts move in the same transaction to statuses representing a completed settlement.

In order to transfer funds atomically amongst the three parties, the number of transactions will have to be reduced from 3 to 2, as shown in the diagram below:

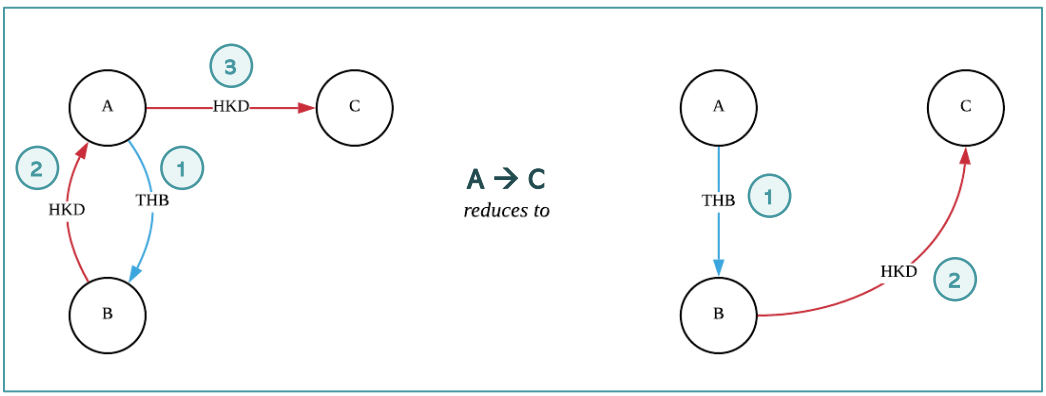


Figure 28 - Illustration of FX settlement flow

As a result, ownership of funds by B only changes hands once. Furthermore, privacy consideration of C's identity in the two trades, A to B and A to C, can be alleviated by assigning an anonymous identity of C as the new owner of B's assets.

Flow

One flow per FX trade method is developed. The flows determine whether both parties have sufficient funds - in Figure 28, we check whether *A* has sufficient THB, and B has sufficient HKD. Party A then instructs B to credit the HKD to an anonymous identity of C. Since only A recognises the identities used for both trades, A must always facilitate such transactions. As a result, all smart contracts are synced.

In an FX transaction with an FX Board Rate, the manual process of retrieving the best board rate would be required before executing the transaction. This differs from the original workflow of FX board rate.

10 Acknowledgements

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TH Participating Banks

Bangkok Bank Public Co. Ltd.

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Krung Thai Bank Public Co. Ltd.

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Bank of Ayudhya Public Co. Ltd.

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TH Participating Banks

Kasikornbank Public Co. Ltd.

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