INTHANON

PHASE 2

BANK OF THAILAND

Enhancing Bond Lifecycle Functionalities & Programmable Compliance Using Distributed Ledger Technology

FOREWORD

Technology advancement is continuing on a path of rapid acceleration, impacting our lives, experiences, industries, and global economies. Through digitalisation and the harnessing of data, breakthroughs have been made across a myriad of fields and applications. Today, the synergy of Internet-of-Things, Artificial Intelligence and robotics are applied to automate complex activities in many operations. These transformative forces are also re-shaping the financial services industry and challenging traditional business models.

The Bank of Thailand (BOT) plays a crucial role in supporting Thailand's long-term competitiveness, and one role is to foster financial technologies that will help Thailand's financial sector transform into a new digital era. Project Inthanon is one of the key initiatives where the BOT catalyses an industry-wide effort to innovate digitally by bringing together eight leading financial institutions in Thailand, along with technology partner R3 to collaborate, explore and assess the potentials and applications of Distributed Ledger Technology (DLT) for financial infrastructure.

The first phase of Project Inthanon started in August 2018, focused on developing a Proof-of-Concept decentralized Real-Time Gross Settlement system (RTGS) that uses wholesale Central Bank Digital Currency (CBDC) on a distributed ledger. The study successfully demonstrated the technical feasibility of such a DLT-based payment infrastructure, both in terms of achieving current basic payment functionalities as well as delivering new capabilities that could enhance payment efficiency and expand operational scope. The study also highlighted the further steps required to meet international payment standards, as well as areas where technology needs to mature further.

In February 2019, the second phase of Project Inthanon was initiated to further explore how DLT can be used to extend new functional capabilities. Two areas of interest were explored, the first is the tokenisation of BOT-issued debt instruments on a distributed ledger to achieve their life-cycle activities and delivery-versus-payment settlement. The second is the incorporation of regulatory compliance and data reconciliation functionalities into the payment process on a distributed ledger, so as to improve process efficiency and mitigate operational and compliance risks. The outcomes of this study are very promising as we are able to streamline and automate existing processes through the use of workflows driven by smart contracts.

Throughout the Project Inthanon journey to date, the collaborative approach of involving different stakeholders has helped bring technology and innovation to tackle real business challenges. More importantly, through collaboration, we have fostered a community of DLT industry practitioners and promoted technological readiness amongst the participants. We believe Project Inthanon will encourage other financial institutions to further experiment and develop DLT for other use cases.

Finally, the BOT would like to extend our appreciation towards the eight participating banks, especially to the members of the development team as well as to our technology partner R3 who contributed to the successful journey of Project Inthanon Phase 2 and the completion of this report. We hope that this report will provide insights into DLT use cases for the Thai financial sector and we strongly believe that the outcomes from both Phase 1 and 2 have laid a strong foundation for our next exploration of cross-border payments in Phase 3, and any other developments of DLT for Thailand's financial sector.

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PUSHING THE FRONTIERS OF DISTRIBUTED LEDGER TECHNOLOGY

INTHANON PHASE 2 – ENHANCING FUNCTIONALITIES

CONTENTS

POSITIONING THE THAI FINANCIAL SERVICES INDUSTRY AT THE FOREFRONT OF THE DLT REVOLUTION

01 EXECUTIVE SUMMARY

Project Inthanon is a collaborative effort initiated by the Bank of Thailand and a consortium of industry partners to explore Distributed Ledger Technology and its potential applications to enhance Thailand's domestic financial market infrastructures.

The BOT as the regulator and operator of the Thai financial market infrastructures in collaboration with leading industry participants consisting of 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, along with technology partner R3, were brought together to develop the blueprint for the Thailand's financial market infrastructures for the future.

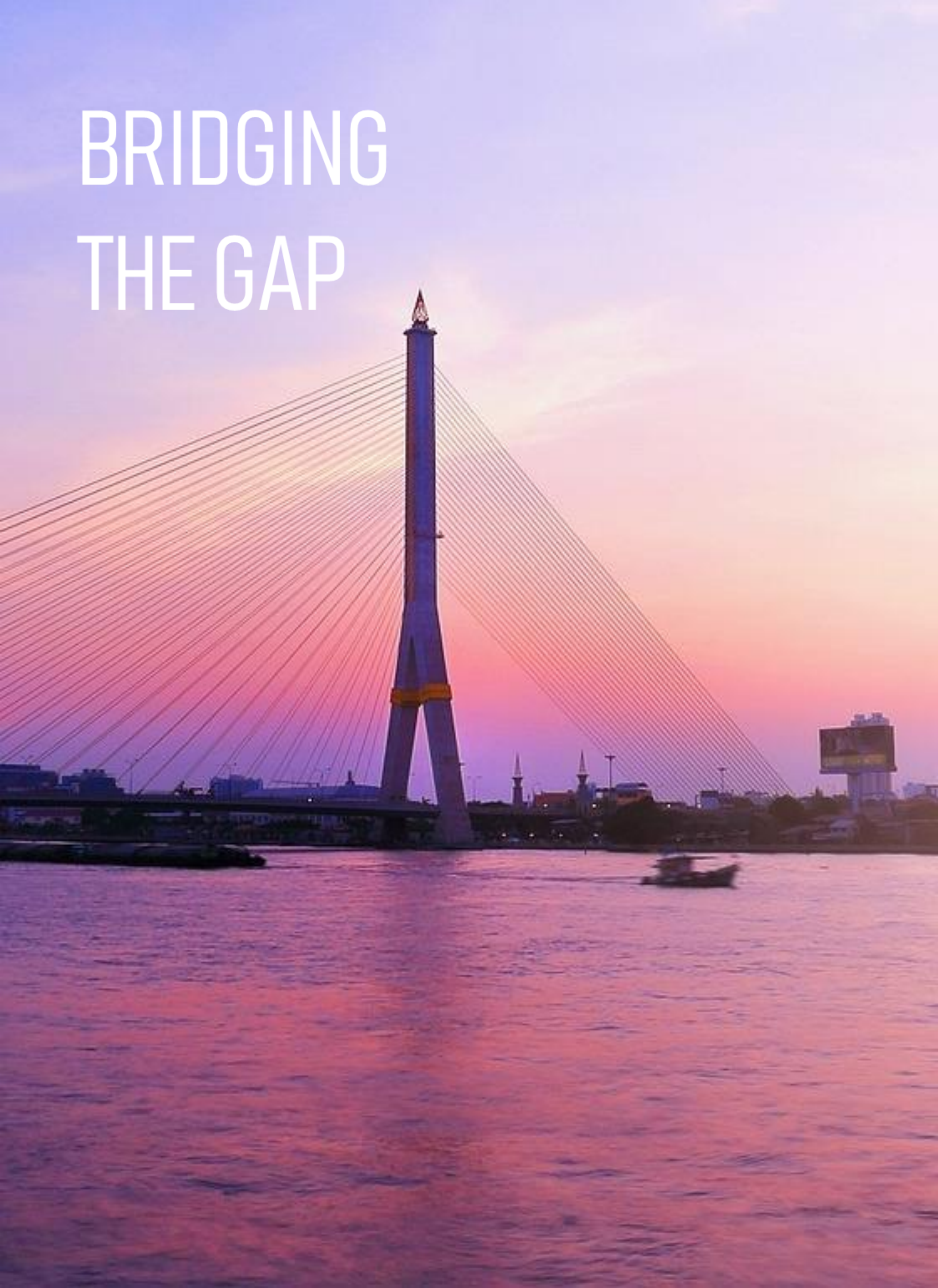
Phase 1 of Project Inthanon concluded in January 2019, successfully delivering a Corda-based proof-of-concept (POC) that demonstrated a decentralised Real-Time Gross Settlement system (RTGS) design that is resilient, efficient and integrated with an innovative Gridlock Resolution (GR) architecture.

Launched in February 2019, Phase 2 aimed at enhancing the earlier POC with extended capabilities related to the tokenisation of bonds, automation of bond life cycle events using smart contracts, and implementation of a decentralised delivery-versus-payment (DvP) mechanism for the BOT bonds settlement in interbank market trading and repurchase agreement (repo). These new capabilities offer a view of how the future DLT-based financial market infrastructure could operate and help enhance post-trade operational efficiency. Additionally, the network participants could gain higher efficiency of liquidity usage from the newly designed Multi-Asset Liquidity Saving Mechanism (MLSM).

In addition, the applicability of DLT for data reconciliation and non-resident (NR) regulatory compliance within the funds transfer process was explored. The transactional workflow relating to third-party funds transfer was redesigned by incorporating fraud prevention mechanism. Moreover, an automated pre-matching of account balance forecasting engine was employed to facilitate the banks' regulatory compliance. These capabilities prove to help strengthen pre-settlement validation and reduce the likelihood of erroneous transactions and failed payments due to information mismatches. Also, it allows the banks to adopt a proactive compliance process by using analytics-driven forecasts and alerts to mitigate potential breaches. As the process is integrated into the funds transfer workflow, the banks can also enhance operational efficiency through the streamlining and automation of tasks.

With the successful conclusion of Phase 2, we will be transitioning to Phase 3, where the focus will be shifted to cross-border payments and exploration of potential design for a payment network that enables Payment-versus-Payment (PvP) of Thai Baht (THB) and other foreign currencies.

BRIDGING THE GAP



FOSTERING INNOVATION & EXPLORING POTENTIAL DLT APPLICATIONS

02 PROJECT OVERVIEW

> Project Inthanon was initiated with the vision of creating a collaborative environment for Thai financial services industry players to foster innovation and gain a better understanding of the characteristics of DLT through hands-on experience.

2.1 INTRODUCTION

Project Inthanon was devided into three progressive phases, each leveraging on the findings and learnings of the previous phase:

01

Phase 1 – Building the Fundamental

A POC for a DLT-based RTGS using wholesale CBDC for interbank settlement was built. A key highlight was the development of an innovative GR architecture with integrated Automated Liquidity Provision (ALP) functionality that achieved privacy and atomicity properties.

02

Phase 2 – Enhancing Functionalities

The objective is to build on the Phase 1 POC and augment it with additional functions to handle DvP settlement for interbank bond repo & trading, data reconciliation and handling of NR regulatory requirements. Outcomes from Phase 2 demonstrate the practicality of DLT at enabling transformative process improvement and technical feasibility of achieving DvP in real-time through an experimental MLSM.

03

Phase 3 – Exploring Cross-Border Funds Transfer Models

The DLT-based RTGS prototype will be expanded to connect with the other systems to support cross-border funds transfer transactions. The scope will also cover the regulatory and compliance issues from both THB and foreign currencies.

OVERVIEW OF INTHANON ROADMAP

The current objective is to build upon developments in Phase 1 and enhance the functionalities to cover other key areas of the financial system.

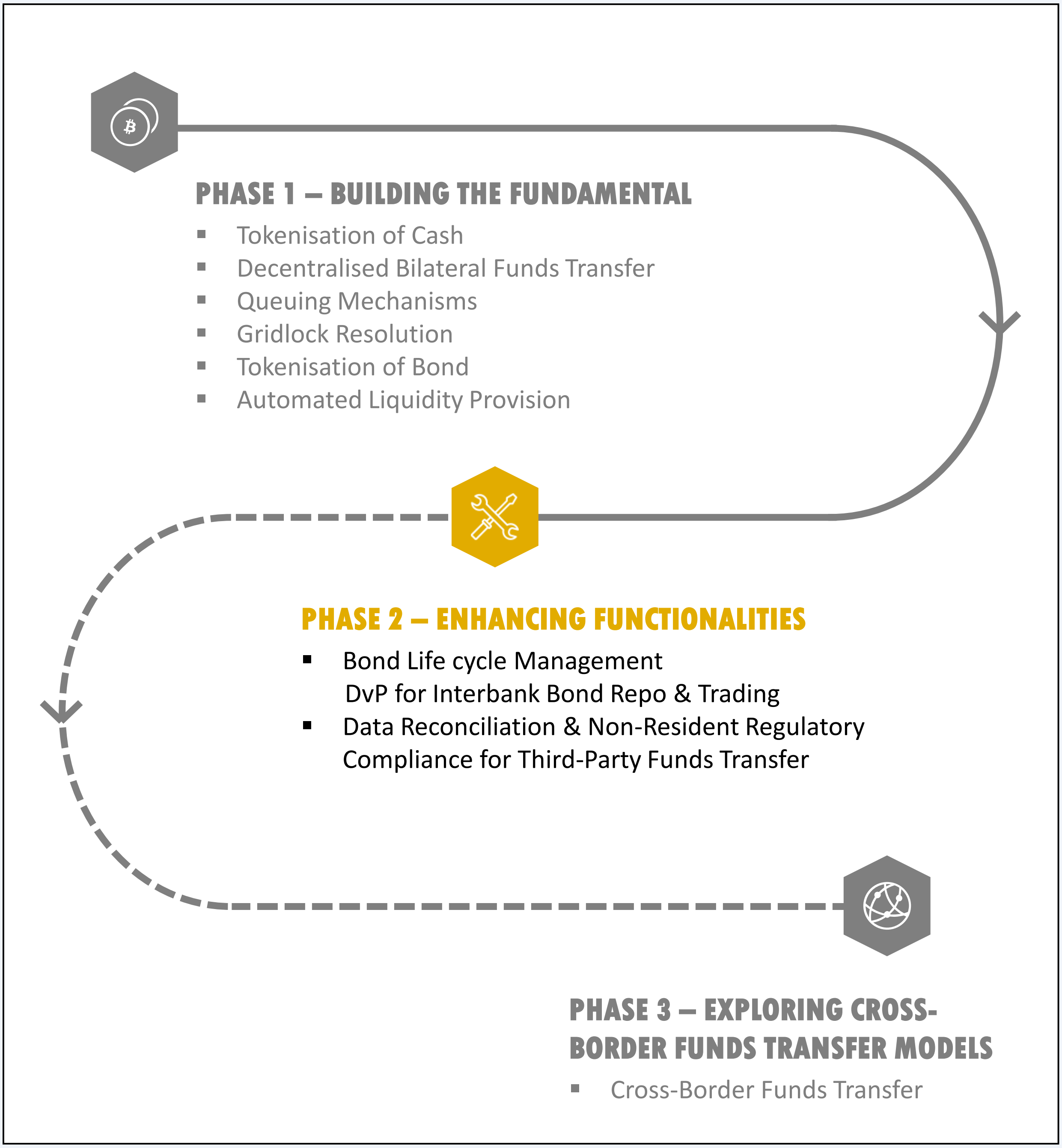


Figure 1: Roadmap detailing the objectives of the 3 phases in Project Inthanon

2.2 HIGHLIGHTS OF PHASE 1 POC[1]

Building on lessons learnt from other CBDC projects, we took an approach of designing and building an infrastructure that enabled a novel GR mechanism suited for Thailand's interbank large-value funds transfer in Project Inthanon Phase 1. The solutions sought to help players address key issues and inefficiencies faced in the current local financial market.

Exploration of Interbank Payment: Tokenisation of Cash, Decentralised Bilateral Funds Transfer and Queueing Mechanism

A decentralised payment network was set up with the BOT node and participating bank nodes. The BOT node had sole capability to issue and destroy Thai Baht (THB) cash tokens on the network. Other participating nodes were entitled to convert their RTGS balance into cash tokens and to use such tokens to make payments to other nodes. A notary service would ensure no double-spending of cash tokens in transactions and established deterministic settlement finality and irrevocability to a decentralised payment network.

Participating nodes could also set priorities[2] to their queued outgoing payment obligations to meet business and operational needs when they encounter temporary liquidity insufficiency for payment settlement.

Enhanced Gridlock Resolution (GR) Architecture

Enhancements to previous models were made with the breakthrough in GR architecture that was able to provide both privacy and atomicity properties. The Inthanon team redesigned the GR process to include both centralised and decentralised features in the Liquidity-Saving Mechanism (LSM). An LSM oracle node retained centralised calculation of the GR, while the settlement process was executed by participating nodes in a decentralised manner. This resolved the inherent privacy issues of a decentralised GR process and provided participating nodes with full anonymity during the GR process.

Tokenisation of Bond and Automated Liquidity Provision (ALP)

Another innovative solution explored in Phase 1 was the addition of bond tokens in the DLT-based RTGS system.

One of the most significant benefits of having a multi-asset platform was the enabling of ALP functionality to be introduced. By pledging bond tokens for CBDC with the BOT, banks could obtain additional liquidity through the ALP function to meet urgent payment obligations and resolve deadlocks.

The introduction of bond tokens and the ALP process also allowed banks to increase the efficiency of bond usage and reduce the opportunity cost of holding eligible bonds with the BOT to facilitate Intraday Liquidity Facilities (ILF) in the current BAHTNET system.

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[1] Readers are advised to consult Project Inthanon Phase 1 report for further details - https://www.bot.or.th/English/FinancialMarkets/ProjectInthanon/Documents/Inthanon_Phase1_Report.pdf

[2] For priority rules defined in Phase 1, please see Section 9.1 in the Appendix.

2.3 PHASE 2 OBJECTIVES

In Phase 2, we will explore the applicability of smart contracts for automating bond life cycle events, facilitating third-party funds transfer and enhancing the monitoring of regulatory compliance activities.

The functional objectives of Phase 2 includes (1) the viability of an integrated cash RTGS with the BOT bonds DvP on DLT with extended tokenisation of bonds and (2) the integration of regulatory compliance functionalities into the DLT workflow for funds transfer.

Additionally, three non-functional objectives, including finality, privacy and resiliency have been identified as key considerations during the solution design and development.

FUNCTIONAL OBJECTIVES

DvP for Interbank Repo & Trading of Bonds

- Ensuring DvP settlement for interbank bond repo & trading transactions
- Utilising smart contracts for modelling bond life cycle, including coupon calculation, coupon payment and repo margining
- Enhancing post-trade processing efficiency

Third-Party Payment Integration & Regulatory Compliance

- Exploring regulatory compliance related to third-party funds transfer
- Improving transaction transparency and prevention of certain types of fraud
- Ensuring compliance with Non-resident Baht Account (NRBA) / Non-resident Baht Account for Securities (NRBS) limits and regulations

Regulatory Compliance on NRBA and NRBS

Under the current foreign exchange regulation, non-residents (NRs) can open two types of THB account which are Non-Resident Baht Account (NRBA) and Non-Resident Baht Account for Securities (NRBS). NRBA shall be used for general purposes (excluding portfolio investment activities) such as trade, services, lending or direct investment activities in Thailand, while NRBS shall be used solely for investment activities in financial instruments in Thailand such as equity and debt securities. End-of-day balance limit and overdraft outstanding limit[3] are imposed on NRBA and NRBS. The purpose of such regulation is to maintain the stability of the exchange rate by limiting the degree of speculation on Thai baht.

NON-FUNCTIONAL OBJECTIVES

Settlement Finality

- Recognising change of asset ownership when a transaction takes place
- Creating an immutable record of transaction

System Resiliency

- Ensuring the system remains operational and transactions can still occur when individual nodes become incapacitated or fail

Transaction Privacy

- Ensuring that business sensitive data is anonymised where necessary and only disclosed to relevant parties on a need-to-know basis

[3] Amount limit, counted per group of NRs by each financial institution, are placed on transactions made with THB borrowings without underlying trade and investment in Thailand, including overdraft by NRs from onshore financial institutions.

2.4 PHASE 2 ARCHITECTURAL DESIGN

In Phase 2, we have successfully developed, deployed, tested and conducted POC trials for the infrastructure required for interbank bond repo & trading, third-party payment integration and regulatory compliance.

The core components of the system's architectural design remain largely unchanged from Phase 1. However, some functions are added to the BOT and the participating nodes to support the broader functions offered in Phase 2.

For example, the BOT/Oracle node is responsible for providing the MLSM and running the Non-Resident Forecasting System (NRFS) functionalities[4].

The participating nodes in Phase 2 are required to run the scheduler to ensure the execution of payment transactions related to bonds.

OVERVIEW OF ARCHITECTURAL DESIGN

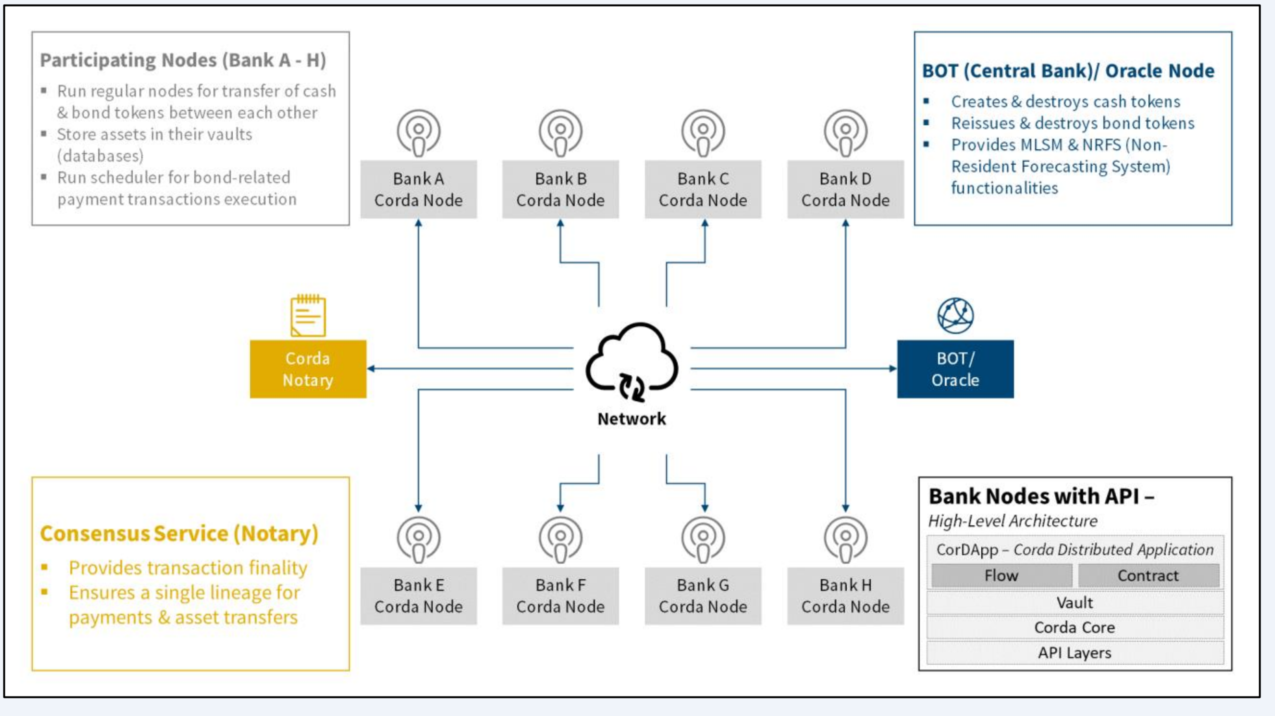


Figure 2: High-level representation of the system architectural design used in Phase 2. The design includes the BOT/Oracle node, the participating bank nodes and a Corda Notary node that provides the consensus service.

[4] For further details on the Non-Resident Forecasting System (NRFS), please see Section 4.3 Functional Design.

“ENHANCING BOND TOKEN FUNCTIONALITIES TO ENABLE MORE COMPLEX USE CASES

03 DVP FOR INTERBANK BOND REPO & TRADING

> In this section, we cover the first objective of Phase 2 – achieving DvP for interbank bond repo and trading. We seek to expand beyond the proven DvP models explored in other central bank projects previously.

3.1 BACKGROUND

Models for DLT-Based DvP

Prior to the design of the DLT-based DvP mechanism, the review of previling studies by other central banks on modelling of DLT-based DVP has been conducted, most notably Phase 2 of Project Stella, Phase 3 of Project Jasper and Phase 3 of Project Ubin.

- Project Stella (Phase 2) set out the basic DLT-based DvP models and provided comparative findings between the two models of single-ledger DvP and cross-ledger DvP without any connection between individual ledgers using Hashed Time Lock Contract (HTLC) technique.
- Project Jasper (Phase 3) investigated the single-ledger model based on a layered architecture, which proved the feasibility of DvP through loose-coupling between two independent securities and cash settlement systems.
- Project Ubin (Phase 3) built on Stella's experimentation with HTLC but focused on testing the technique's maturity across different combinations of DLT platforms. The project also further developed different arbitration and resolution models for dispute scenarios that may arise with HTLC.

Integrated Single-Ledger Model

The solution built in Phase 2 places emphasis on incorporating a wider functional scope that demonstrates potential innovations in liquidity management and bonds post-trade processing services.

In Project Inthanon Phase 2, we have adopted an integrated single-ledger model that represents a unification of traditionally separate cash settlement system (RTGS) and securities settlement system (SSS). Under this model, cash and securities are recorded on the same ledger and transactions involving both cash and securities are processed as a single transaction. This offers significant benefits of liquidity economisation from shortening asset-locking period and enhancing efficiency of MLSM. With this design, the liquidity performance proves prominence amongst other cross-ledger models.

DLT-BASED DVP MODELS

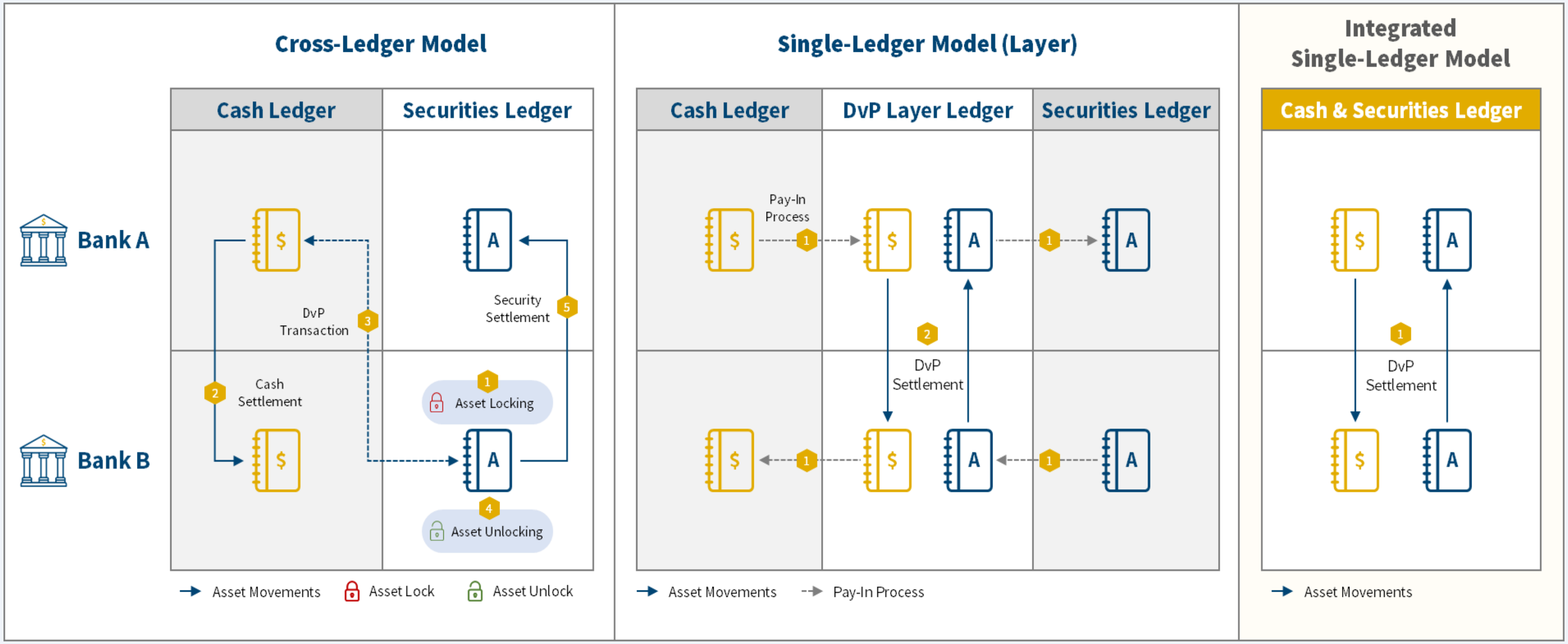


Figure 3: Schematic representations of DLT-based DVP models. (Left) Illustrates the cross-ledger model where cash and securities are recorded in different ledgers. DvP in a cross-ledger model requires the transfer of assets on the different ledgers to be coordinated, typically involving an asset lock on the securities. The implementation of the coordination (steps 1 to 4) may be achieved through the mechanism of hashed time-locked contract (HTLC) or more traditional integration. (Middle) Illustrates a single-ledger through a DvP layer ledger. In this model, DvP happens on DvP layer ledger (in the same platform) that needs to be initiated through some form of pay-in from the cash or securities ledger. (Right) Illustrates the integrated single-ledger model which is adopted in Project Inthanon Phase 2. In this model, both cash and securities are recorded on the same ledger hence allowing atomic DvP between the two types of asset to happen directly on the ledger without needing a separate DvP layer.

3.2 SCOPE

We have investigated the feasibility of utilising smart contracts for the DVP settlement process and modelling bond life cycle events to automate activities such as coupon payment and repo margin management.

Broadly speaking, there are three key areas of functional development to achieve the objective of DvP for interbank repo and trading of bonds:

1. Bond Tokens & Wallets

Bond tokenisation with DvP was first explored in Project Inthanon Phase 1 to enable the implementation of the ALP functionality. In Phase 2, the tokenisation model is improved with the use of smart contracts.

The new model also allows straight-through processing of bond trading with a wider range of transaction and assets types e.g. asset swaps, securities borrowing and lending.

To facilitate banks in managing their bond tokens, three different wallets for ALP, repo, and trading purposes are created for each bank. While bond tokens (of the same issue) are fungible and equally usable for ALP, repo or trading purposes, the 3 wallets are separated to reflect a segregated settlement accounts model. Banks may manage their wallets flexibly by allocating tokens between the wallets. During settlement, the token will be selected and drawn from only the wallet corresponding to the specific transaction type (ALP, repo and outright trade).

2. Automation of Bond Life cycle Events & Post-Trade Processes

Apart from allowing comprehensive structures of bond and related transactions to be accurately modelled, using smart contracts together with schedulers helps automate bond life cycle events such as coupon calculation, coupon payment, bond redemption, bond repo coupon transfer, bond repo margining and DvP settlement.

3. Bond Gridlock Resolution

An integrated cash-bonds GR architecture, also known as Multi-Asset Liquidity Saving Mechanism (MLSM), is a key functional component in Phase 2’s POC. It is an extension from Phase 1's LSM architecture to holistic gridlocks solution combining set of cash and bonds settlements.

3.3 FUNCTIONAL DESIGN

After assessing the available DLT-based DvP models and the scope set out in Phase 2, the integrated single-ledger model is chosen for its ability to transact cash and bonds on a single ledger in an atomic manner.

Based on the integrated single-ledger model, our design premise is to build an asset, transaction and workflow model that most effectively encapsulates the end-to-end processing and life cycle management relating to the interbank repos and trading on BOT-issued bonds.

Single-Ledger and Separate Bond Token Wallets Design

The integrated single-ledger model records both cash and bonds on the same ledger using Corda's native unspent transaction output (UTXO) model that is able to achieve DvP through an atomic transaction to swap cash and bonds.

While bond tokens are recorded on a single-ledger, three separate wallets are set up to partition and hold the tokens for different usages – ALP, repo, and trading – this mapping is implemented through a token level identifier.

Tokens may be moved between wallets through the allocation operation by the token owner that modifies the wallet identifier on the token and enforces a quantity check. The appropriate usage of a token is assured through token selection constraint when the transaction type - ALP, repo and trading - is constructed.

Modelling Assets, Transactions & Workflows

1. Asset & Transaction Modelling

The BOT bonds are tokenised as tokens that represent fungible assets and modelled using smart contracts to automate coupon payments and final maturity. Bond tokens can be traded and repurchased between entities through an ownership transfer. To fully operate a repo life cycle, the smart contract generates daily scheduled events as part of the margin process.

BOND LIFE CYCLE ILLUSTRATION

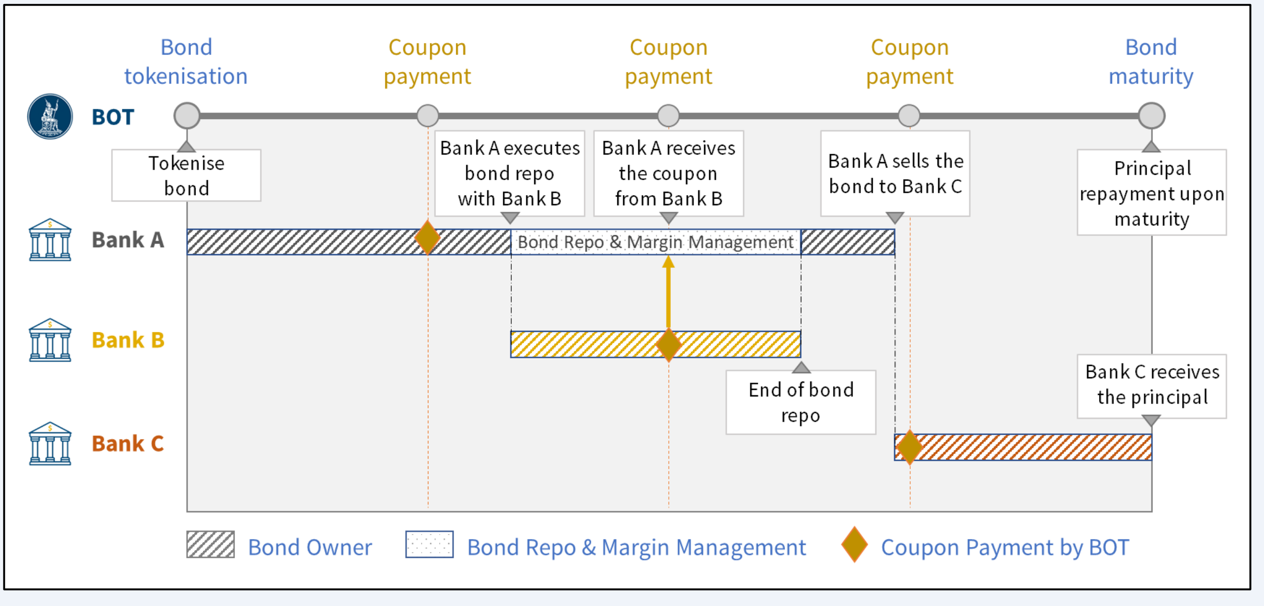


Figure 4: An illustration of the BOT bond life cycle, which shows that after the BOT bond has been issued and tokenised in Inthanon network, Bank A , an owner of the bond, receives the first coupon payment. Bank A can also execute bond repo with Bank B with arranged margin management noted in the repo agreement, and the ownership of bond is then transferred to Bank B. On the second coupon payment date, Bank B receives the coupon and passes it to Bank A, the original owner of a bond according to the repo agreement. The bond is returned to Bank A after the repo period ends. Some day before the 3rd coupon payment, Bank A sells the bond to Bank C, thus on the third coupon payment date, Bank C receives the coupon from the BOT. Bank C holds the bond until the maturity date, and receives the principal.

2. Transaction Workflow Modelling

After bond buyer (Bank A) and bond seller (Bank B) mutually agree on the bond trades/repos, Bank A initiates an instruction on the DLT system. Such instruction includes both bond and cash leg in one transaction. Then, Bank A and Bank B check cash and bond sufficiency. In case of sufficiency, Bank A and Bank B briefly lock cash and bond for settlement. Subsequently, the notary checks double-spending and signs the transaction. At this step, the single DvP transaction settles in an atomic manner.

TRANSACTION PROCESS FLOW

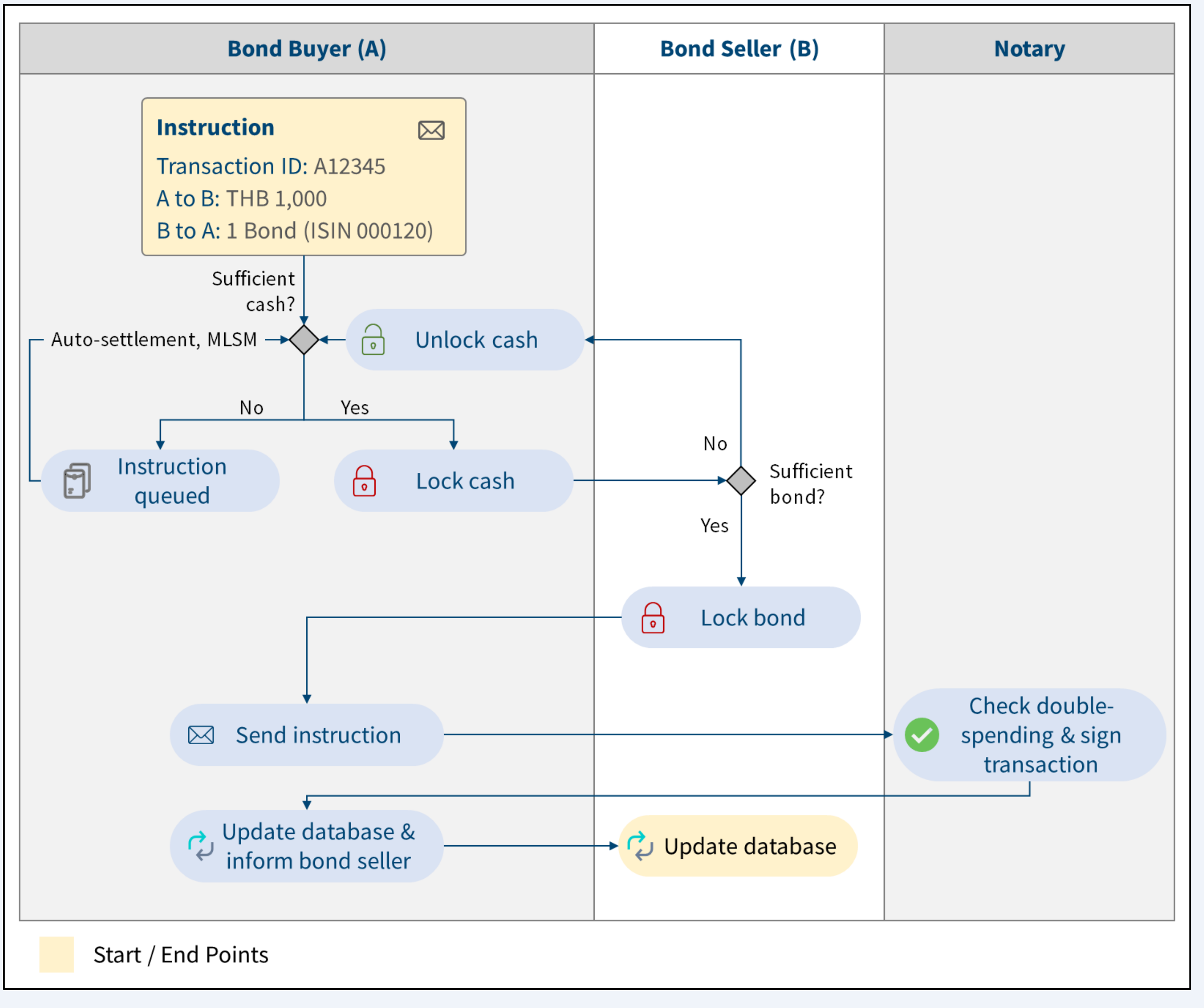


Figure 5: Workflow of transaction process performed on single-ledger DvP.

3. Margin & Coupon Process Workflow

A decentralised margin process is integrated into the overall DvP architecture as an extended post-trade processing functionality by utilising smart contracts and schedulers. The margin process is initiated by each participating node. A net margining mechanism collates margin calculation inputs which are ongoing repo contracts of any individual counterparty, margin threshold, prices of bond tokens posted as collateral. A margin call is then issued by a margin payee to a margin payer to review and confirm for subsequent settlement.

Apart from the margin process, smart contracts and schedulers are also adopted for coupon payment. The coupon is paid by the BOT on coupon payment date to bondholders. Additionally, the smart contacts are designed to support coupon passing between repo parties.

MARGIN WORKFLOW

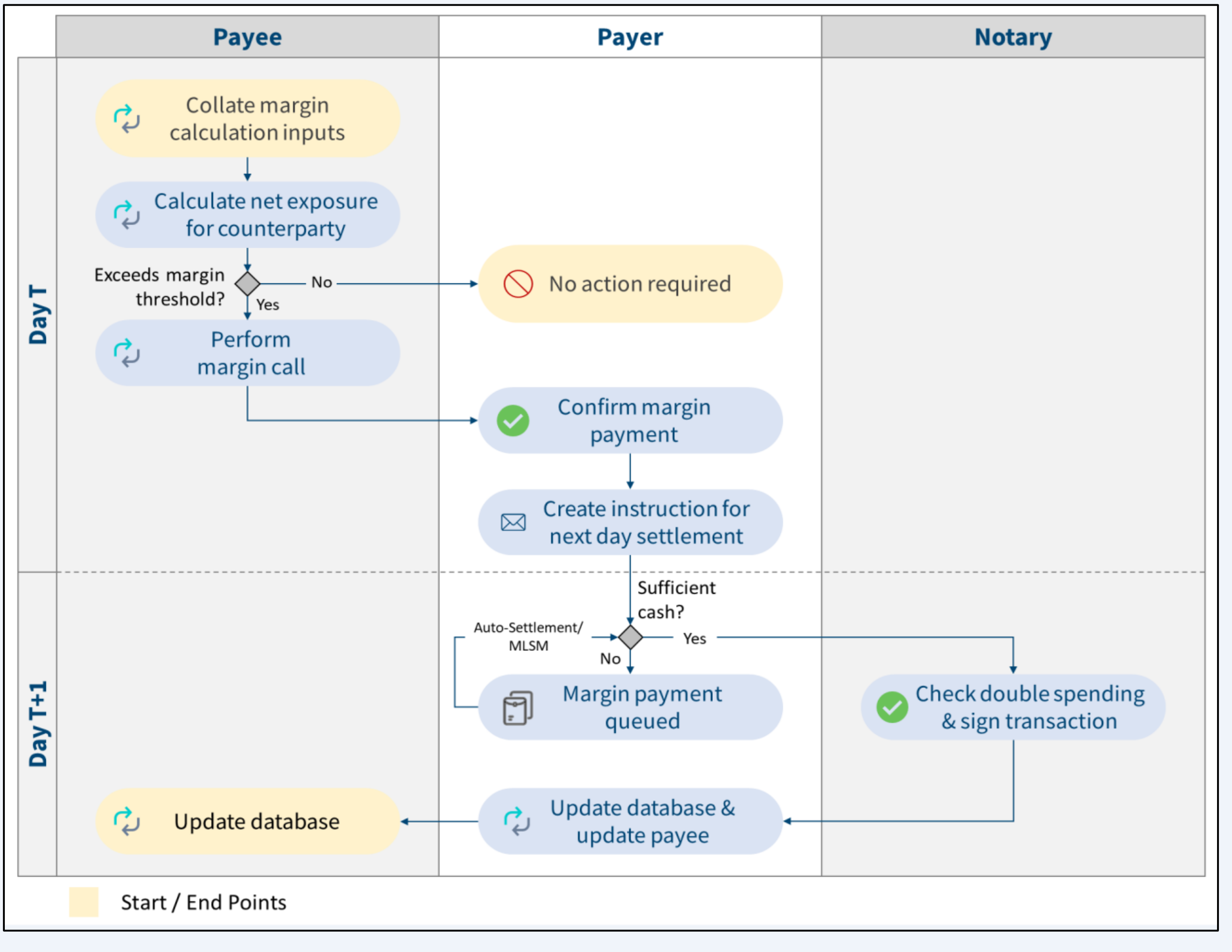


Figure 6: Illustration of the margin workflow.

Cash-Bond Gridlock Resolution

The integrated single-ledger of cash and bond offers a straightforward transaction flow that natively supports DvP gross settlement and provides a set-up to explore how liquidity economisation can be optimised holistically across traditionally segregated pools of cash and bonds.

Phase 2's GR design is developed based on Phase 1's design, with a novel MLSM at the heart of our experimentation. It is designed to resolve all assets in the scenario of cash and bonds gridlocks and deadlocks[5].

3.4 FINDINGS

Applicability of Smart Contracts for Bond Life Cycle Events

To replicate bond life cycle events, smart contracts are used extensively to model bond securities and the related financial transactions of outright trades and repos. Hence, this supports various events around bond life cycle, including auto-triggered coupon and principal payment as well as disbursement using auto-generated cash token transfer transactions. This relational linking of smart contracts allows interdependent events to be constructed, such as in the passing of bond coupons received between the repo parties[6].

Our POC successfully demonstrates smart contracts' flexibility for codifying complex product structures and interdependencies.

The use of smart contracts will have interesting implications for existing trading and operational practices. For example, smart contracts with the real-time ownership registration may render current practices of ex-interest (XI) date less relevant.

Repo Margining

The current repo margin process is partly manual, especially when aligning positions and valuations between counterparties.

Extending our DLT-based POC with the margin process has two key advantages. Firstly, on-ledger data provides consistent position-keeping data amongst parties. Secondly, operational efficiency is improved by integrating the margin process into the overall end-to-end post-trade processing workflow on DLT.

Our approach demonstrates the feasibility of implementing the margin process on DLT, as well as a potential compression of the process to a same-day basis through efficiency gains.

[5] For further details on the technical design of the Multi-Asset Liquidity Savings Mechanism (MLSM), please see Section 9.2 in the Appendix.
[6] The reverse repo party is required to pass the coupon received on the repo collateral back to the repo party.

Process Efficiency

Existing processes and technologies are mainly based on the SWIFT messaging standards to transmit and translate across the multiple systems used in the end-to-end process flow. Throughout this chain, intermediate validation and reconciliation steps are required to ensure consistency as the data crosses between systems.

Our POC using only one representation of assets and transaction throughout the end-to-end process provides native singular provenance. The immediate gain is the elimination of intermediate validation and reconciliation steps and a resultant streamlined operational process.

MLSM and Liquidity Economisation

In this project, we demonstrate the feasibility of real-time DvP settlement mechanism with an MLSM. Aside from the operational efficiency gains, there are improvements in liquidity economisation, largely attributable to:

- Improved liquidity of bonds through the shortened period of the asset-locking
- Optimisation of settlement liquidity usage holistically across cash (RTGS) and bonds through the introduction of MLSM

NEW END-TO-END WORKFLOW FOR SECURITIES SETTLEMENT

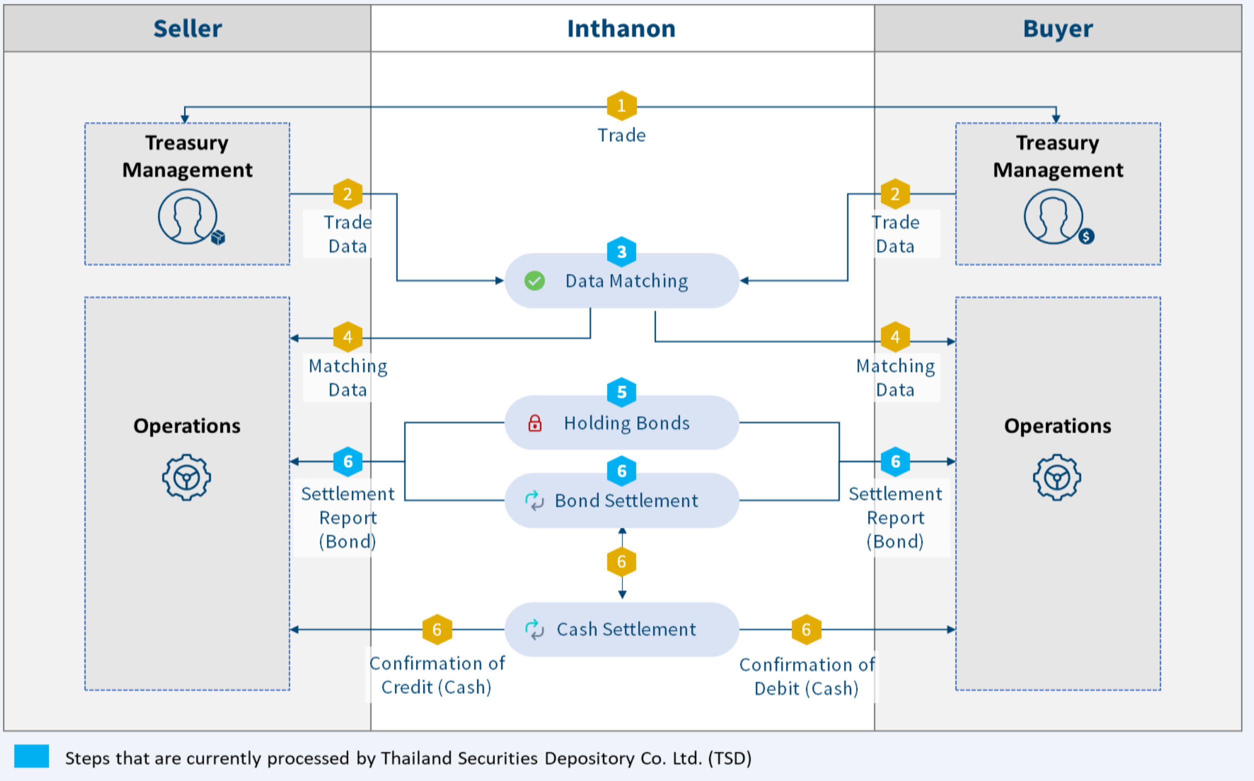


Figure 7: Illustration of the new end-to-end process flow for securities settlement.

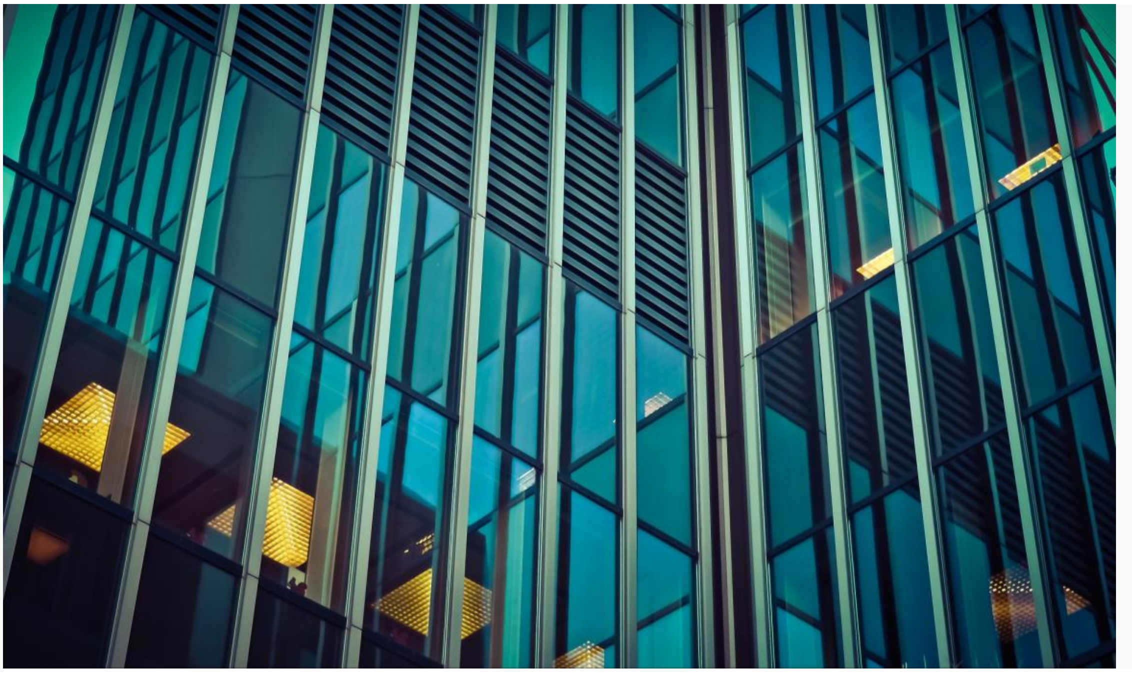
INCORPORATING SMART CONTRACTS FOR PROGRAMMABLE COMPLIANCE

04 DATA RECONCILIATION & REGULATORY COMPLIANCE

We explore the viability of operationalising the payment workflow, from initiation to finalisation, on a DLT platform. This could potentially minimise operational costs and enhance data reconciliation & regulatory compliance capabilities.

4.1 BACKGROUND

In Phase 2, the third-party funds transfer end-to-end process is extended on top of Phase 1's funds transfer workflow. This allows the pre-settlement operational steps, which include creation, checking, validation, and confirmation to be integrated with the settlement mechanism. This enable end-to-end status updates to be fed back to related parties in a similar way to SWIFT gpi[7] tracking. By driving this convergence of payment capabilities onto a common DLT-based platform, there is better end-to-end traceability of transactions, improved consistency in the performance of payment and payment control processes, while at the same time help lessen the banks' operational and compliance burdens.



[7] For further information, please visit https://www.swift.com/our-solutions/swift-gpi

CURRENT BAHTNET FUNDS TRANSFER WORKFLOW

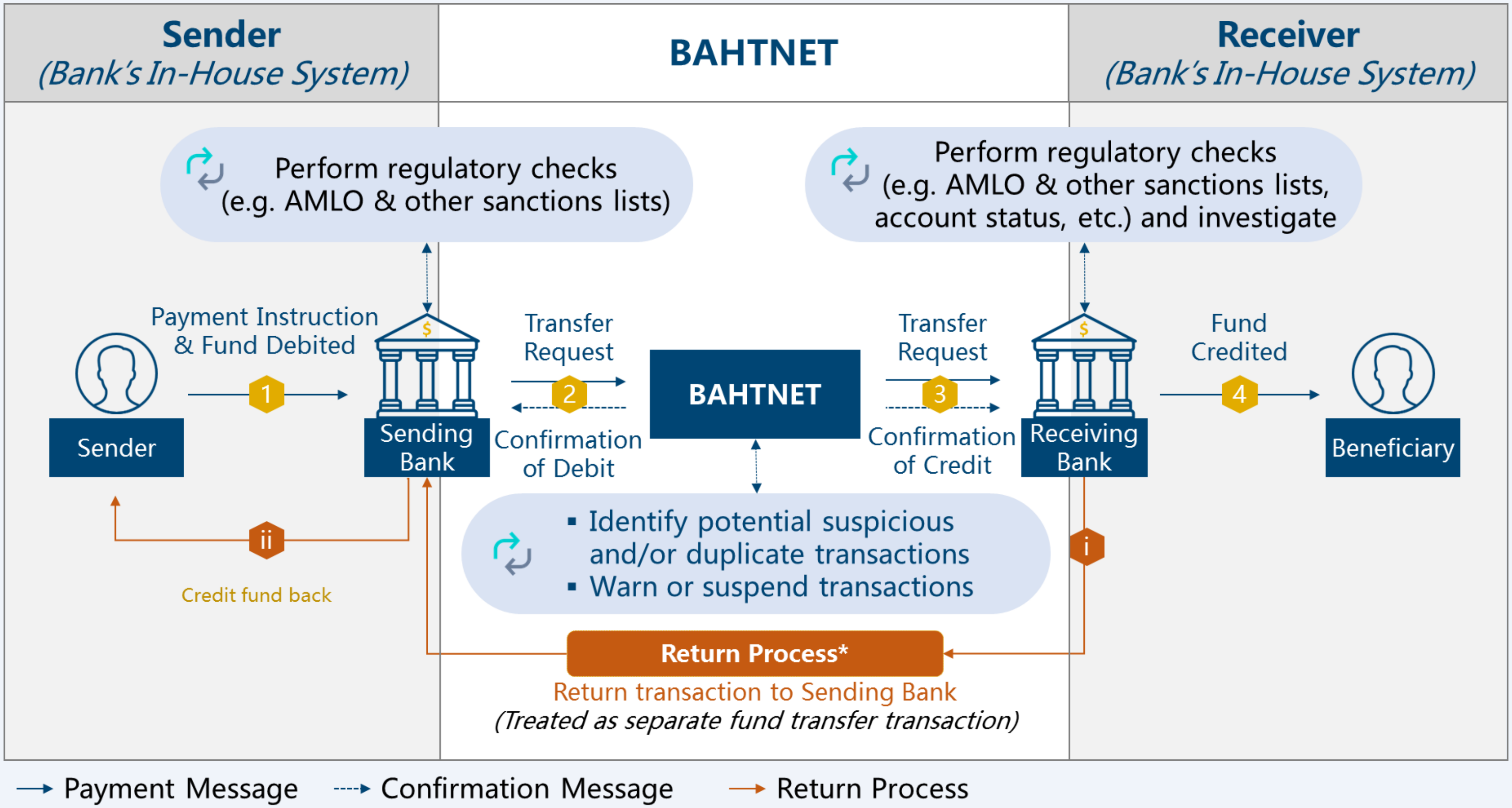


Figure 8: Existing end-to-end process BAHTNET workflow for customer funds transfer.

Return Process*

In cases where Receiving Banks cannot proceed with crediting funds to beneficiary, 'Return Process' is initiated:

1. Receiving Bank contacts Sending Bank as soon as issue is identified.
2. Receiving Bank returns fund to Sending Bank as soon as possible (within same day).

4.1.1 FRAUD PREVENTION

Similar to many other RTGS systems utilised by other central banks, the prevailing compliance architecture and framework of the BAHTNET system is institutional driven which shows rooms for improvement through DLT solutions.

1. Unavailability of Beneficiary Account Information

Since there are no cross-platform automated validating functions available in the current system, a sending bank creates a transaction in BAHTNET with the information given by the sender, regardless of validity of its correctness. Once a receiving bank receives the funds from BAHTNET, it is obliged to investigate and perform necessary compliance checks before crediting the funds to beneficiary accounts. Thus, this reduces the efficiency of payment operations as payments are delayed by the receiving banks during the verification process after interbank settlement of funds.

2. Gaps in Payment Validation & Controls

In the current process, each bank applies an independent practice and judgement for transaction validation, resulting in practice discrepancy. Payment fraud may be committed by exploiting this payment validation gap. Fraudsters can replace legitimate beneficiary's actual account number with their own account number, knowing that there is no validation of beneficiary details.

Additionally, in case of fraudulent payment, the customer requests for either sending or receiving bank to take responsibility. Without a standard industry-wide practice or rule that the financial industry can follow, attribution of responsibility is inconclusive.

3. Manual Funds Return Process

In cases of mismatched beneficiary names or inactive account status, the receiving bank cannot proceed to credit to the beneficiary account. The receiving bank then notifies the sending bank of the reason to return funds. The return transaction is initiated on BAHTNET as a new transaction which incurs operational costs and additional transaction fees.

4. Inability to Trace End-to-End Payment Status

BAHTNET, as an interbank payment system, provides status tracking for interbank purposes. Hence, the last status shown in the system is when receiving bank receives funds from sending bank. This creates ambiguity for all stakeholders not knowing the transaction status after interbank settlement in real-time. Without status tracking and a standard audit trail, it is difficult to trace payment status and determine the attribution of responsibility.

4.1.2 NRBA/NRBS REGULATIONS

Banks have faced challenges in monitoring and ensuring compliance with NR-related regulations due to information gaps, preventing banks from having a holistic view of transactions affecting NR accounts. Nowadays, all banks put in place manually intensive processes to ensure compliance. However, non-compliance to regulations can still occur through operational errors and other unforeseen circumstances.

The NBRA/NBRS regulations in Thailand consist of the following rules:

1. Transfer Restrictions between NRBA and NRBS

Although NRBA and NRBS are both Thai-baht accounts, funds transfer between NRBA and NRBS is prohibited. However, NRBA is allowed to make transfers to other NRBA (same account type) or resident accounts. The same rule also applies for NRBS.

2. Daily Outstanding Balance Limit

NRBA and NRBS are prohibited from having an aggregated ending balance exceeding THB 300 million[8] 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 THB in the amount exceeding the limit at the rate specified by the BOT.

3. Overdraft Limit

Additionally, NRBA and NRBS are also subject to a THB 600 million limit[9] on the amount of THB liquidity received in the form of THB overdrafts from financial institutions in Thailand. If NR breaches the overdraft limit, banks are required to notify the NR to buy THB in the amount exceeding the limit at the rate specified by the BOT.

Manual Compliance Processes

As all banks face an information gap with respect to their NR customers, banks coordinate amongst themselves to perform an additional pre-settlement verification process in order to ensure compliance.

This manual process includes checking account type, pre-matching funds, calculating forecasted balances, identifying possible NR-related settlement gridlocks and planning GR. Banks confirm with each other on the expected transactions to ensure that their NR client's balances stay within the limits. While this process does help to some extent, its operation is still very intensive and relies largely on human judgement to manage compliance.

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[8] The ending balance limit has been changed to THB 200 million per NR entity on 12th July 2019, after project completion.

[9] Amount limits, counted per group of NRs by each financial institution, are placed on any THB borrowing without underlying trade and investment in Thailand which include overdraft by NRs from onshore financial institutions.

4.2 SCOPE

For data reconciliation and regulatory compliance, we aim to explore how DLT's provenance-centric data architecture and smart contracts can be synergised to create a single platform to manage end-to-end payments and control workflow.

To address the fraud prevention and regulatory compliance objectives, the following areas of functionality development are needed:

1. Integration with External Systems for Validations & Checks

The end-to-end third-party payment workflow requires multiple sources of data, various controls and decision points from external systems such as beneficiary account validation, Anti-Money Laundering Office (AMLO) screening and BOT's flag for suspicious transactions. Our POC redesigns payment workflow to integrate with mock external systems and services to handle all validations and checks required. Such integration allows exchange of data and interaction between relevant parties. This helps broaden coverage of checking and expedite the payment process.

2. Single Platform

The POC is based on a single platform design which the end-to-end payment workflow is captured and managed. The single platform allows all parties to operate and share a common "single source-of-truth" because any transaction has only one representation for all parties throughout the entire life cycle. This single platform design does not only enhance efficiency by eliminating redundancy of data reconciliation process, but it also offers transactional traceability and ability to check account veracity.

3. Proactive Compliance

With the convergence of process and data onto our single platform design, it is possible to generate proactive compliance support features for banks. Banks can be proactively alerted and notified by the platform of suspicious or non-compliant transactions, such as AMLO sanctions and NRBA/NRBS controls. Banks can then take necessary corrective actions before further processing.

4. Data Privacy and Message Standard

Another important characteristic is the preservation of client data privacy and confidentiality. Furthermore, the POC should be able to support Thai language and ISO 20022 message standards to maintain relevance with both the domestic and global operating environments.

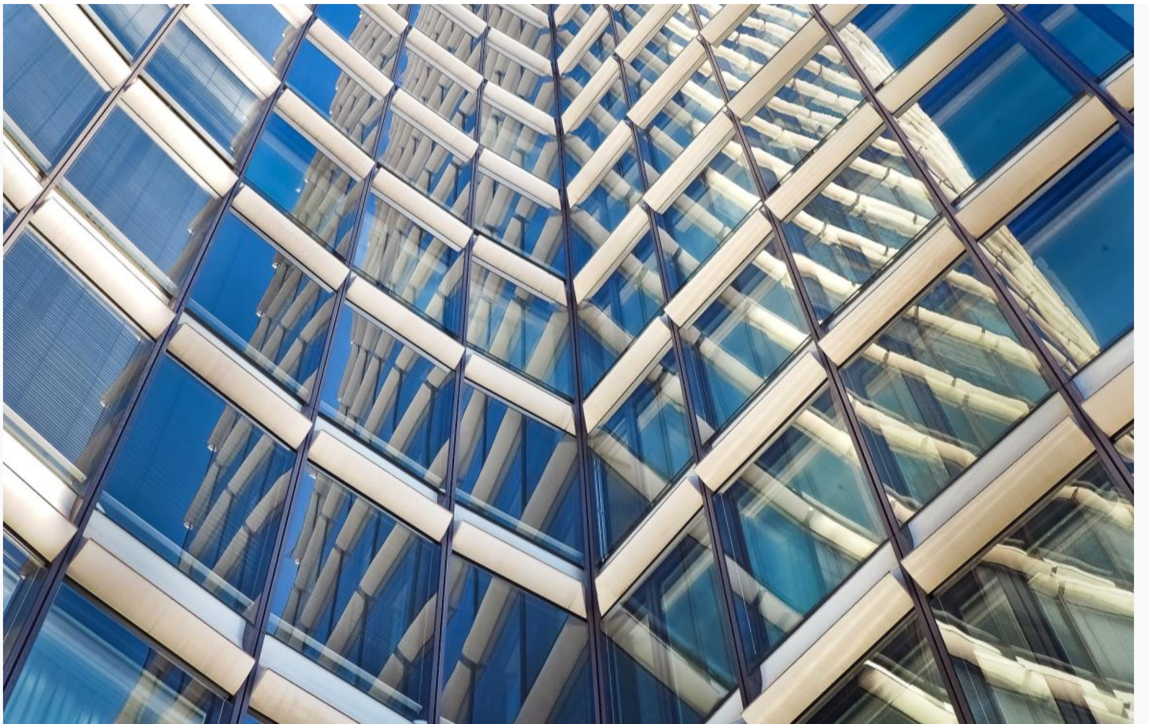
4.3 FUNCTIONAL DESIGN

Our key design centres around a single platform that is open to integration and has proactive compliance features. The design leads us to use self-executing smart contracts to support an end-to-end workflow, matching the operational scenarios. Openness to integration is achieved by placing connection points at key control steps to allow interaction with external services or pre-defined decision logic. Lastly, proactive compliance is achieved through programmable constraints within smart contracts, and by applying analytics to on-ledger data for active management, monitoring and reporting.

End-to-End Payment Workflow

The design of the new end-to-end workflow primarily moves all actions (except those directly involve the end-customer) onto the DLT platform and incorporates new pre-settlement bilateral validation that should replace or alleviate the burden of current post-settlement validation for receiving banks. The workflow simplifies and clearly segregates the roles for all parties, helping ensure equitable sharing of fraud prevention and compliance responsibilities.

The workflow depicted on the following page shows the general flow activities on the DLT platform.



NEW END-TO-END FUNDS TRANSFER WORKFLOW

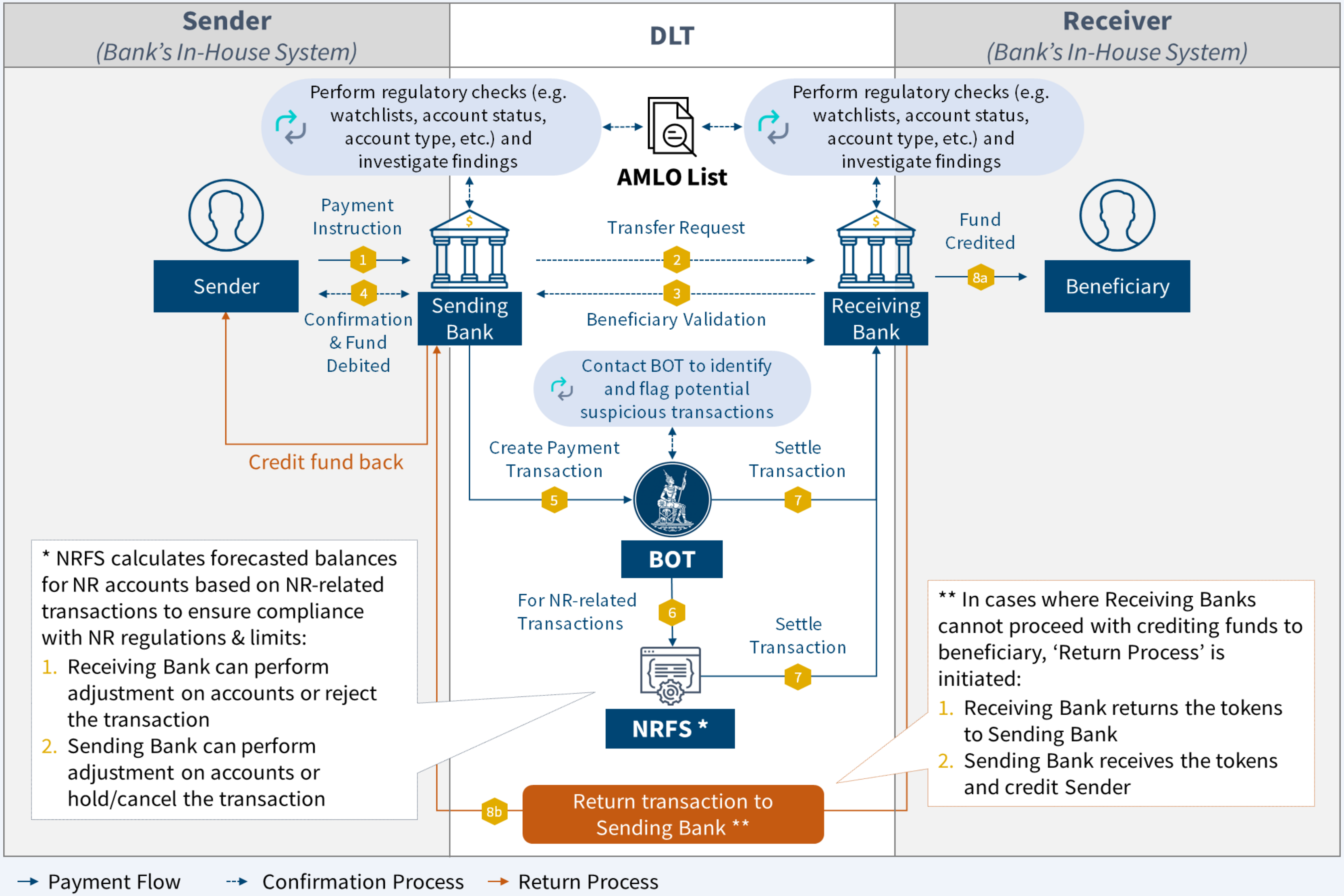


Figure 9: New end-to-end business workflow for fraud prevention & NRBA/NRBS compliance checks.

1. Payment Instruction

The new payment workflow embedded in the DLT platform is initiated when a sender submits payment instructions to the sending bank. During this step, the sender can choose whether to provide consent. The consent allows the sending bank to proceed the transaction on the sender’s behalf despite any identified mismatches in beneficiary information or duplicate transactions. Without the sender’s consent, sending banks are obliged to request for the sender’s confirmation on whether to submit or cancel the transaction.

2. Transfer Request

Before proceeding with transfer request, the sending bank performs compliance validation checks, which includes validating the sender’s information and screening the sender’s name against the AMLO sanction list by utilising the system integration points. After satisfying all validation checks, the sending bank sends only the relevant transaction details to the receiving bank.

3. Beneficiary Validation

The responsibility for ensuring the compliance is then handed over to the receiving bank as it performs its own regulatory checks, which includes AMLO screening and verifying the account status and account type of the beneficiary. In cases where transfer requests are made between different NR account types (e.g. NRBA transfer to NRBS), the receiving bank immediately rejects the transaction as it breaches NR account restrictions. Once all the verification checks have been performed and approved, the receiving bank forwards the beneficiaries account name to the sending bank.

4. Confirmation & Fund Debited

Upon receiving the beneficiary information for the transaction, if there is any mismatch, the sending bank with sender's consent can perform a final check on behalf of the sender. If the sender does not provide consent, the sending bank must inform the sender about any mismatched beneficiary name or duplicate transactions. The sender can choose either to cancel the transaction or to confirm the transaction.

If there are no regulatory breaches and the sender’s confirmation is received, the sending bank then initiates the payment by debiting the sender’s account and starts creating the payment transaction.

5. Create Payment Transaction

After debiting the sender’s account, the payment transaction is then created and sent to the BOT, who identifies and flags any suspicious transactions.

6. Non-Resident Forecasting System (NRFS) - For NR-Related Transactions

It is required for NR-related transactions, of which at least sender or receiver is an NR, to go through NRFS to check that NR controls are respected. This NRFS is considered as a pre-matching mechanism before transferring transaction to Inthanon's settlement engine.

The NRFS is the first study amongst DLT projects to successfully materialise data analytics capabilities. The NRFS is designed to gather all NR related transactions and NR account balances across the entire banking system to perform balance forecasting to ensure that balances are within regulartory limits.

This effectively eliminates the need for manual checks and mitigates the risk of NR breaches. The key attributes of NRFS are summarised as follows.

1. Data Consolidation

To perform data consolidation, NRFS "main rounds" are run on an hourly basis. During the "main round", the NRFS, performed by the BOT node, retrieves the snapshot balance of each NR account, NR-related cross-bank payment instructions and NR-relating bank internal transfers from all banks. Sending banks can set priorities for payment instructions which are used later when NRFS proposes suggestions to banks.

2. Forecasting Balances & Suggestions

For each "main round", once the data is consolidated on the BOT node, a forecasted balance is calculated based on beginning account balances, proposed payments and any expected receipts. NR accounts' forecasted balances can be categorised into 2 groups – (1) forecasted balance is "in range" of THB 0-300 million and (2) forecasted balance is "out of range" of THB 0-300 million. For any payment instructions (transactions) not related to "in range" NR accounts, the transactions proceed to settlement.

For the transactions related to "out of range" NR accounts, the NRFS provides transaction-level suggestions (e.g. to hold payments or reject fund receipts) that allows the NR account's forecasted balance to move closer to the required range of THB 0-300 million. Banks may follow the suggestions or make adjustments by adding/removing THB amount to/from NR accounts.

The NRFS then runs a "mini round" to re-calculate NR forecasted balances based on banks' selected actions to check if the transactions can be settled. Any transactions related to "in range", NR accounts are settled, while for those related to "out of range" NR accounts, the system provides suggestions if any, so that banks can take further actions. This "mini round" loop continues until the next "main round" begins or until all transactions in that "main round" are settled or managed.

Since all NR-related transactional information is collated at the BOT node, the data privacy is the key consideration in designing the NRFS process. When the BOT node informs bank nodes, which transactions have been approved for settlement, only the approved transaction ID numbers are sent out. Banks then match the list of approved transactions with their own outstanding transactions to identify transactions that can be settled. This design successfully ensures data privacy by only disclosing necessary information, while protecting sensitive information.

3. Settlement

Transactions that have been approved by the NRFS process are then settled in the decentralised RTGS system. The unsettled transactions of each "main round" is passed on to the next "main round" where account balances are re-calculated. However, the unsettled transactions of the last "main round" of the day have to be resolved between the relevant banks.

4. Monitoring Analytics

As banks' information regarding NRBA/NRBS account balances and transaction details are gathered at the BOT node, the BOT has a near real-time view of NR account balances and transactions. In addition, the BOT has a clear picture of NR entity aggregate balances across all banks during the day. Therefore, the BOT is able to actively monitor when certain accounts have a high risk of breaching NRBA/NRBS limits.

Banks also benefit from the designed data network that allows them to manage their clients' balances, allowing banks to act in a timely manner to ensure that NR regulations are effectively complied with.

7. Settle Transaction

Subsequently, the receiving bank checks the transaction flag by the BOT to decide whether any further investigation is required. If the transaction has no flag, the receiving bank can proceed to credit the money to the beneficiary's account. If the transaction is flagged suspicious, the receiving bank is responsible for conducting further investigation.

8a. Fund Credited

Once the settled transaction with any suspicious transaction flags are investigated and cleared, the receiving bank proceeds to credit the funds to the beneficiary's account.

8b. Return Transaction to Sending Bank

The transactions deemed fraudulent are returned to the sending bank. In the return process, the receiving bank remits the cash tokens back to the sending bank, who then credits the amount of funds back to the sender's account.

Reporting & Monitoring

Front-end modules are also developed to allow easy tracking and monitoring of funds transfer by alerting sending/receiving banks of any required action. Additionally, these modules imitate the core banking system (CBS) in providing customer confirmation and status of the transaction throughout the settlement process.

For NRFS, the BOT has an access to reports showing the transactions and balance of NR accounts across all banks, highlighting accounts that have breached the limit. In addition, banks are able to have near real-time tools which serve the tracking purposes of their clients' balances and transaction status, alleviating the limitations of current practices.

4.4 FINDINGS

Enhanced Payment Validation & Controls

By providing banks with a single platform that is integrated with trusted information sources, there are significant enhancements to the validation and controls. In our POC, banks are now able to operate a consistent two-way validation process without data inconsistencies before actual settlement; consequently, we can expect reductions in both payment failure and fraudulent transactions, thereby avoiding the cost of the fund return process and penalty charges for breaches.

In addition, the payment workflow design addresses the issue of inconclusive role and responsibility for transaction validation, as sending banks and receiving banks now have clearly segregated roles and responsibilities.

Better NR Regulatory Compliance

The POC developed the NRFS process with the explicit goal of improving NR regulatory compliance and streamlining the existing operational processes. Consolidating NR account balances and transactions, the NRFS provides analytics capabilities in calculating NR forecasted balances for monitoring and control. Also, it helps propose suggestions to resolve NR-related transactions settlement gridlocks. This NRFS process brings significant improvements to the current process in terms of efficiency as well as offering banks an effective approach towards NR regulatory compliance.

From a central bank point of view, the POC also enables the BOT to monitor banks' compliance on a near real time basis. This POC provides the updated and aggregated NR account information allowing better monitoring capability.

Greater Transaction Status Transparency

Transparency of transactions is enhanced by providing banks with channels where they can track the status of their transactions in real-time, from initiation to final settlement and funds transfer to end beneficiaries. This is a key function for banks as they are better able to monitor their transactions and can respond quickly to any issues arising during the transaction processing phase.

05 TECHNICAL DESIGN & NON-FUNCTIONAL FINDINGS

> Phase 2's POC is built on the Corda DLT platform (version 4.0 open source edition). This section provides an overview of the architecture and technical components developed to meet the objectives and scope of the phase.

5.1 TECHNICAL DESIGN

System Architecture

The POC is built as a private and permissioned Corda network. Each authorised participant operates a Corda node on the network; in all, there are 9 nodes representing the BOT and each of the 8 participating banks. The network also operates a doorman service which provides network permission, and a single notary node. To reflect a security setup similar to reality, each participant node is placed behind the firewall and a connection is opened to the network.

Each participant operates the following components as the solution stack for the POC:

1. Corda Node & POC CorDapp

   The Corda node runs the POC CorDapp which is the core business application providing all the required capabilities and functionalities for the scope of the project. The Corda node also operates the H2 database for the CorDapp' s data architecture and storage.

2. DLT API Services

   It is a REST API to programmatically interact and operate with the Corda node and POC CorDapp.

3. Web-based User Interface (UI) Client

   The user interface ("UI") is built with Angular web framework, it provides bank operators a web-based UI to perform business actions and interact with the mock CBS module or with the POC CorDapp via the DLT API service.

For each bank, there is also a further CBS component that is provided as a mock system simulating a bank's core banking system for the management of customer accounts. For the BOT, another mock system is the AMLO Service which maintains the AMLO sanction list and performs a screening check for funds transfer instructions.

SYSTEM TECHNICAL ARCHITECTURE

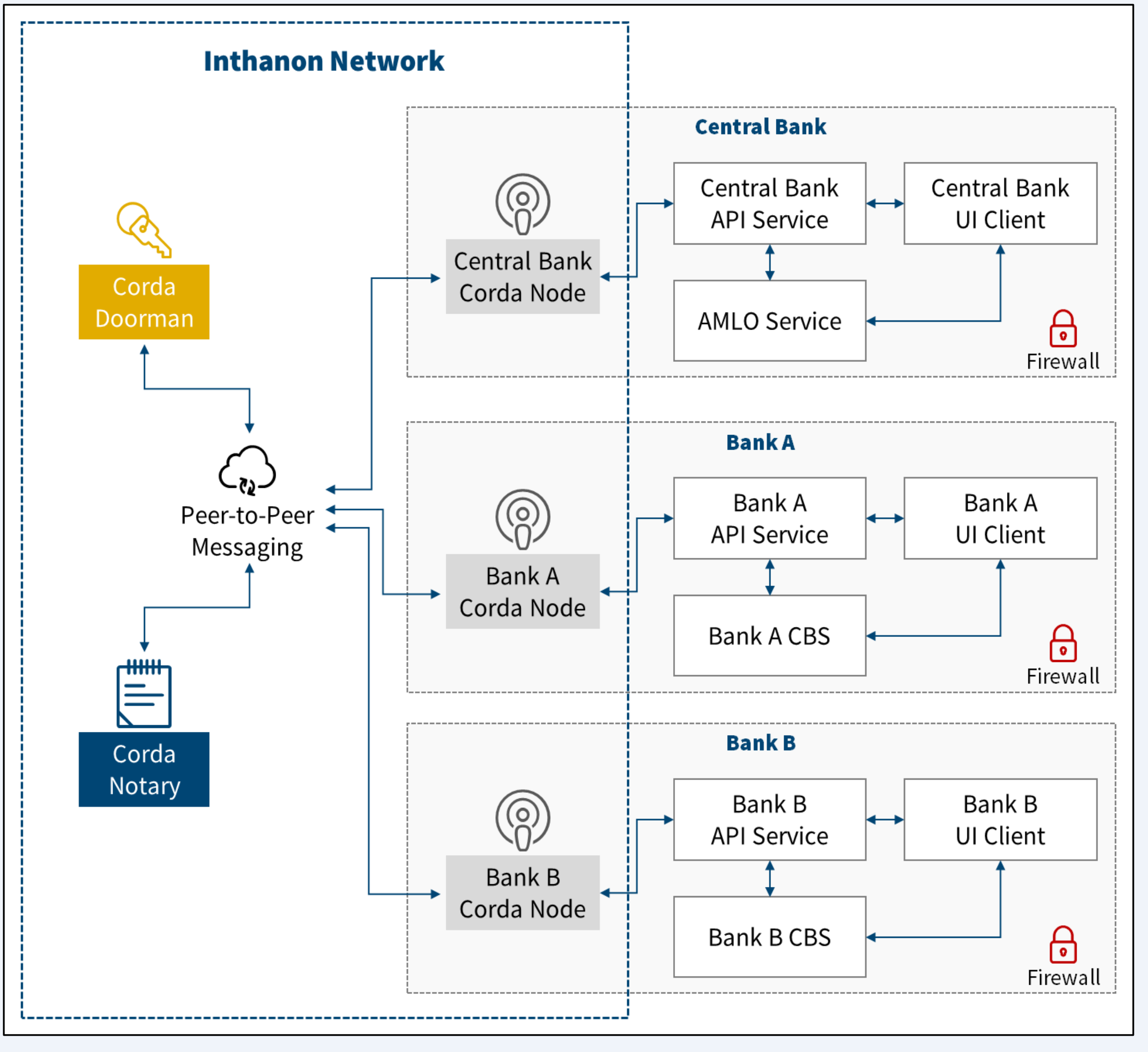


Figure 10: Graphical representation of the system architecture built on a private and permissioned Corda network.

Application Architecture

In Phase 2, the original POC inherited from Phase 1 is renewed and extended into a modular application architecture comprised of 4 main modules - Core, Bond, Customer Transfer, and Plug-Ins.

This refreshed application architecture is also built around loose-coupling between modules, and a high reusability code structure. This new architecture is able to effectively ease future platform extension into new financial instruments and capabilities.

APPLICATION ARCHITECTURE

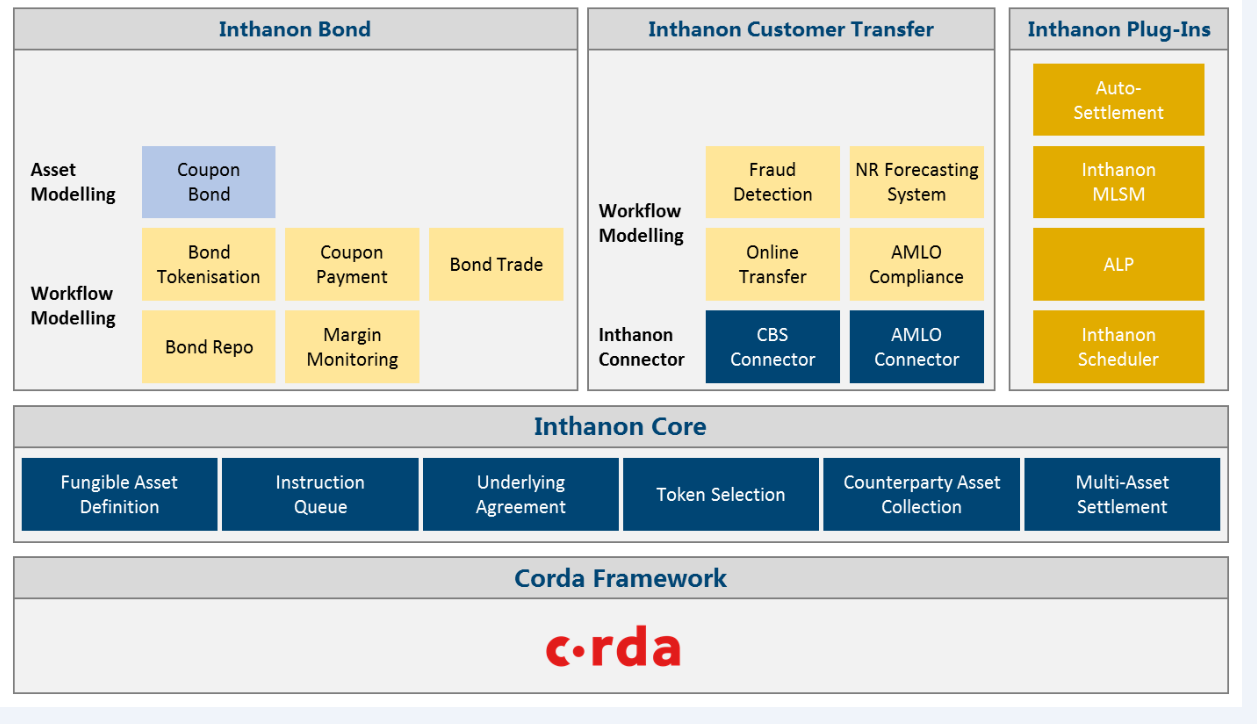


Figure 11: Illustration of the application architecture.

1. Inthanon Core

The Inthanon Core module provides the basic data structures and workflows that support general financial modelling and core settlement framework.

- **Fungible Asset Definition**: Fungible assets are financial assets of which each unit is indistinguishable and interchangeable. In our implementation, Cash and Bond are defined as Fungible assets.
- **Instruction Queue**: An instruction is a Corda transaction that represents a simple transfer of only one asset, or the generic exchange of two assets between two different parties. The instruction may be settled immediately or later by being placed into the Instruction Queue with prioritisation options.
- **Underlying Agreement**: In a financial agreement between the two parties, the parties are obliged to perform exchanges or transference of assets either unconditionally or conditionally upon pre-defined criteria.

- **Token Selection**: When there are multiple concurrently active instructions, token selection becomes non-trivial. Our token selection algorithm is designed to prevent the scenario that the same token is used to settled multiple concurrently active instructions.
- **Counterparty Asset Collection**: Exchange of two assets between two different parties involves extra coordination in gathering tokens. This Inthanon Core module helps the transaction proposer to request counterparty for available tokens.
- **Multi-Asset Settlement**: With Phase 2's scope for bonds settlement, the original cash settlement mechanism is re-designed as a universal settler that generically constructs and executes instructions with respect to any fungible asset types.

2. Inthanon Plug-Ins

Inthanon Plug-Ins module comprises of configurable components that are peripheral or supportive with respect to the Corda DLT key building blocks, as such they are designed to be generic and decoupled from the Inthanon Core module.

- **Auto-Settlement**: The auto-settlement scheduled task automatically settles the first-order instruction, given the priority rule, for which the settlement date is due. Auto-settlement supports instructions on any fungible assets.
- **Multi-Asset Liquidity Saving Mechanism**: Settlement via the MLSM requires resolution of gridlocks and deadlocks as well as coordination of payments across multiple parties in an atomic settling manner. This is achieved through a four-step process of detect, plan, propose, and execute that was already built in Phase 1. In Phase 2, the new MLSM supports GR across multiple fungible assets.
- **Automated Liquidity Provision**: ALP is an autonomous liquidity injection functionality that is integrated with the MLSM to resolve deadlocks and settle urgent instruction under insufficient cash tokens.
- **Scheduler**: Scheduler provides a common scheduling and configuration framework for handling all scheduled tasks on the platform such as:
  - Coupon payment
  - Margining process
  - MLSM and ALP
  - NR Forecasting System

3. Inthanon Bond

The Inthanon Bond module provides the necessary components for modelling bonds as asset tokens on DLT. In addition, this module provides workflows relating to bond life cycle events, trading and post-trade processing.

4. Inthanon Customer Transfer

The Inthanon Customer Transfer module constructs the funds transfer instruction using smart contract, models the compliance checks and settlement workflow, and provides connectors for interactions with external systems.

Data Architecture

1. Data Relevant to Interbank Operations

Data relevant to interbank operations are represented as Corda states and sent over the Corda network in accordance with the contract and flows defined.

These include details of various agreements between banks such as bond trade, bond repo, and funds transfer. In general, data are visible only to the relevant participants. For instance, a bond trade state and transactional information are visible to only the two parties involved in the trade.

2. Data Relevant to the Banks' Internal Operations

The Inthanon network primarily processes contracts on the bank level, so it does not process data relevant to the bank's internal operations. However, there are use cases that require the information, including customer information and account balances. In our design, we store these data in the database of the mock CBS. The Corda node of the bank does not have direct access to the database and must request the information via the CBS. This robust architecture provides a clear pathway for future integration with existing CBS.

5.2 NON-FUNCTIONAL FINDINGS & IMPROVEMENTS

Settlement Finality

Finality describes the way a system reaches 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 has occurred. In this phase, we have proved and ensured that the system can provide a technical settlement finality of the exchange between cash and bond token.

For Corda, there is a point of finality, which is the moment when the notary signs against a transaction. The notary guarantees that every state can be consumed at most once, thus preventing double spending.

Privacy

In Phase 2, data privacy features from Phase 1 are maintained. The first feature is that transactions are broadcasted only on the need-to-know basis. Another feature is the use of confidential identities to ensure privacy in MLSM. Corda node can generate multiple confidential identities to obfuscate the identity of the parties involved. On top of those features used in Phase 1, partial data visibility is implemented by separating sensitive information from the instruction before sending to the related parties.

For instance, in the NRFS process, the oracle node retrieves detailed transactions related to NR from all nodes. In informing each bank node of transactions ready to settle, the oracle node sends only the transaction ID to all relevant nodes.

Resiliency

1. Flow Suspension

The Corda platform is designed to ensure data integrity as well as the success of transaction flows by imposing dependency conditions on involved nodes. This means that the system cannot ignore involved nodes for the completion of transaction flow.

In other words, when one involved node is suspended during the transaction flow, it leads other nodes to keep waiting until the suspended node resumes as there is no timeout mechanism in Corda.

Nonetheless, the issue of having no timeout mechanism may affect some functionalities of the system, particularly those involving multi-parties e.g. MLSM or NRFS.

2. Scheduler Resiliency

Under the Inthanon system, a scheduler is adopted to help automate key system's functionalities e.g. MLSM, coupon payment and margin calculation. The scheduler is automatically triggered at the predefined time by all involved nodes in the system. Given the current design, the scheduler was found to be operationally resilient. This means that the scheduler would be automatically triggered after a failing node resumes to normal operations.

3. Resilient Notary Service

Any system that transfers assets (or value) needs to address the problem of double-spending to prevent an asset owner from fraudulently spending an asset more than once. Early DLT platforms resolve the double-spend problem through transparency by globally broadcasting all transactions to all network participants and resolve any detected conflicts using consensus mechanisms such as Proof-of-Work or Proof-of-Stake. This approach, however, compromises on privacy, scalability, and only has probabilistic settlement finality.

Corda's approach to solving double-spending is through the notary service which is done by central verification in the network. Due to the criticality of the centralised notary service, the resiliency of the Corda network depends heavily on one single point notary node. A notary cluster is an approach which could be implemented to strengthen the system resiliency. The cluster of notary design is discussed in Appendix Section 9.3.

06 FUTURE CONSIDERATIONS

6.1 FUNCTIONAL FEATURES BUILD-OUTS

1. Integration and Interoperability

Our POC is not set out to explore integration with other external systems and networks. Nonetheless, by building connections with mock external system (such as ThaiBMA's bond price data, and AMLO's sanction list) basic integration approaches are explored. A roadmap for future enhancements is needed to further elaborate and develop feasible integration models to support connectivity between the DLT platform and the real-world ecosystem. Aside from technical interoperability, these integration models will also need to address the operational aspects of how responsibilities can be shared across platforms to safeguard privacy, data provenance, and security.

Another critical driver for any successful integration model is the harmonisation of data standards. This is especially important for integration with the wider payment landscape that is rapidly growing and becoming more diverse. Any future DLT-based RTGS will need to interoperate with global payment systems and emerging fintech payment solutions. In this context, it is essential to incorporate ISO 20022 messaging standards adoption into the development roadmap. In Project Inthanon Phase 2, for example, the funds transfer instruction is aligned to ISO 20022 with this consideration in mind.

2. Legal & Regulatory Considerations

As set out in the scope, the in-depth exploration on the legality of asset tokens and the impacts of DLT-based RTGS on the relevant regulations are not the primary focus of Phase 2. Nonetheless, we are well aware that the legal status and regulatory treatments for the tokenised assets are another essential factors for assessing the operational readiness of the POC. With the current design, CBDC and bond tokens in Inthanon System could be treated as the Depository Receipt (DR) of the assets in the real world. Besides, if the DLT-based RTGS operates with the around-the-clock basis, the related regulations (e.g. accounting practice related to the asset tokens or liquid asset requirements) must be reviewed and clarified to the market participants before pushing it into the production level.

3. Operational Considerations

Several operational aspects must be considered before moving the POC towards the production-grade system. A good illustration for this is that banks are required to adjust their internal operational process in order to support the new functionalities including fraud prevention mechanism, new transactional bond trading and repo workflows with 'around-the-clock' operation. Also, it requires the cooperation with other stakeholders who may be disrupted or impacted from the new process workflow or new capabilities e.g. TSD or AMLO.

The governance structure of the network is another key aspect for operational consideration. The issues regarding shared operating and maintenance cost or accountability should also be explored and established before proceeding to the production level.

6.2 LOOKING FORWARD TO PHASE 3

Cross-Border Payment

After the successful completion of Phase 1 and 2, the BOT and participating banks are committed to extending the collaboration for DLT-based innovative solutions. In Phase 3, exploring interoperability will be the main focus, particularly in the area of cross-border payments and settlements. This requires coordination with a foreign central bank to holistically re-design all related processes, including cross-border model and system integration.

07 CONCLUSION

Leveraging on the foundational solutions built in Phase 1, coupled with the collaborative efforts of the BOT, eight participating banks and technology partner, R3, Phase 2 of Project Inthanon successfully concluded with the development of the POC that achieved all intended functional and non-functional objectives.

The findings from Phase 2 demonstrated the feasibility of smart contract utilisation to automate bond life cycle events and DvP of interbank bond trading & repo transactions. The effective use of smart contracts shown potential to significantly streamline operational workflows and increase efficiencies.

Fraud prevention capabilities of the RTGS system were also augmented by the creation of a new end-to-end workflow that allowed validation of transactional information with external sources through integration points.

Use of smart contracts for regulatory compliance purposes was also successfully tested in Phase 2 with the introduction of the NRFS mechanism, which could potentially eliminate multiple manual operational processes and allow banks to monitor NRBA/NRBS limits more effectively.

The successful delivery of objectives in Phase 2 was made possible by the collaborative and innovative environment created by the participating banks and the technology partner, allowing the development team to push the boundaries of DLT to greater heights in creating new solutions to overcome existing obstacles.

After the successful conclusion of Phase 2, focus can now be shifted to Phase 3 where the primary objective will be to create a connected platform that is operable on a global scale. We will delve into the possibility of interoperability with other platforms to achieve cross-border, multi-currency transactions and compatibility with the existing system to ease future transition.

Overall, Phase 2 has been a tremendous success and has gone a long way in helping raise awareness of DLT applications and the benefits it can bring to the Thai financial market. While the journey to scale Inthanon is full of challenges, we have taken another step closer to reaching the forefront of the DLT revolution that will shape the financial markets of tomorrow and the future looks promising.

08 GLOSSARY

Term	Definition
ALP	Automated Liquidity Provision - function that allows participating banks requiring liquidity to automatically enter into a repo with the BOT to use available bond tokens as collateral to exchange for cash tokens provided by the BOT
AMLO	Anti-Money Laundering Office
BAHTNET	Bank of Thailand Automated High-value Transfer Network – Current financial infrastructure serving for Real-Time Gross Settlement of large value funds transfer between financial institutions or other organisations maintaining deposit accounts at the Bank of Thailand
BOT	Bank of Thailand
CBDC	Central Bank Digital Currency
CBS	Core Banking System
DLT	Distributed Ledger Technology
DVP	Delivery versus Payment
EAF2	The German payment settlement system – Elektronische Abrechnung mit Filetransfer 2
GR	Gridlock Resolution - 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
ILF	Intraday Liquidity Facilities - intraday interest-free liquidity facility provided on BAHTNET against available collateral
LSM	Liquidity-Saving Mechanism - functions that enhance efficiency of liquidity management
MTM	Mark-to-Market
NRBA	Non-Resident Baht Account
NRBS	Non-Resident Baht Account for Securities
NRFS	Non-Resident Forecasting System

Term	Definition
POC	Proof-of-Concept
REST API	Application program interface which is based on representational state technology
RTGS	Real-Time Gross Settlement System
SSS	Securities Settlement System
SWIFT gpi	SWIFT global payments innovation
TSD	Thailand Securities Depository
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.
CorDapp	Corda Distributed Application (CorDapp) are distributed applications that run on the Corda platform. The goal of a CorDapp is to allow nodes to reach agreement on updates to the ledger.
Corda Doorman	Admissions process for a Corda-based network, enabling prospective participants to request signed certificates to use when transacting on the network.
Corda States	An immutable object representing a fact known by one or more Corda nodes at a specific point in time. States can contain arbitrary data, allowing them to represent facts of any kind (e.g. stocks, bonds, loans, KYC data, identity information…).
Deadlock	A situation where gridlock resolution algorithm could not find a netting solution given available cash tokens. Deadlock arises when a potential netting solution results in a negative net liquidity across of any participants, and so no resolution is possible unless additional liquidity is provided by one or more of the participants.
Gridlock	Group of obligations that cannot settle individually in gross due to insufficient liquidity, but two or more obligations are resolvable with one or more net payments.
Notarisation	A process for going through uniqueness consensus checking with a notary. This process attests that, for a given transaction, its input states are not double spent.
Notary Cluster	A group of connected computing instances which provides the notarisation service.
Repo	An asset sale-and-repurchase agreement, usually involving fixed-income securities.

09 APPENDIX

9.1 PRIORITISATION OF TRANSACTION

As defined in Phase 1, there are 3 types of queue priorities that remain applicable in the Phase 2 design.

1. **Urgent**
   a. Only one Urgent in the queue at a time
   b. Being settled first
   c. Block lower priority obligations
   d. Can be re-prioritised to High and Normal
2. **High**
   a. No limits for High in the queue
   b. Obligations can be reordered within High
   c. Being settled in FIFO basis
   d. Block lower priority obligations (applies also within High)
   e. Can be re-prioritised to Urgent (if none in the queue) and Normal
3. **Normal**
   a. No limits for Normal in the queue
   b. Obligations cannot be reordered within normal
   c. Being settled in FIFO basis
   d. Non-blocking feature (orders in Normal do not affect the settlement of obligation)
   e. Can be re-prioritised to Urgent (if none in the queue) and High

9.2 MULTI-ASSET LIQUIDITY SAVING MECHANISM

The MLSM algorithm is an extension of Inthanon Phase 1's LSM algorithm[9], extended through three nested loops.

- The first nesting is an asset-specific loop within which the base MLSM algorithm is iterated sequentially for each (offending) asset until resolution of the non-negative balance constraint[10].
- The second nesting is an evolutionary optimisation loop wherein the first nesting is re-run with randomised starting (offending) asset until no better optima arise.
- The last nesting is a multi-asset optimisation loop wherein the second nesting is re-run against an objective function that maximises the largest amount of assets settled.

Reframed, the asset-specific loop may be considered as the base multi-asset version of the GR problem[11] formulation. The subsequent evolutionary optimisation and multi-asset optimisation loops are heuristic search algorithms[12] overlaid on top of the solution set of the base problem. In our implementation, there are two optimisation objectives - firstly, within each run of the base EAF2 algorithm the solution is optimised against the objective of maximising total value settled system-wide in the selected asset. Secondly, on the levels of evolutionary optimisation and multi-asset optimisation, the solution search is against the objective of maximising total value settled system-wide across all assets.

[9] Readers are advised to consult Project Inthanon Phase 1 report - https://www.bot.or.th/English/FinancialMarkets/ProjectInthanon/Documents/Inthanon_Phase1_Report.pdf - specifically section 3.2.3 and the Appendix 8.2 for details of the base LSM mechanism.

[10] The base MLSM algorithm is slightly modified with respect to Phase 1 in the sense that there are two non-negative balance constraints - one in the offending asset, and one in cash - where in Phase 1 there is only one non-negative balance constraint (in cash).

[11] 2001, Bech & Soramäki, Bank of Finland Discussion Papers: Gridlock Resolution in Interbank Payment Systems

[12] It is speculated without proofs that the GR problem for multiple assets without prioritisation is a NP-complete problem, hence requiring heuristic methods.

MULTI ASSETS GRIDLOCK RESOLUTION

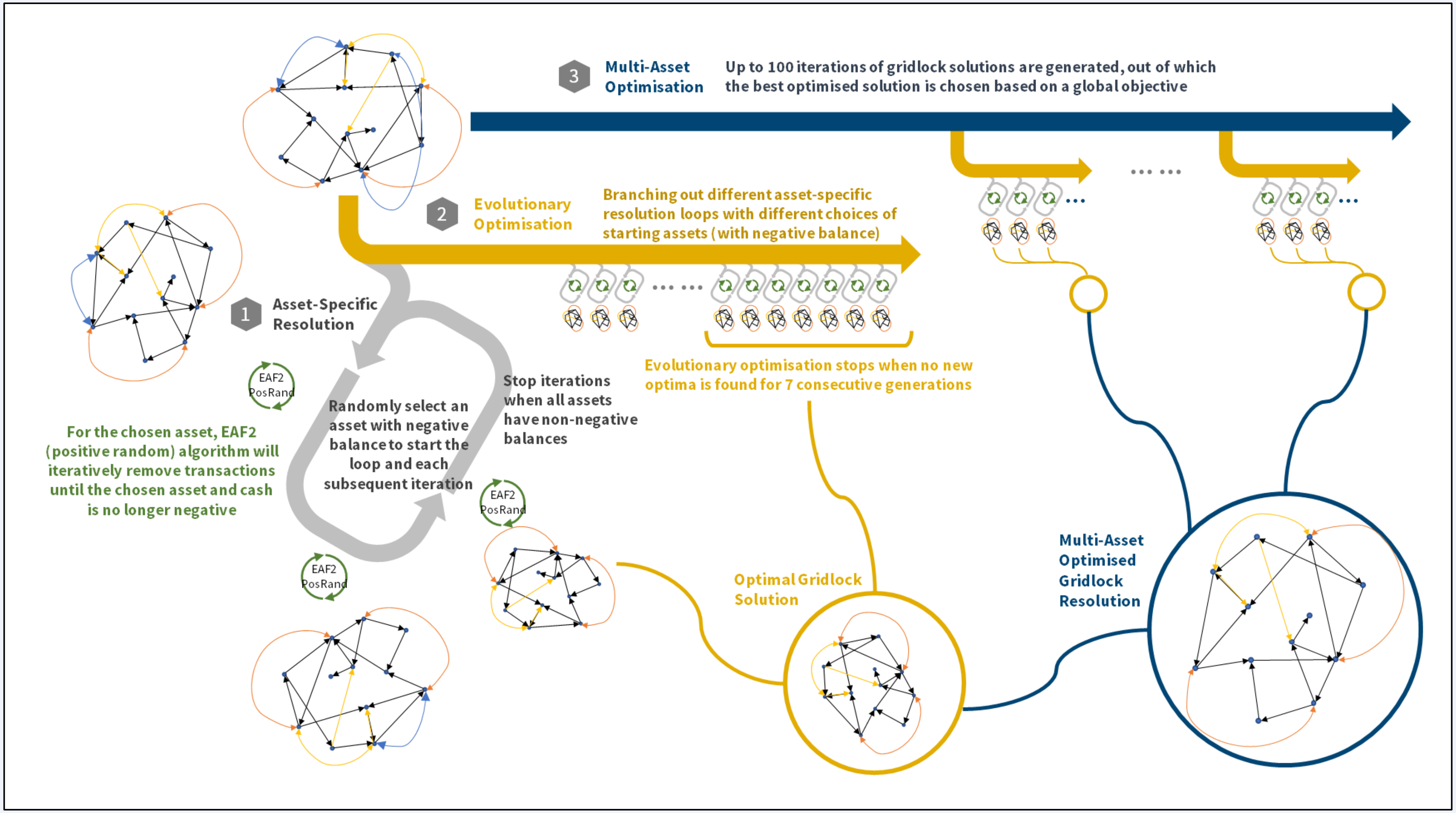


Figure 12: the above is a schematic representation of the multi-assets gridlock resolution algorithm using a graph representation of the payment instructions across participants and across assets. Starting with a complete graph (of all payment instructions), the algorithm executes across 3 layers of nested loops - the multi-asset optimisation (blue) that nests and iterates evolutionary optimisation (yellow) which in turns nests and iterates asset-specific resolution (grey) within which a modified EAF2 is performed (green).

9.3 CLUSTER OF NOTARIES

Centralised single notary service, which is adopted in Phase 1 and 2, may raise a concern of constituting to a-single-point-of-failure problem. A clustered notary service using Corda Enterprise offering is a well-tested approach for alleviating such concerns and enhancing system resiliency. This involves setting up multiple notary worker nodes on a Percona XtraDB Cluster. Such a notary cluster may be further geo-distributed across different physical locations.

NOTARY CLUSTER ARCHITECTURE

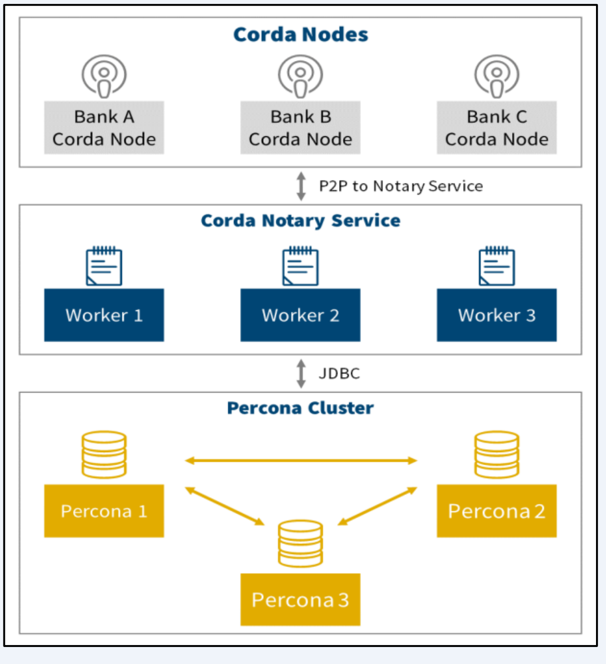


Figure 13: Illustration of the cluster architecture. The figure above displays Corda client nodes in green on the top, then the Corda notary worker nodes in red in the middle and on the bottom are the Percona nodes in blue. Client nodes that request a notarisation by the service name of the notary, connect to the available worker nodes in a round-robin fashion. The task of a worker node is to verify the notarisation request, the transaction timestamp (if present), and resolve and verify the transaction chain (if the notary service is validating). It then commits the transaction's input states to the Percona database. Since our notary cluster consists of several Percona nodes and several worker nodes, we achieve high availability (HA). Individual nodes of the Percona and notary clusters can fail, while clients are still able to notarise transactions. The notary cluster remains available. A three-node Percona cluster as shown in the figure above can tolerate one crash fault. In production, it is recommended that 5 nodes or more should be considered to enable tolerance of more than 1 simultaneous crash fault.

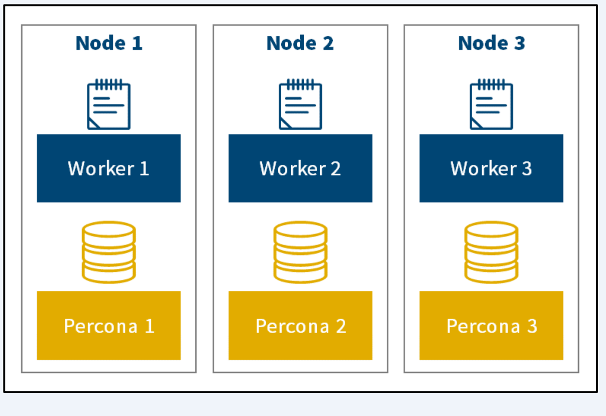


Figure 14: Illustration depicts co-locating a Percona server and a Corda notary worker on the same virtual machine.

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"I am honoured to have had the opportunity to work on such a ground-breaking project and gain first-hand experience on DLT development.

Supagan
Bank of Thailand

"It was a pleasure working together with some of the brightest minds in the industry and helping to drive change and improvements in the financial market infrastructure in Thailand.

Worapol
Bank of Thailand

"Working on a national scale project with developers across the industry has been a fantastic experience and helped me to expand my knowledge on DLT.

Thanapon
Bangkok Bank

"This project has provided me with invaluable experience on DLT software development and allowed me to build my capabilities as a developer.

Natpong
Bank of Ayudhya

"Through this project, I was allowed to delve deeper into the world of DLT and understand the intricacies behind it.

Project Inthanon has broadened my perspective on the world of development, allowing me to learn and experiment with coding with Kotlin on the Corda platform.

Samanun
Kasikornbank

I am glad to have had this opportunity to explore areas outside of my comfort zone and develop myself by learning about DLT.

Supatporn
Siam Commercial Bank

Thank you Project Inthanon for creating a collaborative environment for us to explore and learn more about the business and technical aspects of DLT.

Patsakorn
Thanachart Bank

Even though the development journey was tough, I believe the innovative solutions created will greatly improve the overall efficiency and transparency of financial services in Thailand.

Yogesh & Suvit
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