BANK INDONESIA
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Proof of Concept (PoC) Report

Project Garuda

Wholesale Rupiah Digital Cash Ledger

December 2024

Project Garuda: Proof of Concept (PoC) Report
Wholesale Rupiah Digital Cash Ledger

BANK INDONESIA
Jalan M.H. Thamrin No.2
Jakarta - 10350
Indonesia

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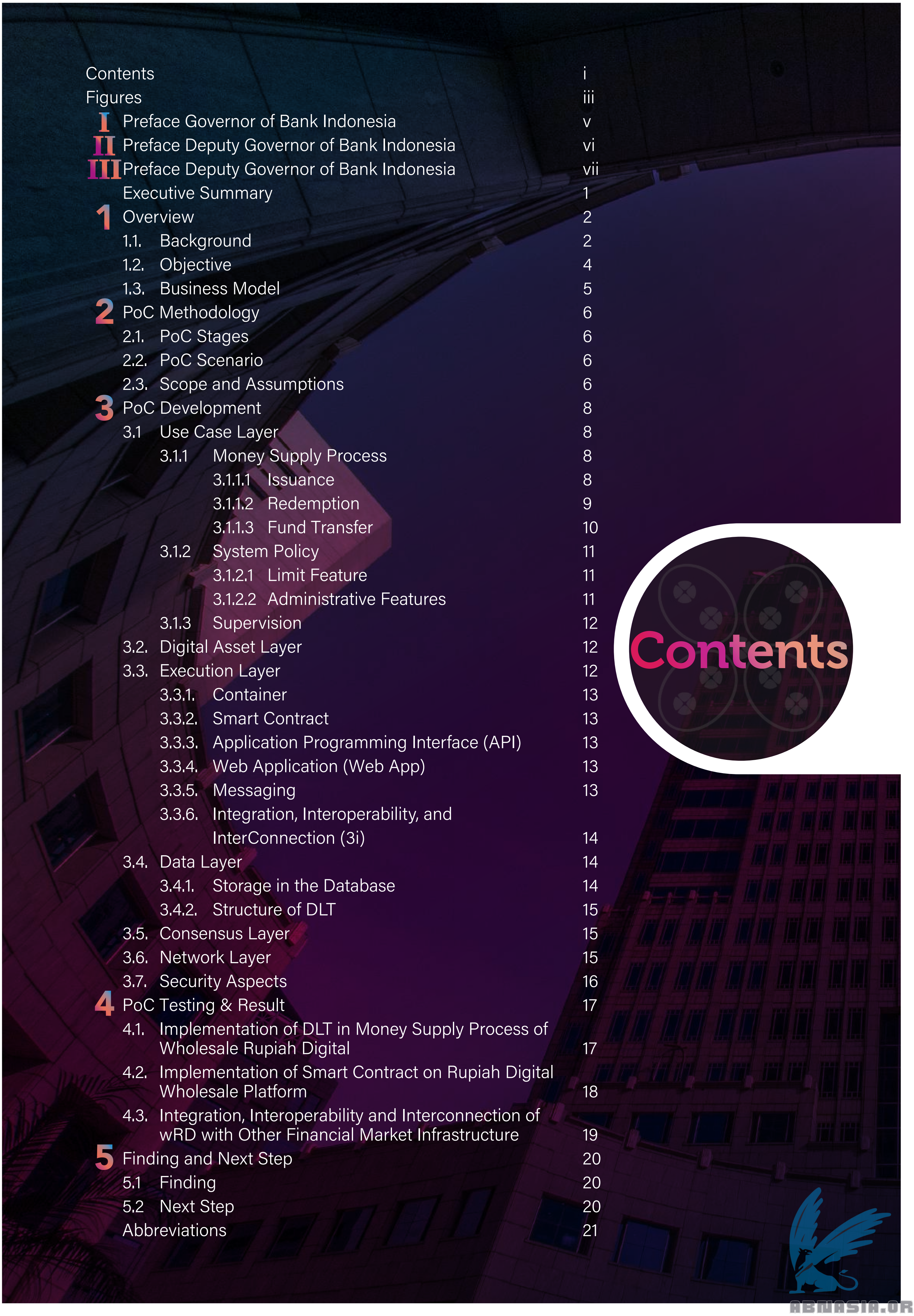
Design and Layout by Setyo Kuncoro, Bagas Aji Pratama, Kevin Eza Rizky,
Timothy Thamrin Andrew H. Sihombing, Sirria Panah Alam, Dewi Septina Br Pelawi,
Bijak Antusias Sufi, Faradilla Azranur, Dian Nofitri, Annisa Muzdalifa



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GOVERNOR OF BANK INDONESIA

Assalamu'alaikum Warahmatullahi Wabarakatuh,
Greetings to all of us, Shalom, Om swastiastu, Namo buddhaya, Greetings of virtue.

Currently, Bank Indonesia through the Project Garuda has completed the first phase of the Rupiah Digital exploration journey, known as the Immediate State, which is marked by the completion of the proof of concept wholesale cash ledger Rupiah Digital. This achievement is a manifestation of Bank Indonesia's commitment to the development of the Rupiah Digital in response to the rapid growth of the digital financial economy and in its position as the sole authority in issuing legal currency in the Republic of Indonesia.

The development of the Rupiah Digital is carried out by prioritizing the public interest while carrying out the mandate of the effectiveness of the implementation of Bank Indonesia's duties. This makes the Rupiah Digital critical to complement the digitalization of the payment system, especially in supporting the development of an increasingly decentralized digital financial economy in the future. The Rupiah Digital is also directed to be integrated, interoperable, and interconnected with the current payment system and financial market infrastructure, both domestically and cross-border.

The proof of concept stage of wholesale cash ledger Rupiah Digital is taken to ensure the use of the right technology in meeting the design needs of the Rupiah Digital which has also considered various views and public inputs. We see the proof of concept as an essential step to evaluate the feasibility of the technology that will be the basis for the operationalization of the Rupiah Digital in the future, including identifying potential risks. We hope that the proof of concept will not only serve as a means of technical testing, but also as a tool to ensure the long term adoption and success of implementing the Rupiah Digital in Indonesia.

The publication of this report is a manifestation of Bank Indonesia's transparency in every stage of the development of the Rupiah Digital. Bank Indonesia will continue to advance with the Project Garuda initiative in responding to future payment system challenges. We hope that this project will have a great impact and benefit the entire nation, especially in maintaining the sovereignty of the Rupiah in the digital era.

Wassalamu'alaikum warahmatullahi wabarakatuh

Jakarta, December 2024

Perry Warjiyo
Governor of Bank Indonesia

PREFACE

DEPUTY GOVERNOR OF BANK INDONESIA

Assalamu'alaikum Warahmatullahi Wabarakatuh,
Greetings to all of us, Shalom, Om swastiastu, Namo buddhaya, Greetings of virtue.

Bank Indonesia, through the Project Garuda, has completed the proof of concept for Rupiah Digital in the first phase of the wholesale cash ledger, known as the Immediate State. This proof of concept is a strategic step in testing the feasibility of technology that supports the development of the Rupiah Digital business model. The testing was done comprehensively, covering critical technical aspects, transaction security, and interoperability with existing payment systems and financial infrastructure. The proof of concept design, deeply focused on these three aspects, aiming to ensure that the developed system can deliver efficient, secure, and reliable services.

Each stage of the technology testing is a crucial element in the process of enriching ideas, exploring innovation, and validating previously formulated concepts. This testing was conducted using 2 (two) potential technology platforms based on distributed ledger technology (DLT), which underwent thorough technical evaluations and were aligned with the projected needs of the Rupiah Digital business model in the future. The results of the testing show that both technology platforms have different characteristics and advantages, especially in terms of resilience, privacy, speed, scalability, and fault tolerance. The overall results of the proof of concept were able to meet all test scenarios and prove that distributed ledger technology-based solutions can meet the business and technical needs of the wholesale Rupiah Digital cash ledger.

This initial phase of the proof of concept marks an important milestone in the development of the Rupiah Digital. The success and various insights from this proof of concept will form the foundation for strengthening the business and technical aspects of the Rupiah Digital in the future.

Moving forward, we are committed to continuing the exploration of the Rupiah Digital through the Intermediate State phase in Project Garuda. We hope that the exploration of the Rupiah Digital can support Bank Indonesia's efforts to maintain the sovereignty of the Rupiah and provide an innovative and inclusive solution to address various challenges arising from the development of digital economy and finance in the future.

Wassalamu'alaikum warahmatullahi wabarakatuh

Jakarta, December 2024

Juda Agung
Deputy Governor of Bank Indonesia

PREFACE

DEPUTY GOVERNOR OF BANK INDONESIA

Assalamu'alaikum Warahmatullahi Wabarakatuh,
Greetings to all of us, Shalom, Om swastiastu, Namo buddhaya, Greetings of virtue.

The Rupiah Digital, as one of the five initiatives (4 I + 1 RD) in the Indonesia Payment System Blueprint 2030, is currently being explored under the Project Garuda. Each stage of the Project Garuda is carried out through an ongoing iterative process, starting from design drafting to testing the technological feasibility through proof of concept. Bank Indonesia has received various constructive public inputs regarding the design of the wholesale Rupiah Digital cash ledger, which will be tested in the proof of concept.

Collaboration with the public is a key element in the development of the Rupiah Digital. We have conducted a series of consultations and received valuable input from industry, associations, ministries/institutions, academics, and the community. The results of the consultative paper that we received until July 15, 2023, provide in-depth insights and become constructive inputs in improving the design of the Rupiah Digital. Active participation of various stakeholders enriches the development process and ensures that the resulting Rupiah Digital meets the needs and expectations of all stakeholders.

Proof of concept for the wholesale Rupiah Digital cash ledger is focused on testing the business model, particularly related to the processes of issuance, redemption, and fund transfer. We explore a range of use case scenarios and the potential economic benefits that could be gained. This approach ensures that the proposed business model is not only financially sustainable but also adds value to all stakeholders, including banks, financial institutions, and the public.

Overall, this proof of concept plays a crucial role in laying a strong foundation for the Indonesia Payment System Blueprint 2030 initiative, which aims to further integrate digital payment systems into the national economy, facilitate financial inclusion, and promote sustainable economic growth. The proof of concept report is one of the milestones in the early development of the Rupiah Digital, part of the Indonesia Payment System Blueprint 2030's efforts to provide a secure, efficient, and responsive payment solution that meets the needs and expectations of all stakeholders in the digital era.

The involvement and contributions of various stakeholders are key elements in enriching insights to design a Rupiah Digital that best fits the needs of Indonesia's industry and society. Therefore, Bank Indonesia is committed to continuously engaging the public in every iteration of the Rupiah Digital's development.

"Innovation thrives when people come together and collaborate."
— Chris Anderson

Wassalamu'alaikum warahmatullahi wabarakatuh

Jakarta, December 2024
Filianingsih Hendarta
Deputi Gubernur Bank Indonesia

EXECUTIVE SUMMARY

Central bank digital currency (CBDC) is one of the potential uses of distributed ledger technology (DLT) by central banks, which combines the capabilities of distributed ledger technology with the central bank's mandate to issue fiat currency. Bank Indonesia is striving to explore the Rupiah Digital as a form of Indonesia's CBDC through the Project Garuda.

The White Paper "Project Garuda: Navigating the Rupiah Digital Architecture" divides the exploration of the Rupiah Digital into 3 (three) stages: Immediate State, Intermediate State, and End State. This proof of concept (PoC) report is part of the Immediate State, focusing on the exploration of the wholesale Rupiah Digital (wRD) Cash Ledger.3 (three) business processes were tested: issuance, redemption, and fund transfer.

This proof of concept report is a continuation of the Project Garuda's activities. The design and business model tested in the proof of concept were established through previous phases of the Project Garuda, including public consultations via the "Consultative Paper of the Project Garuda Wholesale Rupiah Digital Cash Ledger" and the outcomes of these consultations in the "Public Consultation Report."

The design and business model, resulting from public consultations, will be developed and tested using 2 (two) distributed ledger technology platforms, namely Corda and Hyperledger Besu. To ensure the sustainability of the solution, the development was conducted by the principal developers of each technology: Corda, developed by R3, and Hyperledger Besu, developed by Kaleido.

In addition to detailing the 3 (three) business processes, technical evaluations were conducted on both platforms, focusing on resilience, privacy, and performance aspects of each distributed ledger technology. These evaluations were carried out through 55 test scenarios aimed at answering 3 (three) key questions (KQ):

1. How can distributed ledger technology be leveraged to implement the wRD business model?
2. What are the potential benefits and added value of integrating smart contracts into wRD?
3. How can wRD connect to conventional systems, Bank Indonesia's internal systems, cross-border transactions, and other distributed ledger technologies, in alignment with the principles of integration, interoperability, and interconnection (3i)?

Both platforms successfully developed all scenarios according to the characteristics of their respective technologies. Corda uses a consensus mechanism where a central party validates transactions ("notary") and transaction data is stored in a connected manner from one transaction to another ("directed acyclic graph"). Hyperledger Besu uses a consensus mechanism where transaction validation is carried out by several predetermined validators ("proof-of-authority"), and transaction data is stored in interconnected transaction blocks ("blockchain").

Both platforms were able to meet all testing scenarios and address all key questions. First, distributed ledger technology can effectively support the implementation of a wholesale Rupiah Digital cash ledger. Second, smart contracts offer added value in terms of flexibility for the Rupiah Digital development and transaction efficiency. Third, distributed ledger technology can connect with conventional systems using existing standards and with other systems using the ISO 20022 standard.

The PoC results indicate that there are potential areas that can be further explored regarding privacy, liquidity management, and multi-validator deployment.

CHAPTER 1 OVERVIEW

The proof of concept (PoC) Report for wRD is a follow-up to the Project Garuda, aiming to identify the most suitable technology solutions according to the needs and characteristics of Indonesia's payment ecosystem. The exploration of these needs and characteristics was previously conducted through the publication of a White Paper, a Consultative Paper, and a Public Consultation Report.

1.1. BACKGROUND

Technological advances are driving innovation in the payment ecosystem through distributed ledger technology (DLT)[1]. Central banks worldwide recognize the potential of DLT and are actively exploring its applications. One significant potential use of DLT by central banks is the creation of central bank digital currency (CBDC), which leverages DLT to fulfill the central banks mandate to issue fiat currency.

While central banks share similar views on the potential of CBDC, their specific objectives vary. Some central banks regard CBDC as a means to maintain relevance amid the steady decline in cash usage or as a strategy to enhance financial inclusion. **CBDC could bolster Indonesia's existing payment ecosystem.**

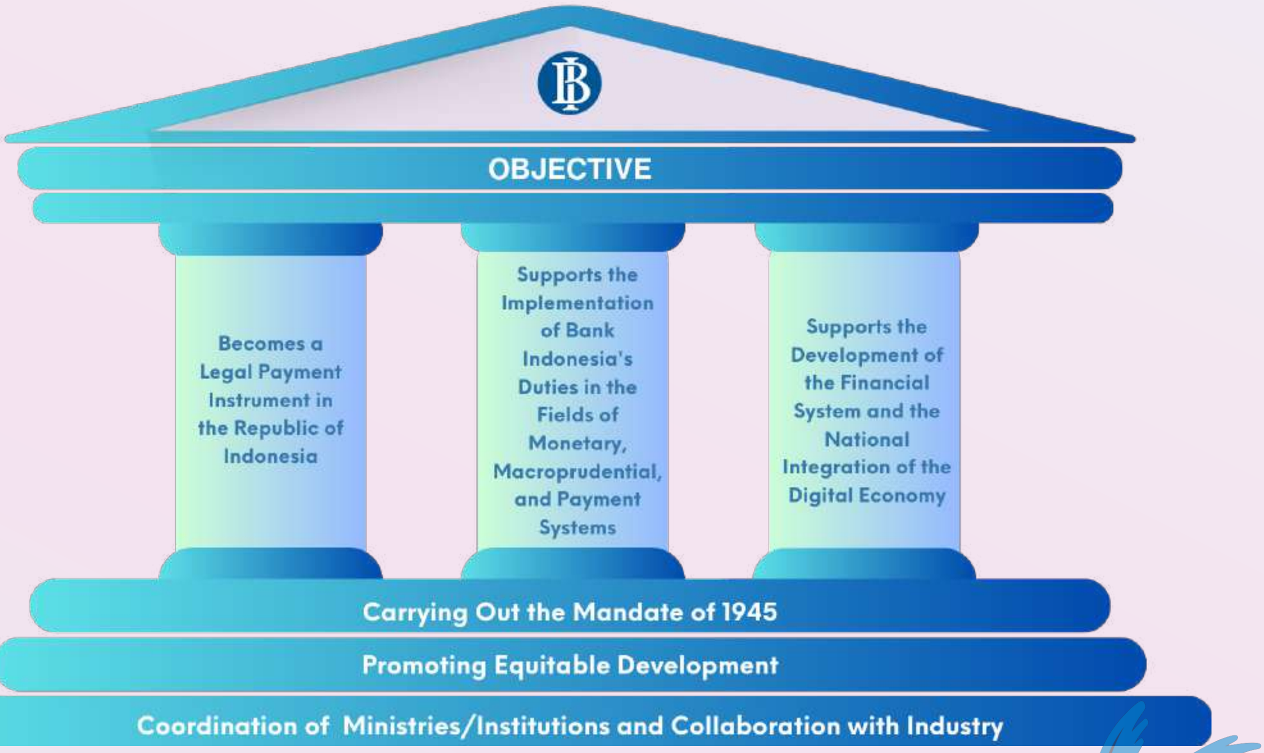
The Rupiah Digital's potential to strengthen Indonesia's payment ecosystem depends on achieving 3 (three) goals, as illustrated in Figure 1:

1. Becoming a legal digital payment instrument in the Republic of Indonesia;
2. Supporting Bank Indonesia's objectives in monetary policy, Financial System Stability (SSK), and Payment System (SP) sectors in the digital era; and
3. Increasing the inclusion, innovation, and efficiency of the financial system.

Bank Indonesia is exploring the Rupiah Digital to achieve these goals through the Project Garuda initiative.

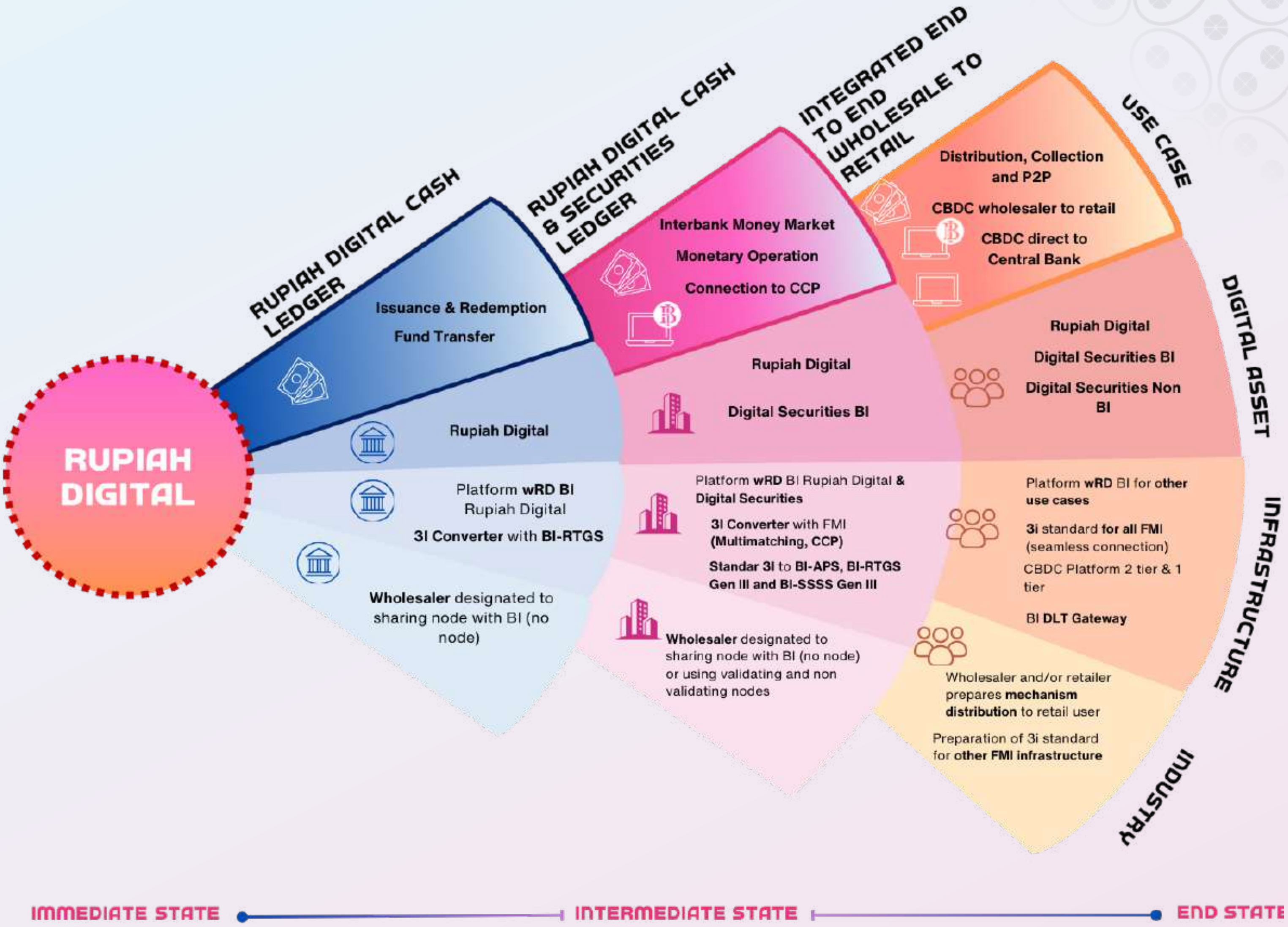
The Project Garuda is an initiative by Bank Indonesia to explore a digital version of the Rupiah, complementing existing paper and

Figure 1. Three Goals of the Rupiah Digital


OBJECTIVE
Becomes a Legal Payment Instrument in the Republic of Indonesia
Supports the Implementation of Bank Indonesia's Duties in the Fields of Monetary, Macroprudential, and Payment Systems
Supports the Development of the Financial System and the National Integration of the Digital Economy
Carrying Out the Mandate of 1945
Promoting Equitable Development
Coordination of Ministries/Institutions and Collaboration with Industry

[1] Distributed ledger technology is a database distributed across multiple locations or institutions and is typically public. One well-known form of DLT implementation is 'Blockchain'.

Figure 2. Project Garuda Stages


RUPIAH DIGITAL
RUPIAH DIGITAL CASH LEDGER
Issuance & Redemption
Fund Transfer
Rupiah Digital
Platform wRD BI Rupiah Digital
3I Converter with BI-RTGS
Wholesaler designated to sharing node with BI (no node)
RUPIAH DIGITAL CASH & SECURITIES LEDGER
Interbank Money Market
Monetary Operation
Connection to CCP
Rupiah Digital
Digital Securities BI
Platform wRD BI Rupiah Digital & Digital Securities
3I Converter with FMI (Multimatching, CCP)
Standar 3I to BI-APS, BI-RTGS Gen III and BI-SSSS Gen III
Wholesaler designated to sharing node with BI (no node) or using validating and non validating nodes
INTEGRATED END TO END WHOLESALE TO RETAIL
Distribution, Collection and P2P
CBDC wholesaler to retail
CBDC direct to Central Bank
Rupiah Digital
Digital Securities BI
Digital Securities Non BI
Platform wRD BI for other use cases
3i standard for all FMI (seamless connection)
CBDC Platform 2 tier & 1 tier
BI DLT Gateway
Wholesaler and/or retailer prepares mechanism distribution to retail user
Preparation of 3i standard for other FMI infrastructure
USE CASE
DIGITAL ASSET
INFRASTRUCTURE
INDUSTRY
IMMEDIATE STATE
INTERMEDIATE STATE
END STATE

coin forms used so far. This exploration aims to preserve the Rupiah's sovereignty in the digital era, in accordance with Act No. 4 of 2023 concerning Financial Sector Development and Strengthening (P2SK), specifically section six titled 'Rupiah Digital'.

Similar to how banknotes in different countries feature distinct designs and security elements, the Rupiah Digital's design must be tailored to the Indonesian payment ecosystem's needs and characteristics. At the end of 2023, Bank Indonesia began exploring the design, impact, and benefits of the Rupiah Digital for Indonesia. The findings from these explorations were subsequently published in 3 (three) documents: the White Paper, the Consultative Paper, and the Public Consultation Report.

The White Paper published in November 2023 outlines the exploration of the Rupiah Digital in 3 (three) stages, as depicted in Figure 2. The first stage is the Immediate State that involves exploring a cash ledger wholesale Rupiah Digital. The second stage is the Intermediate State, which expands the wholesale Rupiah Digital use case to include Digital Assets. The third stage is the End State, which examines interconnection with other DLTs, including cross-border transactions. Each stage prioritizes the sustainability of the money supply process, aligning with Bank Indonesia's policies.

At each stage of the Rupiah Digital project, 3 (three) series of activities were conducted, as illustrated in Figure 3. The first activity is the publication of the Consultative Paper (CP), which serves as a form of communication and public consultation to gather input on the business model at each stage. The second activity involves issuing a Public Consultation Report, summarizing the public input that will be tested. The third activity is the implementation of a proof of concept (PoC) to evaluate the feasibility of technology solutions based on the business model outlined in the Public Consultation Report. These activities ensured that the Rupiah Digital was developed with an optimal design.

This proof of concept (PoC) report continues the Rupiah Digital's exploration of technological solutions for the Rupiah Digital wholesale cash ledger (wRD) business model. The high-level design of wRD is outlined in the Project Garuda White Paper, the Consultative Paper published

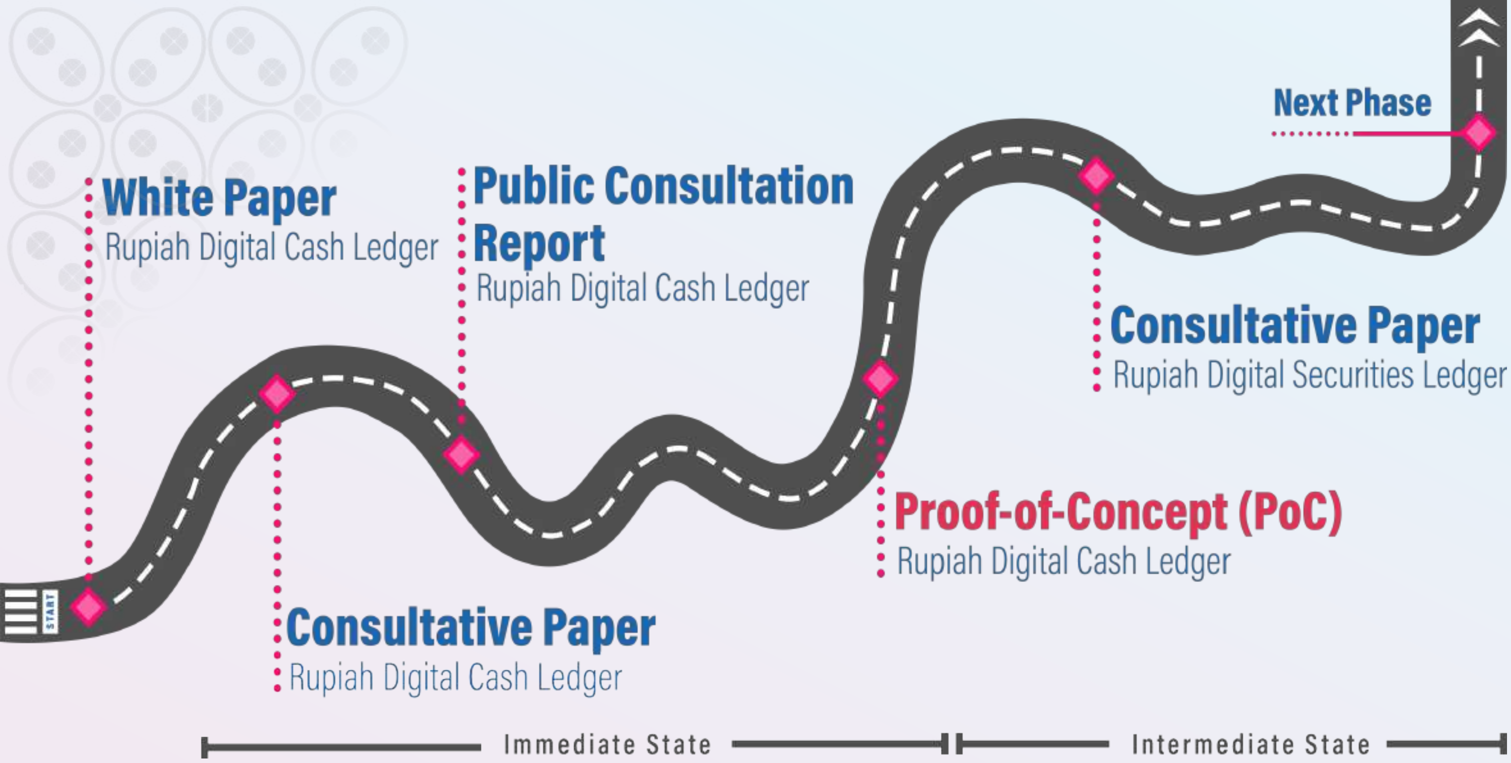

White Paper
Rupiah Digital Cash Ledger
Public Consultation Report
Rupiah Digital Cash Ledger
Next Phase
Consultative Paper
Rupiah Digital Securities Ledger
Proof-of-Concept (PoC)
Rupiah Digital Cash Ledger
START
Consultative Paper
Rupiah Digital Cash Ledger
Immediate State
Intermediate State

Figure 3. Project Garuda Activities

in January 2023, which included public input on the design of the cash ledger, and the Public Consultation Report published in October 2023. These documents also define the business model, including the design of the money supply process and the arrangement of wRD membership.

The wRD money supply process tested in the PoC encompasses issuance, fund transfer, and redemption. In the Immediate State, these processes did not create new monetary value (no money creation), as they utilized the conversion of funds in reserve accounts for the issuance and redemption of the Rupiah Digital. Membership arrangements defined the roles of wRD participants, enabling the establishment of a distributed wRD ecosystem by delegating transaction validation authority to these participants.

The Immediate State of the Rupiah Digital PoC report is presented with the following structure:

1. **Overview,** this section includes the background, objectives, and business model of wRD;
2. **PoC Methodology,** this section explains the implementation of the PoC, including the stages, scenarios, scopes, and assumptions used during the PoC;
3. **PoC Development,** this section describes the development of the wRD platform;
4. **PoC Testing and Results,** this section addresses the objectives of the PoC based on the test results;
5. **Findings and Next Step,** this section explains the findings from the PoC results and outlines future exploration plans.

1.2. OBJECTIVE

The primary objective of the PoC is to identify the most suitable solution for the wRD platform. Based on the evaluation results (see Apendix A), 2 (two) potential DLT platforms have been identified for further exploration: Corda[2] and Hyperledger Besu[3]. The development of both platforms during the PoC was supported by the respective principals, R3 for Corda and Kaleido for Hyperledger Besu. Support from these principals will ensure the sustainability of the solutions developed during the PoC. The solution in the PoC was developed by the principal specifically to meet the needs of Bank Indonesia.

To address the primary objectives of the PoC, 3 (three) key questions have been developed:

1 How can DLT be leveraged to implement the wRD business model?

2 What are the potential benefits and added value of implementing smart contracts on wRD?

3 How can wRD connect to conventional systems, Bank Indonesia's internal systems, cross-border systems, and other DLTs, based on the principles of integration, interoperability[4], and interconnection (3i)?

[2] A blockchain platform that shares transaction data only with the parties involved in the transaction. It is available in an open-source version and an enterprise version called Corda Enterprise.

[3] An open-source blockchain protocol and platform established by Linux Foundation. Hyperledger Besu is a Java-based Ethereum client. Hyperledger Besu adheres to the specifications of the Enterprise Ethereum Alliance (EEA).

[4] The ability of 2 (two) or more systems to exchange information or conduct transactions without middleware.

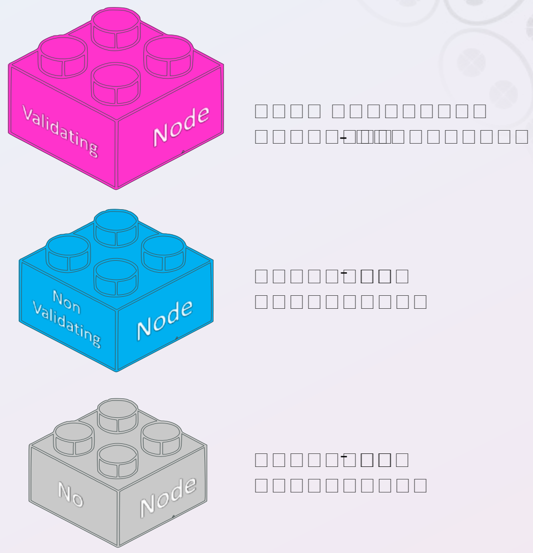
1.3. BUSINESS MODEL

wRD's primary business model encompasses its money supply process and membership arrangements. The money supply process in the Immediate State is conducted through the conversion of current accounts (no-money creation). Concurrently, the wRD membership structure is designed to delegate transaction validation authority to participants (node[5]).

Figure 4 outlines the membership arrangements for wRD participants. Transaction validation authority will be delegated to appointed participants (wholesalers), who can act as validating nodes[6] alongside Bank Indonesia. Meanwhile, non-wholesaler participants can become non-validating nodes[7] or no-nodes[8].

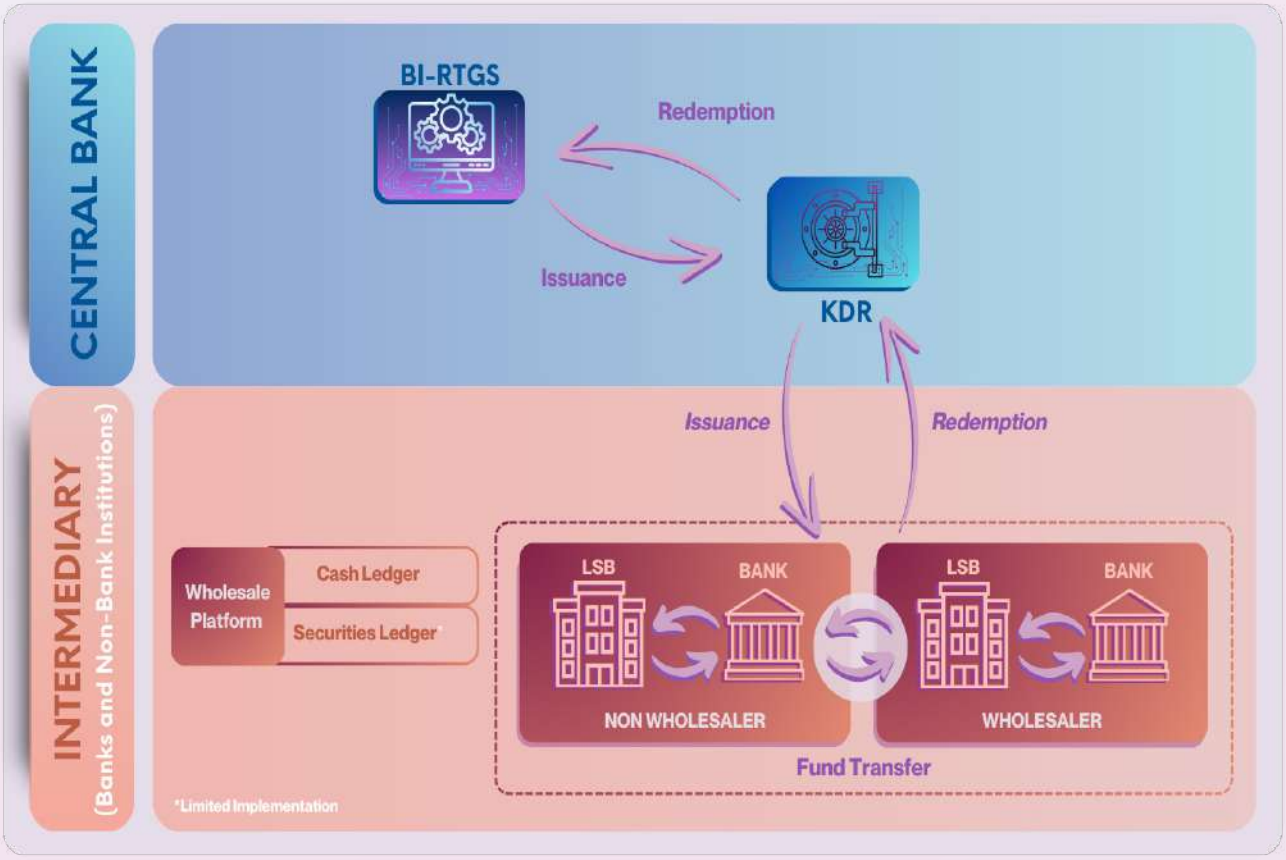
The White Paper illustrates the wRD money supply process in Figure 5, detailing the cycle and interconnectedness of the Rupiah Digital. This cycle begins with issuance and concludes with redemption through the conversion of current accounts in BI-RTGS.

Figure 4. wRD Membership Registration



The Rupiah Digital Treasury, or Khazanah Digital Rupiah (KDR), owned by the central bank, will facilitate this conversion. Unlike a traditional treasury that stores money, KDR acts as a facilitator and does not hold the Rupiah Digital. Instead, KDR will maintain a zero balance and solely distribute money to participants. Participants possessing the Rupiah Digital can transact with other participants on the web platform.

Figure 5. Money Supply Process at wRD



[5] A node is a representation of a participant or party in a DLT network.

[6] Validating node: a participant authorized to manage/store wRD tokens and validate transactions (Public Consultation Report, Project Garuda, 2024).

[7] Non-validating node: a participant authorized to manage/store wRD tokens (Public Consultation Report, Project Garuda, 2024).

[8] No-node: a participant authorized to manage/store wRD tokens but does not have a node and only needs to provide a network connection to access multitenancy services (Public Consultation Report, Project Garuda, 2024).

CHAPTER 2
POC METHODOLOGY

The PoC methodology outlines a systematic approach to achieving the objectives of the PoC. It encompasses the stages, test scenarios, and scope necessary to ensure comprehensive execution of every aspect of the PoC.

2.1. POC STAGES

The wRD PoC is structured into 3 (three) stages to clearly define the scope, focus on the objectives of each stage, and mitigate the risks associated with PoC implementation. The implementation of the wRD PoC involves the Project Garuda Workstream (WS)[9]. The details of the 3 (three) stages are as follows:

1 **Pre PoC**

This stage explores and transforms 3 (three) key questions in this PoC into test scenarios. These activities are conducted through workshops and requirements gathering sessions with stakeholders. During this stage, Bank Indonesia shortlisted 2 (two) technology platforms based on its needs and considerations.

2 **Main PoC**

This stage focuses on building and executing test scenarios on both technology platforms. Both platforms are developed and tested in parallel using agile and iterative approaches.

3 **Post PoC**

This stage involves a detailed analysis of the test results from the Main PoC stage, which are then documented in a comprehensive report.

2.2. POC SCENARIO

The 3 (three) critical questions of the PoC will be addressed through 55 test scenarios (see Appendix H). Building and executing these test scenarios provides a solid foundation for answering key questions and gaining insights for the future development of the Rupiah Digital. The test scenarios are divided into 2 (two) aspects:

1. Business aspect (functional): focusing on "what" the system/platform should do;
2. Technical aspect (non-functional): focusing on "how" the system/platform should perform its functions.

> *wRD PoC involves Project Garuda Workstream, divided into 3 (three) stages: Pre PoC, Main PoC, and Post PoC.*

2.3. SCOPE AND ASSUMPTIONS

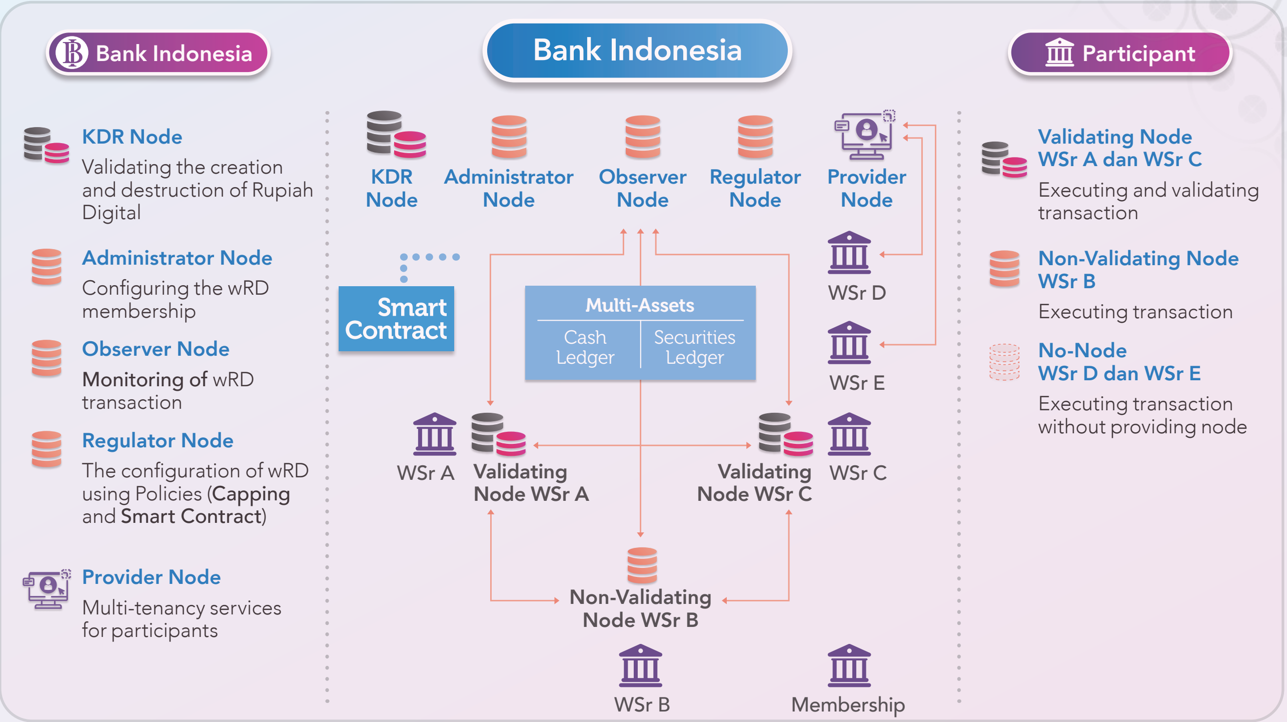
To optimize time and resources, the scope of developing and executing test scenarios has been determined. In this PoC, the model and configuration utilized are illustrated in Figure 6. The wRD platform is designed as a permissioned network, with Bank Indonesia regulating the access and roles of participants.

The wRD platform encompasses various roles and permissions, including:

1. **Master Node (Bank Indonesia)**
   a. KDR Node: responsible for the creation, issuance, redemption, and destruction of the Rupiah Digital.
   b. Regulator Node: determines the rules and policies for managing the Rupiah Digital and oversees smart contract management (see Subchapter 3.3.2).
   c. Observer Node: collects and supervises all transaction activity data on wRD without active participation in the transactions.
   d. Administrator Node: manages participant access on the wRD platform.
   e. Provider Node: supplies multitenant infrastructure for participants who lack infrastructure within the wRD network.
2. **Node Participants (Members)**
   a. Validating Node (Full Node): engages in transaction activities of the wRD and possesses the right to validate transactions.
   b. Non-Validating Node (Light Node): engages in transaction activities of the wRD but lacks the right to validate transactions.
   c. No-Node (Multitenancy): participates in transaction activities of the wRD but does not have infrastructure within the wRD network.

[9] Project Garuda is continuously managed by 3 (three) Workstreams (WS), each with a specific focus: WS1 (business), WS2 (technology), WS3 (regulation).

Figure 6. wRD PoC Configuration

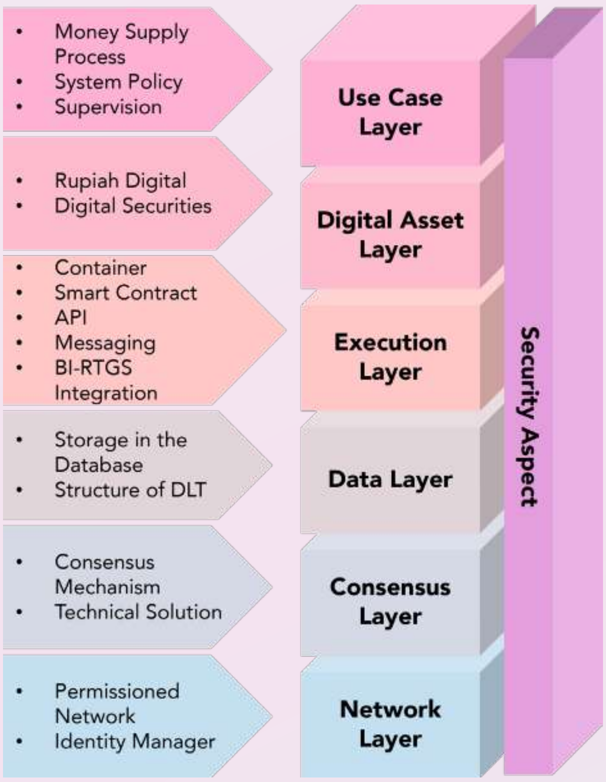

Bank Indonesia
Bank Indonesia
Participant
KDR Node
Validating the creation and destruction of Rupiah Digital
Administrator Node
Configuring the wRD membership
Observer Node
Monitoring of wRD transaction
Regulator Node
The configuration of wRD using Policies (Capping and Smart Contract)
Provider Node
Multi-tenancy services for participants
KDR Node
Administrator Node
Observer Node
Regulator Node
Provider Node
Smart Contract
Multi-Assets
Cash Ledger
Securities Ledger
WSr D
WSr E
WSr A
Validating Node WSr A
Validating Node WSr C
WSr C
Non-Validating Node WSr B
WSr B
Membership
Validating Node WSr A dan WSr C
Executing and validating transaction
Non-Validating Node WSr B
Executing transaction
No-Node WSr D dan WSr E
Executing transaction without providing node

Given the complexity of the DLT system, the concept of the layered architecture, as depicted in Figure 7, has been adopted to facilitate understanding, development, and maintenance. In DLT, there are 6 (six) layers of abstraction and 1 (one) supporting aspect:

1. Use Case Layer: Describes the use cases of applications built on top of the DLT platform;
2. Digital Asset Layer: Describes digital assets developed on top of the DLT platform;
3. Execution Layer: Describes how the DLT platform serves as an environment for executing computer programs;
4. Data Layer: Describes how data is stored and managed;
5. Consensus Layer: Describes how nodes communicate to reach agreement on adding transaction blocks to the ledger;
6. Network Layer: Describes how nodes connect, the protocols used, and the connectivity between nodes and their respective ledgers;
7. Security Aspect: Explains how security is implemented in the DLT platform, encompassing an aspect that is integral to all 6 (six) layers mentioned above.

> *Bank Indonesia together with participant (wholesaler) of wRD platform will have different roles to support operational resilience of wRD platform.*

Figure 7. wRD PoC Architecture



CHAPTER 3
POC DEVELOPMENT

As outlined in the methodology section, the wRD technology architecture layer, which consists of 6 (six) layers of abstraction and 1 (one) supporting aspect (security), was developed in the implementation of PoC using 2 (two) DLT platforms, namely R3 Corda dan Kaleido Hyperledger Besu version 24.3.0. Both DLT platforms have characteristics that meet the objectives of the Rupiah Digital. R3 developed Corda using the Corda Enterprise DLT platform version 4.10, while Kaleido developed Hyperledger Besu using a DLT platform based on Hyperledger Besu.

3.1 USE CASE LAYER

The use case layer is the uppermost layer of the wRD platform, where users interact directly with the platform. The business process in wRD is built on the use case layer, which includes the money supply process, system policy, and supervision. Implementing the wRD business processes involves smart contracts that allow various business processes in the network to be carried out automatically, minimizing human intervention.

3.1.1 MONEY SUPPLY PROCESS

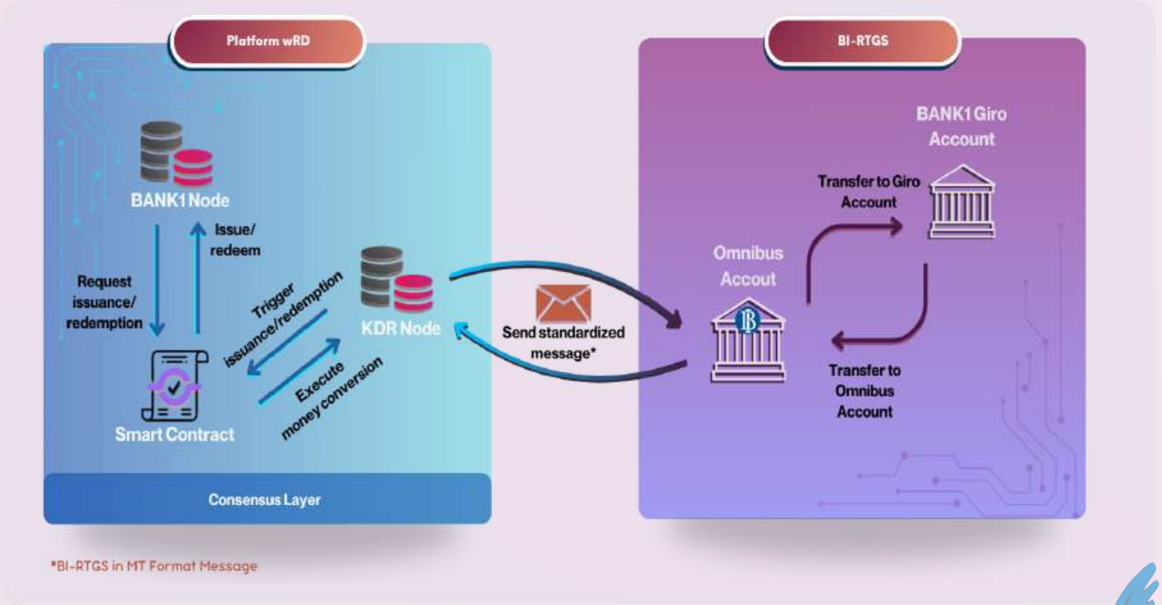
The Rupiah Digital is designed with the principle of no harm to monetary stability and financial system stability. The money supply process consists of issuance, redemption, and transfer. As explained in Figure 8, issuance is carried out through the conversion of current accounts in BI-RTGS into the Rupiah Digital while the process of redemption is carried out through the conversion of the Rupiah Digital into BI-RTGS current accounts. Through this conversion process, there is no addition/decrease in the amount of money in circulation so that in the PoC phase Immediate State there is no creation of new money value.

3.1.1.1 ISSUANCE

Issuance process can be initiated through the wRD platform (Platform Triggered) or BI-RTGS (RTGS Triggered). Both trigger types involve the omnibus account[10] on the BI-RTGS system to complete the settlement on the BI-RTGS side and the KDR node on the wRD platform to make settlements on the wRD side. Figure 9 illustrates the process of issuance carried out by Bank 1 using both types of triggers.

On the BI-RTGS settlement, refer to Figure 9 (a) RTGS triggered issuance; the process begins with debiting the current account and crediting the omnibus account.

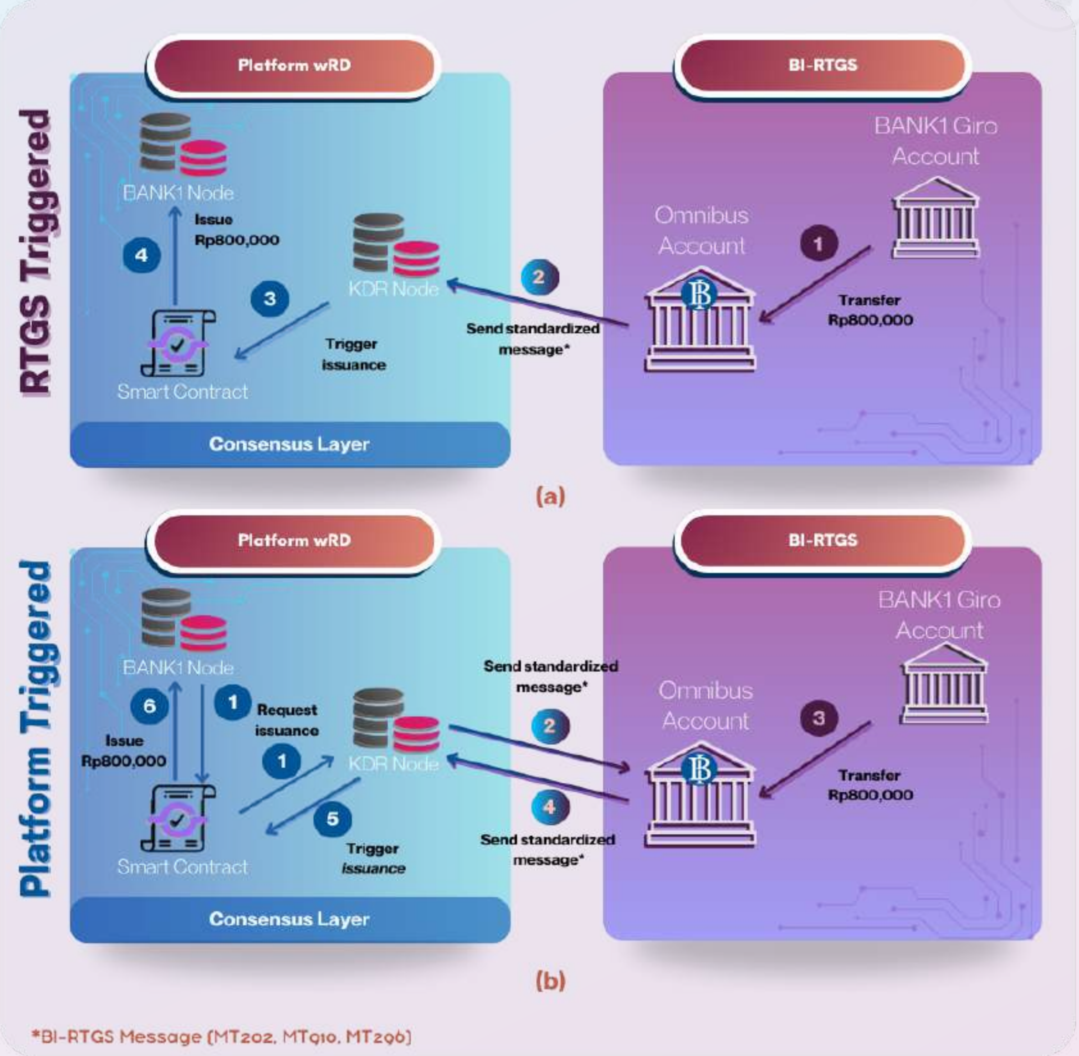
Figure 8. Issuance and Redemption wRD Platform Integrated with BI-RTGS



*BI-RTGS in MT Format Message

[10] The account in BI-RTGS that holds all the participants' funds converted into Rupiah Digital, therefore the giro balance in the omnibus account will be equal to the total Rupiah Digital in circulation. In the omnibus account, all participants' funds are pooled together.

Figure 9. (a) RTGS Triggered Issuance Process (b) Platform Triggered Issuance Process



*BI-RTGS Message (MT202, MT910, MT296)

Then, BI-RTGS sent MT202 along with MT910 to indicate that the settlement on the BI-RTGS side had been completed. Meanwhile, referring to Figure 9 (b) Platform triggered issuance, Bank 1 initiated the issuance of the Rupiah Digital through the wRD platform, which was carried out both when the bank wanted to increase the stock of the Rupiah Digital and when it occurred auto-issuance[11]. Next, a message is exchanged between the KDR node and BI-RTGS using the MT202 standard format.

> *Issuance process can be initiated through the wRD platform (Platform Triggered) or BI-RTGS (RTGS Triggered). Both trigger types involve the omnibus account on the BI-RTGS system to complete the settlement on the BI-RTGS side and the KDR node on the wRD platform.*

Settlement on the wRD side is also known as the process of creating the Rupiah Digital with the implementation according to each technology (see Appendix B.2). On R3 Corda, the creation process will create a new Rupiah Digital token owned by participants. In contrast, in Kaleido Hyperledger Besu, the creation process will add a balance of the Rupiah Digital to the accounts of participating banks through new token minting. R3 Corda and Kaleido Hyperledger Besu validate the creation of transactions through the consensus layer (see Subchapter 3.5).

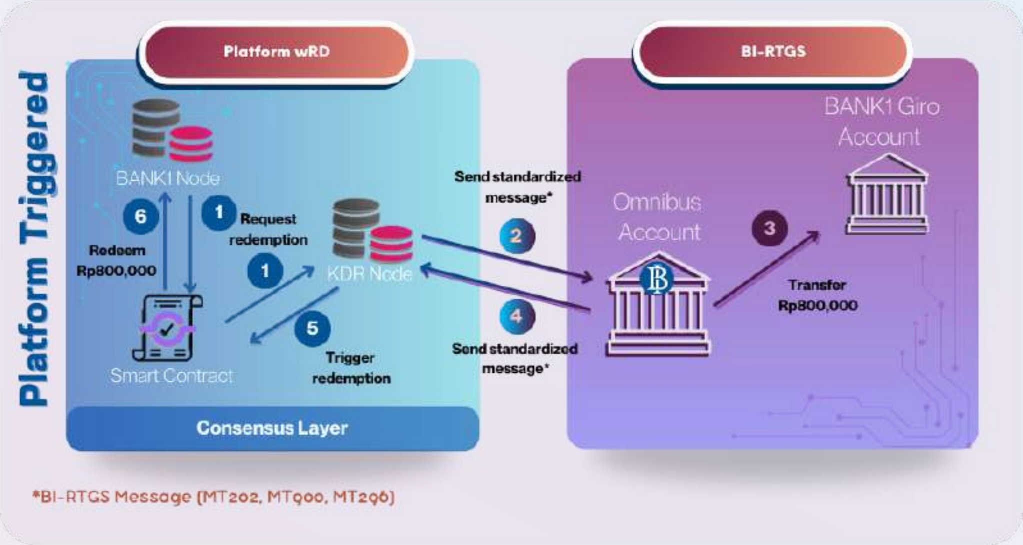
3.1.1.2 REDEMPTION

Redemption is done through the wRD platform (platform triggered)[12] and initiated by the participating banks to Bank Indonesia. The redemption process engages the omnibus account BI-RTGS system to complete settlements on the BI-RTGS side and the KDR node on the wRD platform to make settlements on the wRD side. Figure 10 shows an example of the redemption process by Bank 1.

[11] Auto-issuance occurs when the balance at a participant's bank falls below a threshold set by each bank.

[12] Initiation of the redemption process from BI-RTGS was technically tested but could not be executed commercially due to regulations on the BI-RTGS side (see Appendix B.4).

Figure 10. Redemption Flow Platform Triggered



The bank can initiate redemption when it needs to reduce the Rupiah Digital stock and during the auto-redemption[13] process. Both begin with sending a request to the KDR node, as shown in the Figure 10 (number 1). Furthermore, in process number 2, messages are exchanged between the KDR node and BI-RTGS using the standard MT format.

When BI-RTGS receives MT202, the settlement (number 3) occurs on the BI-RTGS side, then when the process is completed (number 4), MT900 (success) or MT296 (failed) is sent to the KDR node. Furthermore, the KDR node initiates the settlement on the wRD side, also called destruction process, with the implementation according to each technology (see Appendix B.2).

On the destruction process in the R3 Corda platform, the KDR node makes a transaction that destroys the Rupiah Digital token. In contrast, in Kaleido Hyperledger Besu, the KDR node redeems the Rupiah Digital, thus reducing the account balance by sending it to the burn address[14]. The validation process of the transaction involves the consensus layer, which is explained in more detail in Subchapter 3.5. If the KDR node receives a failed message in MT296 format, then the KDR node does not follow up on the redemption request belonging to the participating bank.

3.1.1.3 FUND TRANSFER

The fund transfer process on the wRD platform replicates the practices that apply to the current wholesale payment system. Some of the features of the wholesale payment system include:

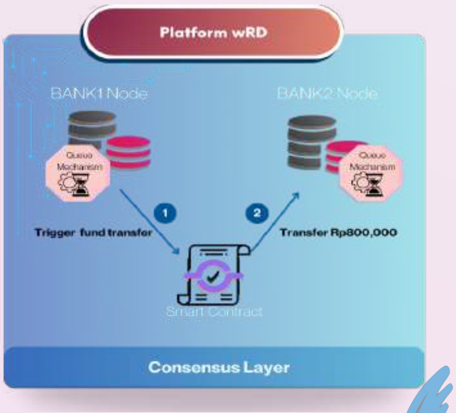
1. Transaction processing occurring in real-time and gross;
2. A queue mechanism, especially for high priority transactions.

The transaction processing feature in the wRD platform will be completed in real-time and gross if the sender has sufficient funds/liquidity and queued if liquidity is insufficient.

Transaction processing features and queue mechanisms will be facilitated through smart contracts, as shown in Figure 11. An additional component outside the smart contract for the queue mechanism was developed for each participant's application. In contrast to issuance and redemption, which require KDR node for current account conversion validation, fund transfers can be validated by any validating node. Distribution of validation allows fund transfer to no longer depend on a central authority, which is made possible by using consensus (see Subchapter 3.5).

A decentralized queue mechanism in which participants are responsible for managing their respective queues is expected to distribute the queue processing load on each node, making the decentralized queue process more resilient than the conventional system.

Figure 11. Fund Transfer Process with Queue Mechanism



[13] Auto-redemption occurs when the balance at a participant's bank exceeds a threshold set by each bank.
[14] Specific address used by Kaleido Hyperledger Besu to burn tokens is 0x0000000000000000000000000000000000000000.

The optimal queue solution for the R3 Corda platform is a First In First Out (FIFO) queue. In FIFO, transactions earlier in the queue are processed first when the participant's balance has fulfilled the transaction.

Meanwhile, the optimal queue solution for the Kaleido Hyperledger Besu platform is a First Available First Out (FAFO) queue, where transactions with sufficient balance are processed first.

Besides decentralized queue, there are model options for queue centrality, which can be further explored (see Appendix G). A centralized queue will manage the queue from all participants by an entity, making it easier to resolve gridlock problems, which causes a transaction not to be completed between participants.

3.1.2 SYSTEM POLICY

The wRD platform must implement transaction and activity management features to support central bank policies. The limit feature regulates the Rupiah Digital transactions, while the administration feature oversees participant activities.

3.1.2.1 LIMIT FEATURE

The limit on wRD is divided into 2 (two) categories based on the regulating party. The first category is the limit set by Bank Indonesia, which applies to all wRD participants. The second category is the limit that each participant can set for themselves.

The limit feature is parameterized to allow adjustments as needed. However, Bank Indonesia has not yet committed to implementing this feature; its development is currently intended for testing purposes only.

Bank Indonesia's limit aims to regulate the amount of the Rupiah Digital in circulation and prevent the concentration of the Rupiah Digital ownership among a few participants. Bank Indonesia sets these limits through regulator node. 6 (six) limits have been developed:

1. **Total circulation limit**, regulates the total amount of the Rupiah Digital that can be circulated at any given time;
2. **Limit per issuance per participant**, sets the maximum conversion value from a current account to the Rupiah Digital that a participant can perform;
3. **Limit per redemption per participant**, sets the maximum conversion value of the Rupiah Digital to a current account that a participant can perform;
4. **Transfer limit between participants**, sets the maximum value of the Rupiah Digital that can be transferred between participants;
5. **Maximum participant balance**, sets the maximum balance that a participant can hold at any given time;
6. **Minimum participant balance**, sets the minimum balance that a participant must hold at all times.

The participant limit aims to manage the liquidity of each participant according to their needs. If the limit set by the participant is exceeded, an automated conversion process (auto-issuance and auto-redemption) will be triggered. 2 (two) limits have been developed for participants:

1. **Maximum balance**, regulates the maximum balance each participant can hold, which cannot exceed the maximum participant balance set by Bank Indonesia.
   The auto-redemption process will be initiated automatically if this limit is exceeded.
2. **Minimum balance**, regulates the minimum balance each participant must hold, which cannot be lower than the minimum participant balance set by Bank Indonesia. If this limit is exceeded, the auto-issuance process will be initiated automatically.

> “*The limit feature is parameterized to allow adjustments as needed...*”

To avoid a continuous conversion process, the PoC also includes a buffer value feature, which acts as an additional value during the automated conversion process.

In its implementation, R3 Corda and Kaleido Hyperledger Besu have incorporated the limits set by Bank Indonesia into smart contracts/ CorDapps. This approach ensures that the limits set by Bank Indonesia are distributed and checked by each participant. Meanwhile, the limits set by participants are implemented within each participant's application using R3 Corda and Kaleido Hyperledger Besu.

3.1.2.2 ADMINISTRATIVE FEATURES

The permissioned DLT network wRD platform requires an administrative feature to manage participant memberships. As a result, 4 (four) administrative features were developed for this purpose:

1. **On-boarding**, allows Bank Indonesia to add new participants to the wRD platform;

2. **Freeze**, Bank Indonesia to stop funds from entering and exiting participant nodes;
3. **Unfreeze**, allows Bank Indonesia to revoke the frozen status of participants;
4. **Off-boarding**, allows Bank Indonesia to remove participants from the wRD platform.

Bank Indonesia can manage these 4 (four) administrative features on the wRD platform using the administrator node. This ensures that Bank Indonesia has the final authority over who can participate in the wRD.

R3 Corda utilized Business Network Membership (BNM) tools to implement membership feature. Kaleido Hyperledger Besu managed membership features via Hierarchical-Deterministic (HD) Wallets. The membership data for both wRD platforms is accessible through smart contracts.

3.1.3 SUPERVISION

For more effective and efficient policy making and to protect participants and customers, Bank Indonesia, as the regulator of the wRD platform, must be able to supervise transactions in real-time. The distribution of transaction data on the DLT platform does not inherently hinder Bank Indonesia's supervisory process. However, it is necessary to balance the need-to-know basis[15] principle in wholesale transactions with the interest in supervision.

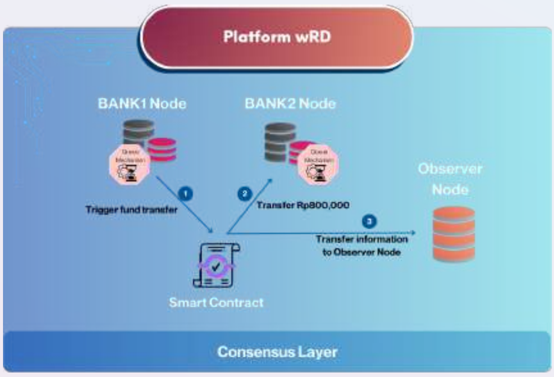
> *...it is necessary to balance the need-to-know basis principle in wholesale transactions with the interest in supervision.*

R3 Corda and Kaleido Hyperledger Besu have distinct characteristics when implementing transaction recording. R3 Corda uses the concept of shared facts, where no singular ledger contains all transaction data. Transaction data on R3 Corda is shared with and stored only by the involved participants. In contrast, on Kaleido Hyperledger Besu, participants have identical data on the ledger, but this data is stored in encrypted form. Only the parties involved can decrypt and access the transaction data. Therefore, a monitoring solution that can be implemented on both platforms while maintaining the confidentiality of participant transactions is necessary.

Monitoring solutions to maintain transaction confidentiality involve adding a node with specific features for supervision. This specific node is the observer node, which receives a copy of the transaction between participants, as shown in Figure 12. The observer node can only be owned and operated by Bank Indonesia.

In R3 Corda, supervision is implemented by utilizing the broadcast feature to the observer node to send transaction data upon settlement finality. Meanwhile, Kaleido Hyperledger Besu implements observer nodes by utilizing the emit event feature on smart contracts.

Figure 12. Observer Node Solution



3.2. DIGITAL ASSET LAYER

The digital asset layer represents the digital assets transacting on the wRD platform. In the wRD technology architecture, Bank Indonesia can manage 2 (two) types of digital assets: the Rupiah Digital and the digital securities. The existence of various digital assets on a single platform is known as a unified ledger. The use of a unified ledger optimizes automation and customization of asset (programmability), integration of one asset with another (composability), and simultaneous settlement of multiple assets (atomic settlement).

The Immediate State phase PoC focuses on developing the Rupiah Digital (cash ledger) assets across all test scenarios. Digital securities assets are developed in a limited manner within the Delivery Versus Payment (DVP)[16] scenario. Further exploration of digital securities assets will be conducted at a later stage.

> *In the wRD technology architecture, Bank Indonesia can manage 2 (two) types of digital assets: Rupiah Digital and digital securities.*

3.3. EXECUTION LAYER

The execution layer comprises components that facilitate the execution of transactions and computing processes on the wRD platform.

[15] Need-to-know basis is a principle where only participants involved in a transaction can access the transaction data.

[16] A securities settlement mechanism that links transfer of securities and transfer of funds in such a way that the delivery of securities occurs only if the corresponding payment has been made.

1. Container, as the development environment for the wRD platform;
2. Smart Contract, as a form of business functionality implementation on the wRD platform;
3. Application Programming Interface (API), as a communication protocol to execute smart contract functions;
4. Web Application (Web App), as an interface to access the wRD platform;
5. Messaging, as a communication method between nodes on the wRD platform;
6. Integration, Interoperability, and Interconnection (3i), as the communication standard between wRD and BI-RTGS.

3.3.1. CONTAINER

The use of containers[17] allows the wRD platform to run consistently across various operating systems. Containers minimize compatibility issues that can affect performance test results. Additionally, containers simplify the scalability of the wRD platform by enabling the creation and management of multiple application instances for performance testing under varying loads. Containers also promote modular application development by packaging all application dependencies within the containers, thereby reducing development complexity. Both platforms utilize Kubernetes[18] as a container orchestration tool.

R3 Corda and Kaleido Hyperledger Besu use a Kubernetes cloud service on AWS called AWS Elastic Kubernetes Service (EKS). The platforms, however, have different Kubernetes cluster configurations (see Appendix C).

3.3.2. SMART CONTRACT

Smart contracts are computer programs that run on blockchain technology and contain the rules and functions of business processes. The use of smart contracts supports the money supply process, system policy, and supervision of the Rupiah Digital.

Each platforms has a different implementation of smart contracts.Smart contract in the R3 Corda, resides within a CorDapp file written in the Java programming language, which operates on the Java Virtual Machine (JVM)[19]. Meanwhile, in Kaleido Hyperledger Besu, smart contracts are created using the Solidity programming language, which runs on the Ethereum Virtual Machine (EVM)[20] (see Appendix C).

3.3.3. APPLICATION PROGRAMMING INTERFACE (API)

Application Programming Interface (API)[21] on R3 Corda solutions utilize the HTTP-REST protocol and are built using Java Spring Boot. The API on R3 Corda serves as an intermediary to execute functions on smart contracts operating within the blockchain, off-chain[22] transactions, and facilitate communication between the back-end and front-end.

Similarly, Kaleido Hyperledger Besu solutions employ the HTTP-REST protocol, built using the Golang programming language. In Kaleido Hyperledger Besu, the HTTP-REST interface can be generated automatically based on the predefined smart contract functions, simplifying the integration with other platforms.

3.3.4. WEB APPLICATION (WEB APP)

A web application (web app) serves as the user interface for executing business processes. In R3 Corda-based solutions, web apps are developed using HTML and JavaScript, with the Angular.js framework, and are stored in cloud storage AWS S3 Bucket. An example of a web app developed with R3 Corda is shown in Figure 13.

In Kaleido Hyperledger Besu-based solution as shown in Figure 14, web apps are developed using HTML and JavaScript. These web apps are then packaged into a container, designed to run after deployment on a Kubernetes cluster.

3.3.5. MESSAGING

Both DLT platforms employ messaging queues[23] to facilitate asynchronous communication between application components within the web platform. R3 Corda utilizes Apache Artemis as its messaging system, whereas Kaleido Hyperledger Besu uses the Firefly Event Bus (see Appendix C).

[17] A container is a virtualization method used to run and distribute applications consistently across various computing environments (portability), which is required by both DLT platforms to be developed.

[18] Kubernetes is a container orchestration tool used to automatically scale applications up and down based on demand.

[19] JVM (Java Virtual Machine) is responsible for executing Java bytecode programs.

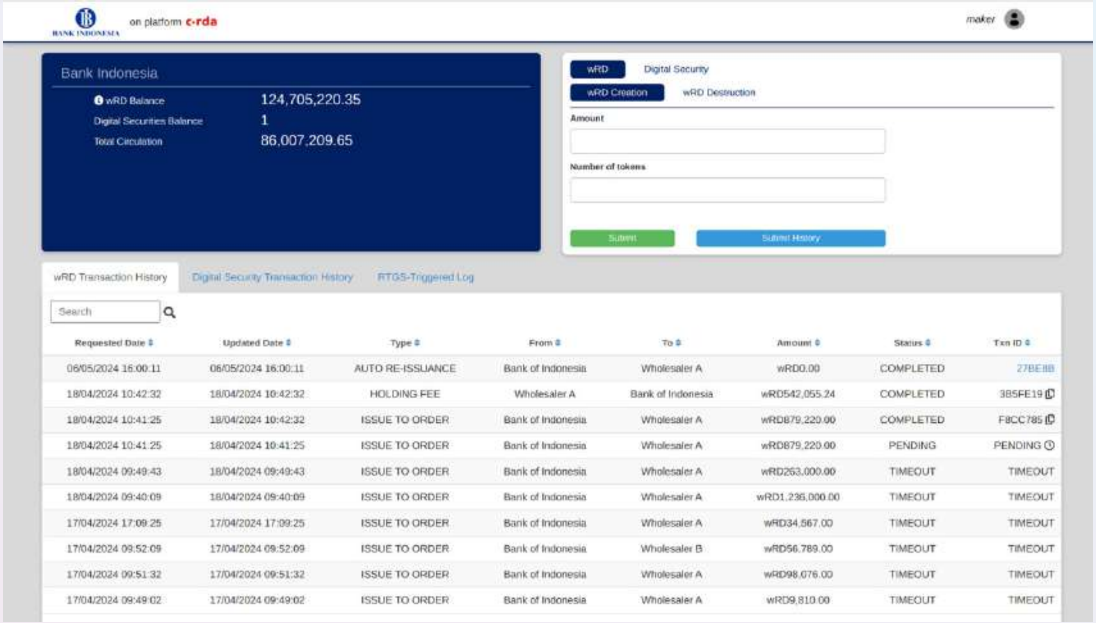
[20] EVM (Ethereum Virtual Machine) is a program responsible for executing smart contracts on the Ethereum blockchain network.

[21] API (Application Programming Interface) is a protocol that allows one software application to interact and communicate with other software applications.

[22] Off-chain transactions are processes that occur within the wRD platform without involving DLT database, such as limit policies, user management, file transfers, etc.

[23] Messaging queue is a mechanism for communication through messages using a queue. It works by placing a message generated by a producer into the queue, and then the message is retrieved from the queue to be processed by a consumer.

Figure 13. Web App View on R3 Corda Solution



Bank Indonesia

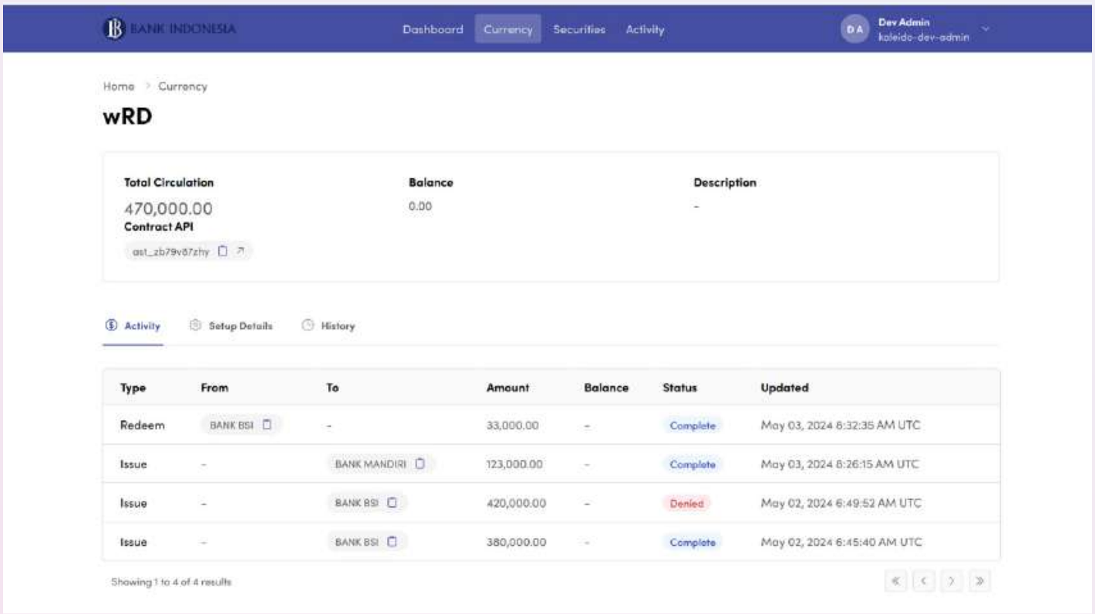
wRD Balance	124,705,220.35
Digital Securities Balance	1
Total Circulation	86,007,209.65

Amount

Number of tokens

Requested Date	Updated Date	Type	From	To	Amount	Status	Txn ID
06/05/2024 16:00:11	06/05/2024 16:00:11	AUTO RE-ISSUANCE	Bank of Indonesia	Wholesaler A	wRD0.00	COMPLETED	27BE8B
18/04/2024 10:42:32	18/04/2024 10:42:32	HOLDING FEE	Wholesaler A	Bank of Indonesia	wRD542,055.24	COMPLETED	385FE19
18/04/2024 10:41:25	18/04/2024 10:42:32	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD879,220.00	COMPLETED	F8CC785
18/04/2024 10:41:25	18/04/2024 10:41:25	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD879,220.00	PENDING	PENDING
18/04/2024 09:49:43	18/04/2024 09:49:43	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD263,000.00	TIMEOUT	TIMEOUT
18/04/2024 09:40:09	18/04/2024 09:40:09	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD1,236,000.00	TIMEOUT	TIMEOUT
17/04/2024 17:09:25	17/04/2024 17:09:25	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD34,567.00	TIMEOUT	TIMEOUT
17/04/2024 09:52:09	17/04/2024 09:52:09	ISSUE TO ORDER	Bank of Indonesia	Wholesaler B	wRD56,789.00	TIMEOUT	TIMEOUT
17/04/2024 09:51:32	17/04/2024 09:51:32	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD98,076.00	TIMEOUT	TIMEOUT
17/04/2024 09:49:02	17/04/2024 09:49:02	ISSUE TO ORDER	Bank of Indonesia	Wholesaler A	wRD9,810.00	TIMEOUT	TIMEOUT

Figure 14. Web App View on Kaleido Hyperledger Besu Solution



wRD

Total Circulation	Balance	Description
470,000.00	0.00	-

Contract API

ast_zb79v87zhy

Type	From	To	Amount	Balance	Status	Updated
Redeem	BANK BSI	-	33,000.00	-	Complete	May 03, 2024 6:32:35 AM UTC
Issue	-	BANK MANDIRI	123,000.00	-	Complete	May 03, 2024 6:26:15 AM UTC
Issue	-	BANK BSI	420,000.00	-	Denied	May 02, 2024 6:49:52 AM UTC
Issue	-	BANK BSI	380,000.00	-	Complete	May 02, 2024 6:45:40 AM UTC

Showing 1 to 4 of 4 results

3.3.6. INTEGRATION, INTEROPERABILITY, and INTERCONNECTION (3i)

In the PoC, BI-RTGS is integrated with the wRD platform for issuance and redemption. In R3 Corda, this integration is achieved through file exchange using AWS S3 Bucket, a cloud file storage service. Conversely, Kaleido Hyperledger Besu utilizes a web based interface to transmit BI-RTGS messages (see Appendix C).

3.4. DATA LAYER

The data layer encompasses both data storage methods and data structures. On the wRD platform, data is stored in a relational database. The data structure outlines the DLT structure, which meets the requirements of the use case layer (see Subchapter 3.1).

3.4.1. STORAGE IN THE DATABASE

In the wRD PoC, both R3 Corda and Kaleido Hyperledger Besu utilize the Relational Database Management System (RDBMS)[24] for data storage. Participants with nodes (wholesalers and non-wholesalers) are responsible for managing their respective databases. For participants categorized as no-node, the database management is handled by the provider node.

Data storage in R3 Corda is categorized into

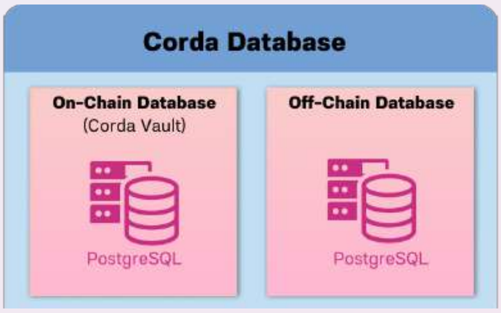
[24] RDBMS technology used is PostgreSQL, provided through AWS Relational Database Service (RDS) (see Appendix D).

[25] On-chain refers to the environment within the wRD platform that specifically uses DLT.

2 (two) types: on-chain[25] data storage, known as the Corda Vault, and off-chain data storage (Figure 15). The on-chain database comprises tables that represent the decentralized ledger. This data is immutable and distributed across nodes based on the need-to-know principle, ensuring a consistent schema throughout the network. Conversely, the off-chain database consists of tables related to access management for the wRD web application. This data is mutable, allowing for changes, and can have different schemas across nodes. For example, tables storing interconnection data with BI-RTGS are only available on the KDR node.

Data storage, both off-chain and on-chain, on Kaleido Hyperledger Besu utilizes Kaleido's Digital Asset Platform[26]. This platform provides a range of off-chain services, such as the Smart Contract Manager, Private Data Manager, and Key Manager, as well as on-chain services, including the Hyperledger Besu node, block indexer, and IPFS node. Each service within the Digital Asset Platform stores data and manages its own database. While the database schema is consistent across all nodes, the number of schemas varies depending on the services required by each node.

Figure 15. Design of Data Layer on R3 Corda



3.4.2. STRUCTURE OF DLT

Despite the similarities in using RDBMS in R3 Corda and Kaleido Hyperledger Besu, the 2 (two) DLT platforms have significantly different structures. The DLT structures used in PoCs are directed acyclic graph (DAG) for R3 Corda and Blockchain for Kaleido Hyperledger Besu (see Appendix D).

In R3 Corda, the Rupiah Digital is stored as a token within a state on CorDapps, with attributes such as nominal value, issuer (Bank Indonesia), and owner. Conversely, in Kaleido Hyperledger Besu, the Rupiah Digital is stored via a smart contract that contains the participant's account and balance.

The DLT structures also shapes how the defined policy are stored (see Subchapter 3.1.2). In R3 Corda, the configuration policy wRD is stored as a state within CorDapp, while in Kaleido Hyperledger Besu, policy wRD is stored as an attribute in a smart contract.

> *The DLT structures used in PoCs are directed acyclic graph (DAG) for R3 Corda and Blockchain for Kaleido Hyperledger Besu.*

3.5. CONSENSUS LAYER

The consensus layer incorporates a method to achieve agreement among nodes when a block of transactions is added to the ledger. This consensus scheme on DLT is designed to enhance operational resilience by distributing transaction validation process, one of which is transfer.

R3 Corda employs a unique consensus mechanism that involves a notary[27] (see Appendix E). In the PoC, the designated notary is a non-validating notary[28] implemented by Bank Indonesia.

Kaleido Hyperledger Besu employs proof-of-authority (PoA)[29] consensus mechanism. In the PoC, the selected PoA is Quorum Byzantine Fault Tolerance (QBFT), involving Bank Indonesia and all full nodes (see Apendix E).

> *R3 Corda employs a unique consensus mechanism that involves a notary... Kaleido Hyperledger Besu employs proof of authority (PoA) consensus mechanism.*

3.6. NETWORK LAYER

The most basic layer of the DLT Layer Framework is the network layer[30], where data exchange communication within the network is determined based on network access. In the PoC, according to the design of the Whitepaper and Consultative Paper, the chosen network access is permissioned network.

There is a difference in network creation between R3 Corda and Kaleido Hyperledger Besu, as illustrated in the Figure 16 below.

[26] Digital Asset Platform is a middleware service from Kaleido that provides services related to DLT platform.

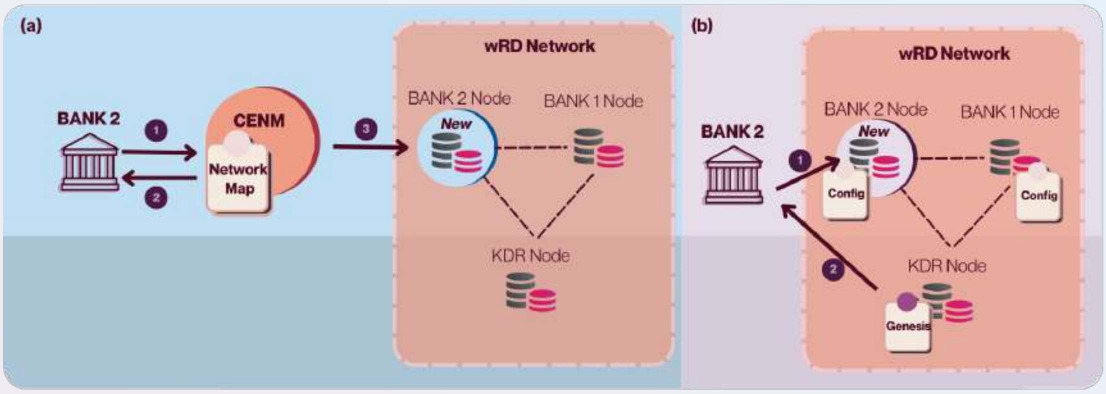
[27] A notary is an entity responsible for preventing double-spending (money being spent twice) by validating the input state of a transaction.

[28] A notary that checks transactions to prevent double-spending (uniqueness validation) but does not verify the correctness of the transactions (transaction validation).

[29] A consensus algorithm in which participants know and trust each other. A central authority designates participants who can perform transaction validation (delegates).

[30] Network Layer is a set of interconnected nodes that adhere to a technology standard (protocol) and actively participate together in storing, exchanging data, and processing information within an integrated communication channel.

Figure 16. The Process of Identifying New Members in the Network (a) In the Implementation of R3 Corda; (b) In the Implementation of Kaleido Hyperledger Besu



R3 Corda relies on an additional component called Corda Enterprise Network Manager (CENM)[31], which is responsible for identifying participants, as well as adding them to the network map[32].

Meanwhile, Kaleido Hyperledger Besu involves creating a network by using bootnode[33] and genesis files[34] for new participants, subsequently adding those participants to the configuration of each node. Both CENM and bootnode are under the authority of Bank Indonesia (see Appendix F).

In R3 Corda, the node must have an identity encapsulated in a digital certificate (which contains public and private keys) issued by CENM, as depicted in numbers 1 and 2 in Figure 16 (a). The identity registered on CENM must be unique to ensure that participants of the wRD platform can be identified through the certificate.

> *The network layer is where data exchange communication within the network is determined based on network access. In the PoC, the chosen network access is permissioned network.*

In Kaleido Hyperledger Besu, adding a new node to the network involves utilizing the genesis file owned by the bootnode, as illustrated in Figure 16 (b). The bank initiates the creation of a new node based on the genesis file and modifies the network configuration accordingly. Additionally, synchronizing the network configuration across all nodes requires establishing a communication link with the new node.

3.7. SECURITY ASPECTS

The security aspects in the implementation of the wRD PoC have been tested and follow the applicable security standards at Bank Indonesia.

[31] R3's commercial service, Corda Enterprise, allows for the operation of a Corda network with full control, including consensus management.

[32] A network map is a component that stores information about all nodes connected to the network and functions like a directory.

[33] Bootnode is node that initially creates the network.

[34] Genesis file is a file that contains the network configuration.

CHAPTER 4
POC TESTING & RESULT

Based on 3 (three) key questions, tests have been conducted to address all scenario topics, encompassing both business and technical aspects.

KQ# 1:
4.1. Implementation of DLT in the Money Supply Process of Wholesale Rupiah Digital

The implementation of wRD on the DLT platform involves a series of processes related to money supply. The issuance and redemption processes adhere strictly to the principle of no-money creation through conversion. This conversion process is executed by transferring the participant's current account balance to/from wRD in real-time, orchestrated by KDR node. Additionally, the DLT platform supports the transfer of funds between participants within the network through the fund transfer process. This process is designed to enhance liquidity efficiency, particularly through the transaction queue function.

The wRD incorporates features designed to support the implementation of monetary and macroprudential policies. These policies are enforced through system controls, such as setting limits on circulating wRD and utilizing administrative features to manage participant eligibility. An observer node is employed to monitor participant activities, as well as track the position and changes of wRD on the DLT platform.

Money supply processes, policy settings, and monitoring on the DLT network are regulated by smart contracts. These smart contracts, with their automation capabilities, are a novel aspect of the system that streamlines transactions.

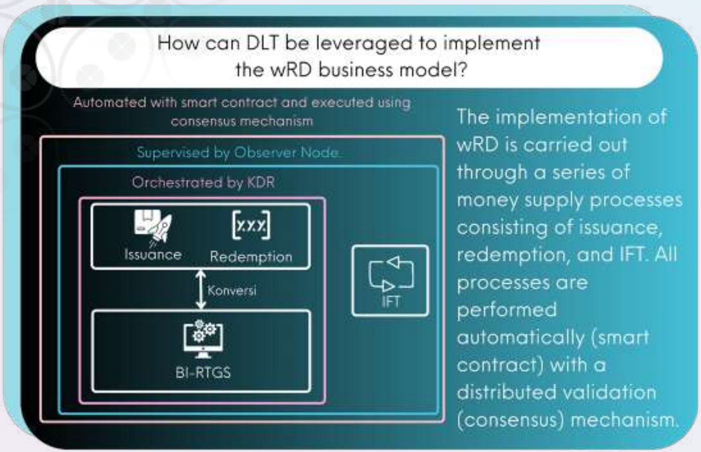
Besides the reliability of smart contracts, the DLT finalizes wRD transactions through a consensus mechanism that differs from conventional systems. This mechanism distributes the burden of transaction processing and validation across multiple participants in the DLT network, rather than relying solely on the central bank.

Kaleido Hyperledger Besu, using the Quorum Byzantine Fault Tolerance (QBFT) consensus algorithm, decentralizes validation rights to DLT participants predetermined by the central bank. Conversely, R3 Corda employs a unique consensus method involving notary nodes and transaction participants.

Through smart contracts and consensus mechanisms, the DLT platform ensures the confidentiality of transaction data. The Kaleido Hyperledger Besu-based solution guarantees confidentiality through encryption methods, while R3 Corda applies the need-to-know principle for every transaction.

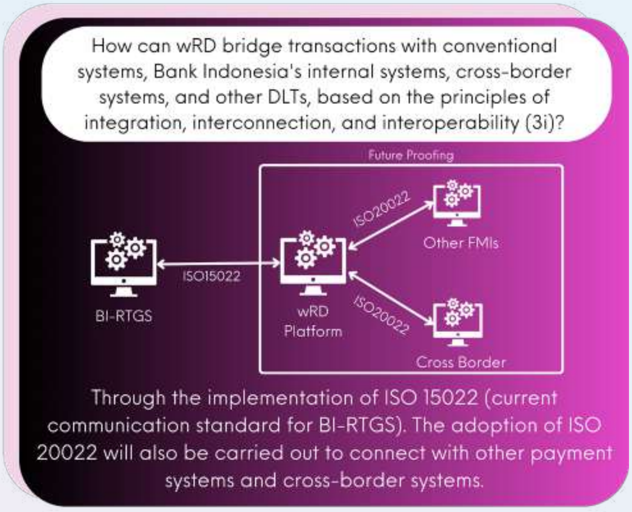
For Kaleido Hyperledger Besu, in addition to the encrypted privacy model, the confidential unspent transaction output (UTXO) model with a notary is also implemented in the PoC. In further exploration, there is a possibility to apply Zero Knowledge Proof (ZKP) privacy model (see Appendix G).

Access management plays a crucial role in supporting privacy aspects and regulating participant authorization on the DLT platform. By leveraging smart contracts and consensus, the DLT platform has significantly increased the speed of money circulation, with each platform capable of processing more than 30 transactions per second (see Appendix I).


How can DLT be leveraged to implement the wRD business model?

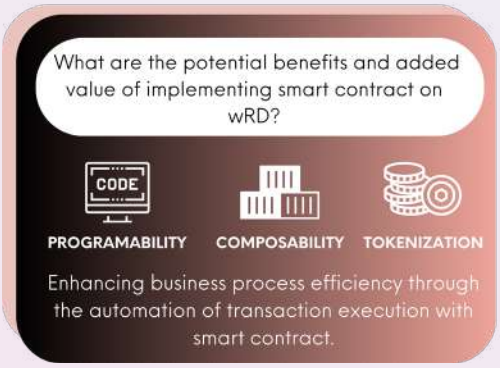
Automated with smart contract and executed using consensus mechanism
Supervised by Observer Node
Orchestrated by KDR
Issuance
{x,y,z}
Redemption
Konversi
BI-RTGS
IFT

The implementation of wRD is carried out through a series of money supply processes consisting of issuance, redemption, and IFT. All processes are performed automatically (smart contract) with a distributed validation (consensus) mechanism.


How can wRD bridge transactions with conventional systems, Bank Indonesia's internal systems, cross-border systems, and other DLTs, based on the principles of integration, interconnection, and interoperability (3i)?

Through the implementation of ISO 15022 (current communication standard for BI-RTGS). The adoption of ISO 20022 will also be carried out to connect with other payment systems and cross-border systems.

FEASIBILITY
INTER-OPERABILITY
VALUE ADDED


What are the potential benefits and added value of implementing smart contract on wRD?

Enhancing business process efficiency through the automation of transaction execution with smart contract.

KQ# 2:
4.2. Implementation of Smart Contract on Rupiah Digital Wholesale Platform

Implementing smart contracts on the wRD platform increases the efficiency of business processes by automating transaction execution based on predetermined rules, leveraging programmability, composability, and tokenization advantages. The programmability capabilities of smart contracts provide the ability to program the Rupiah currency with specific functionality to determine how the currency can be used. For example, a Rupiah Digital could be issued and explicitly programmed for tax payments.

Programmability implies that Bank Indonesia can add or modify smart contracts to enhance the functionality of the wRD platform. In R3 Corda-based solutions, smart contract customization on the network can be achieved through CorDapp (Corda Distributed Application). Meanwhile, Kaleido Hyperledger Besu provides a Contract Management service accessed through the Asset Platform to deploy new smart contracts into the blockchain.

Smart contract composability capabilities allow atomic settlement in payment systems, particularly in Delivery Versus Payment (DvP) transactions. In DvP transactions, the transfer of digital asset ownership and transaction funds occur simultaneously. Atomic settlement reduces settlement risk because the transaction is only completed if both parties meet the requirements.

Tokenization enables the conversion of BI-RTGS current accounts to wRD, allowing the implementation of smart contracts in Rupiah currency. Additionally, tokenization helps the wRD platform manage the Rupiah Digital assets and digital securities.

Each DLT platform has a different tokenization method. R3 Corda's Token SDK supports the issuance and management of digital tokens, while Kaleido Hyperledger Besu uses the ERC20 standard for the Rupiah Digital token base and ERC1400 for digital securities tokens. Use cases for DvP transactions and digital securities are not the primary focus of the Immediate State phase of PoC but will require further exploration for the Intermediate State phase.

> “*Implementing smart contracts on the wRD platform increases the efficiency of business processes by automating transaction execution based on predetermined rules, leveraging programmability, composability, and tokenization advantages.*”

KQ# 3:

4.3. Integration, Interoperability and Interconnection of wRD with Other Financial Market Infrastructure

In this PoC, interconnection focuses on the interoperability of existing Financial Market Infrastructures (FMIs) through connectivity to the Bank Indonesia Real Time Gross Settlement (BI-RTGS) system during issuance and redemption. R3 Corda builds a mock system that replicates the current BI-RTGS system based on ISO 150022. The mock system is designed to read input files from BI-RTGS and trigger the appropriate R3 Corda API. It can also generate output files that can be processed by the BI-RTGS system.

Meanwhile, in Kaleido Hyperledger Besu, the interconnection simulation with BI-RTGS is conducted through the RTGS Bridge (using API). Data exchange in the form of files with BI-RTGS is performed through a user interface in accordance with ISO 150022.

Furthermore, the observer node enables wRD to accommodate the needs of data centers by capturing transactions in a granular, private, and secure manner. This supports monetary policy analysis, financial system stability, and payment systems, while also helping to prevent fraudulent transactions and support the AML/CFT process.

To future proof payment system initiatives, wRD will adopt ISO 20022 as a messaging standard. ISO 20022 has been recognized and adopted globally to facilitate the harmonization of cross-border and cross-industry transactions.

> *In this PoC, interconnection focuses on the interoperability of existing Financial Market Infrastructures (FMIs) through connectivity to the Bank Indonesia Real Time Gross Settlement (BI-RTGS) system during issuance and redemption.*

CHAPTER 5
FINDING AND NEXT STEP

In the Rupiah Digital PoC, findings and considerations for future steps have been identified. Aspects not implemented in the PoC will be explored further, taking into account feedback from the industry, the community, and the current PoC results.

5.1 FINDING

Bank Indonesia and technology experts successfully achieved the objectives and addressed 3 (three) key questions in this PoC. Based on the development and execution of the test scenario, the following conclusions can be drawn:

1 The implementation of the wholesale Rupiah Digital (wRD) business model, including the money supply process and governance of its implementation, can be effectively carried out on distributed ledger technology (DLT) using smart contracts and consensus mechanisms;

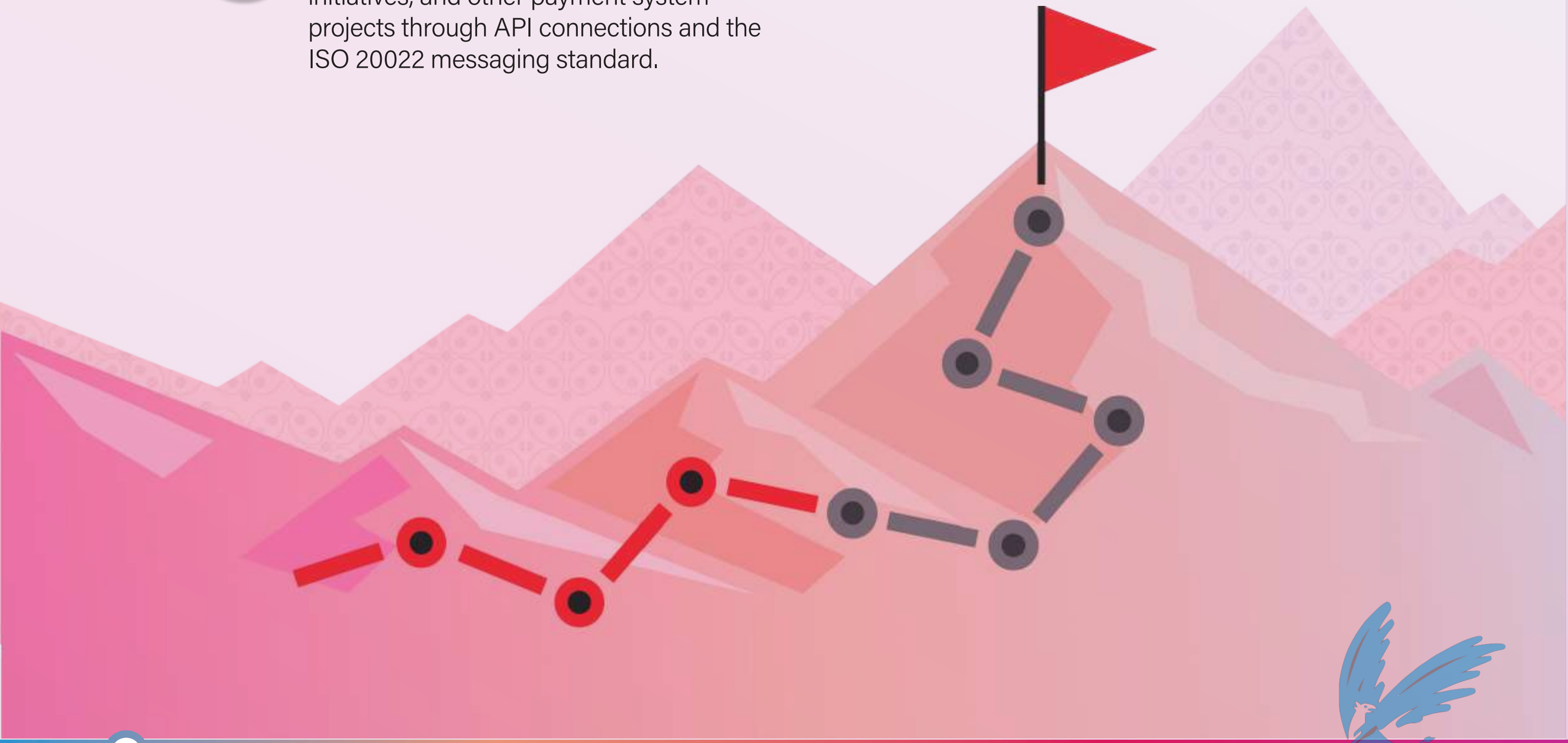
2 The added value of smart contracts in DLT, compared to conventional systems, lies in their capabilities to support programmability, composability, and tokenization;

3 The implementation of wRD on DLT facilitates connectivity with Bank Indonesia's internal systems, domestic financial market infrastructure, cross-border initiatives, and other payment system projects through API connections and the ISO 20022 messaging standard.

5.2 NEXT STEP

This PoC is a milestone in achieving Project Garuda's goals. Project Garuda will proceed with a broader exploration of securities ledger. This includes feasibility analysis, development of utilization and business processes, interoperability with other digital assets, and the exploration of potential advantages offered by the implementation of digital securities.

Based on the PoC results, several exploration topics can enhance the next phase of Project Garuda, specifically in liquidity management (e.g.: Liquidity Saving Mechanism (LSM)) and privacy technology (e.g.: Parallelism of Zero Knowledge Proof). This ensures that the implementation of business models and technology will provide the market with more efficient liquidity and information data privacy in accordance with Bank Indonesia's criteria.



ABBREVIATIONS

3i	Integration, Interoperability, and Interconnection
AML/CFT	Anti-Money Laundering and Combating the Financing of Terrorism
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
App	Application (Software)
AWS	Amazon Web Service
BFT	Byzantine Fault Tolerance
BI	Bank Indonesia
BI-RTGS	Bank Indonesia Real Time Gross Settlement
BNM	Business Network Membership
BSPI	Indonesia Payment System Blueprint
CBDC	Central Bank Digital Currency
CENM	Corda Enterprise Network Manager
CorDapp	Corda Distributed Application
CP	Consultative Paper
DAG	Directed Acyclic Graph
DLT	Distibuted Ledger Technology
DvP	Delivery Versus Payment
EDA	Event-driven Architecture
EEA	Enterprise Ethereum Alliance
EKD	Digital Financial Economy
EKS	Elastic Kubernetes Service
ERC	Ethereum Request for Comment
EVM	Ethereum Virtual Machine
FAFO	First Available First Out
FIFO	First In First Out
HD	Hierarchial-Determinitic
HSM	Hardware Security Modules
HTTP	Hypertext Transfer Protocol
ID	Identity
IPFS	InterPlanetary File System
ISO	International Organization for Standardization
JMS	Java Message Service
JVM	Java Virtual Machine
KDR	Khazanah Digital Rupiah
KQ	Key Question
LSB	Non-Bank Institutions
LSM	Liquidity Saving Mechanism
MT	Message Type
MTO	Make-to-Order
NATS	Neural Autonomic Transport System
NKRI	Republic of Indonesia
P2SK	Financial Sector Development and Strengthening
PoA	Proof of Authority
PoC	Proof of Concept
QBFT	Quorum Byzantine Fault Tolerance
RDBMS	Relational Database Management System
RDS	Relational Database Service
REST	Representational State Transfer
RTGS	Real Time Gross Settlement
S3	Simple Storage Service
SDK	Software Development Kit
SP	Payment System
SSK	Financial Stability System
TLS	Transport Layer Security
TPS	Transaction per Second
UTXO	Unspent Transaction Output
UU	Act, Law
wRD	Wholesale Cash Ledger Rupiah Digital
WS	Workstream
WSr	Wholesaler
ZKP	Zero Knowledge Proof

APPENDIX

A. DETAIL EVALUATION OF DLT

In the series of PoC activities, 2 (two) DLT platforms were selected through a technical evaluation with the objective of ensuring the suitability of the DLT platform characteristics with the needs of Bank Indonesia. The technical evaluation was conducted through 3 (three) stages: the preparation of a long list, a short list, and the final selection.

1. Long List

The long list is a compilation of all potential DLT platforms that can be tested in the PoC. The potential DLT platform candidates were sourced from web searches, news, and correspondence with both national and international DLT practitioners. Based on the evaluation results (as of October 2023), 39 potential DLT platforms were identified, each with its own characteristics as shown in Table 1.

2. Short List

The short list is the result of selecting DLT platforms from the long list based on each platform's track record. The purpose of creating the short list is to ensure that the DLT platforms can be used as a solution for central bank digital currency (CBDC). There are 3 (three) track record criteria used, based on the exploration roadmap for the Rupiah Digital in the White Paper: the use of the DLT platform as a CBDC solution for wholesale cash ledger, wholesale securities ledger, and retail (the option remains open for either DLT or a centralized system). The short list evaluation was conducted by matching the DLT platforms on the long list with those used by central banks and international financial institutions in the exploration of CBDC wholesale cash ledger, wholesale securities ledger, and retail, as published. The assessment results for the short list showed that, out of the 39 DLT platforms in the long list, 5 (five) DLT platforms had been used by central banks or other international financial institutions (as of October 2023) and became candidates for the final selection.

3. Final Selection

The selection of the 2 (two) DLT platforms to be tested in the PoC was based on 3 (three) selection criteria. The first is mandatory requirements, where

Table 1. List of Potential DLT Platform

No	DLT Platform	Used as CBDC Solution	No	DLT Platform	Used as CBDC Solution
1	Hyperledger Besu	Y	21	Nem	N
2	Hyperledger Fabric	Y	22	Factom	N
3	Corda	Y	23	BigChainDB	N
4	Hyperledger Iroha	Y	24	Omni	N
5	Quorum	Y	25	Bubichain	N
6	Hiero	N	26	Multichain	N
7	Ethereum	N	27	Hydrachain	N
8	Solana	N	28	ParallelChain	N
9	Bitcoin Core	N	29	NexLedger	N
10	Hyperledger Sawtooth	N	30	pNetwork	N
11	Domus Tower	N	31	Coinstack	N
12	Swirlds	N	32	NXT Platform	N
13	Aergo	N	33	Ripple	N
14	Zilliaq	N	34	Polkadot	N
15	Waves	N	35	IOTA	N
16	VeChain	N	36	RSK	N
17	TenderMint	N	37	Velas	N
18	Blockstream	N	38	SettleMint	N
19	Chain Core	N	39	Signchain Signature	N
20	Neo	N			

the DLT platform must be supported by a company/legal entity to ensure the sustainability of the technology and is a permissioned network.

The second is the track record of each DLT platform, DLT platform that have been used more frequently in CBDC or digital securities projects receive higher scores. The third is the compatibility of the selected DLT platform with the 3 (three) focus areas to be explored during the PoC, which are:

1. The difference in ledger structures between token/unspent transaction output (UTXO) based and account-based DLT platforms;
2. The data privacy solutions used by each DLT platform to ensure the confidentiality of transaction information;
3. The consensus methods used by the DLT platforms.

Corda and Hyperledger Besu were selected as the DLT platforms with the highest potential based on the 3 (three) final selection criteria to be developed and tested according to the needs of Bank Indonesia. As per the mandatory selection criteria, both platforms have supporting companies/legal entities. Corda is supported by R3, while Hyperledger Besu is supported by Kaleido.

R3 Corda and Kaleido Hyperledger Besu meet the 3 (three) focus areas of the Bank Indonesia PoC, where both have different characteristics in terms of ledger structure, privacy solutions, and consensus methods, as shown in Table 2.

R3 Corda uses a UTXO ledger structure, which can be simply described as recording transactions based on the transfer of token ownership. Kaleido Hyperledger Besu uses an account-based ledger structure, which can be simply described as recording transactions based on changes in account balances.

Privacy solutions on R3 Corda use a vault that only stores transactions relevant to its owner. Kaleido Hyperledger Besu has a global ledger that records all transactions and distributes them to all participants, data privacy is achieved through a private data manager, which performs encryption and decryption of data on the global ledger. Only participants involved in a transaction can decrypt the data on the global ledger.

R3 Corda uses a unique consensus method called 'Notary,' which acts as a central authority to verify the uniqueness of transactions (uniqueness consensus). Kaleido Hyperledger Besu uses a proof of authority (PoA) consensus method, where several validators pre-determined by participants are authorized to validate transactions.

Table 2. PoC Focus Detail

No	Focus Area	R3 Corda	Kaleido Hyperledger Besu
1	Ledger Structure	Token (UTXO)	Account
2	Privacy Solution	Vault	Private Transaction Manager (Kaleido)
3	Consensus	Notary	Byzantine Fault Tolerant (BFT) –

APPENDIX

B. IMPLEMENTATION DETAILS OF THE USE CASE LAYER

1. Integration of wRD Platform with BI-RTGS for Issuance and Redemption

There are 4 (four) types of MT used for communication of the wRD platform with the BI-RTGS system in Table 3.

Table 3. The Use of MT File

No	MT File Types	Information	Process
1	MT202	Contains commands to debit/credit omnibus accounts	Issuance and Redemption
2	MT900	Contains confirmation of successful debiting of omnibus accounts from MT202 process execution	Redemption
3	MT910	Contains confirmation of successful crediting of the omnibus account from the execution of the MT202 process	Issuance
4	MT296	Contains a failed confirmation of the execution of the MT202 process	Issuance and Redemption

2. Creation Detail

In R3 Corda, which utilizes the Unspent Transaction Output (UTXO) model, the creation process involves a transaction that produces the Rupiah Digital token. This transaction is executed by invoking the issuance flow on the Rupiah Digital CorDapps. The illustration of the transaction creation process in R3 Corda is depicted in Figure 17.

Figure 17. Creation on R3 Corda UTXO

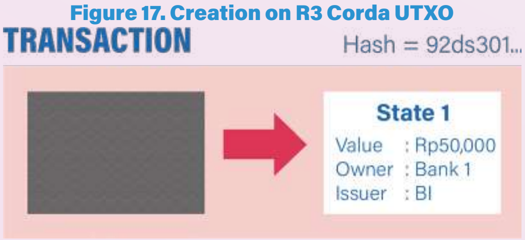
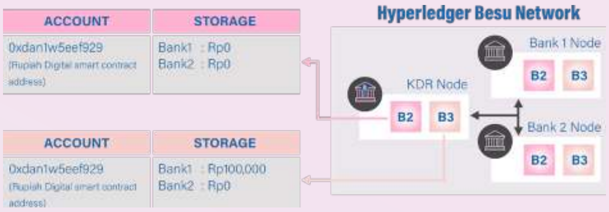


Figure 18. Creation on Kaleido Hyperledger Besu Account Based

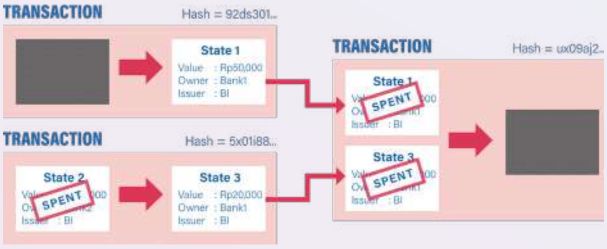


In Kaleido Hyperledger Besu, which utilizes the account model, the creation process involves a transaction that adds balance to an account by updating the world state. This transaction is executed by invoking the issuance flow through the KDR node to the Rupiah Digital smart contract. The illustration of the transaction creation process in Kaleido Hyperledger Besu is depicted in Figure 18.

3. Destruction Detail

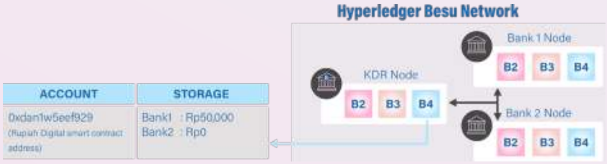
In R3 Corda, which utilizes the Unspent Transaction Output (UTXO) model, destruction is a transaction intended to delete a token. The transaction is executed through the redemption flow call in the Rupiah Digital CorDapps application. The illustration of the destruction flow in R3 Corda is depicted in Figure 19.

Figure 19. Destruction on R3 Corda UTXO



In Kaleido Hyperledger Besu, which utilizes accounts, destruction is a transaction that reduces an account's balance through an update world state. Transactions are made by calling the redemption function in Rupiah Digital smart contract. The illustration of the destruction flow in Kaleido Hyperledger Besu is depicted in Figure 20.

Figure 20. Destruction on Kaleido Hyperledger Besu

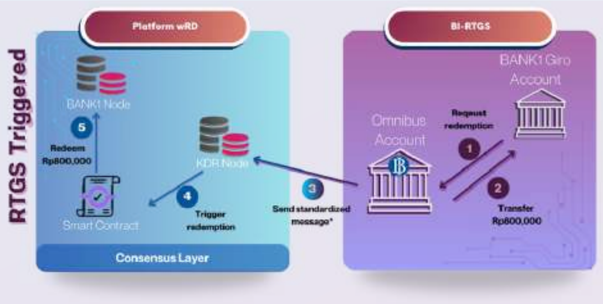


4. Redemption with RTGS Triggered

Redemption initiated from BI-RTGS is explored in the PoC using a mock-up of the BI-RTGS system. However, implementing further processes requires developing BI-RTGS capabilities that are beyond the scope of the Rupiah Digital PoC. The illustration of the RTGS triggered redemption flow is depicted in Figure 21.

Participants registered in the BI-RTGS system initiate requests to credit their current accounts and debit the CBDC omnibus account. Upon completion of the settlement in RTGS, the KDR node on the wRD platform receives MT202 and MT900 messages as confirmation.

Figure 21. Redemption Process RTGS Triggered



Subsequently, KDR node initiates the crediting of the omnibus account and debits participants' balance on the wRD platform to finalize the settlement on the Rupiah Digital side. In R3 Corda, KDR node initiates a flow on CorDapps that receives the Rupiah Digital token input and destroys the token. In Kaleido Hyperledger Besu, KDR node triggers a function in the smart contract to transfer the balance from the participant's account to the burn address.

APPENDIX

C. IMPLEMENTATION DETAILS OF THE EXECUTION LAYER

1. Kubernertes Cluster Configuration

In R3 Corda solutions, the Kubernetes cluster configuration is separated into 2 (two) types: the Bank Indonesia Kubernetes cluster, as illustrated in Figure 22, and 3 (three) participant bank Kubernetes clusters, as depicted in Figure 23.

Figure 22. Bank Indonesia's R3 Corda Cluster Configuration on AWS Infrastructure

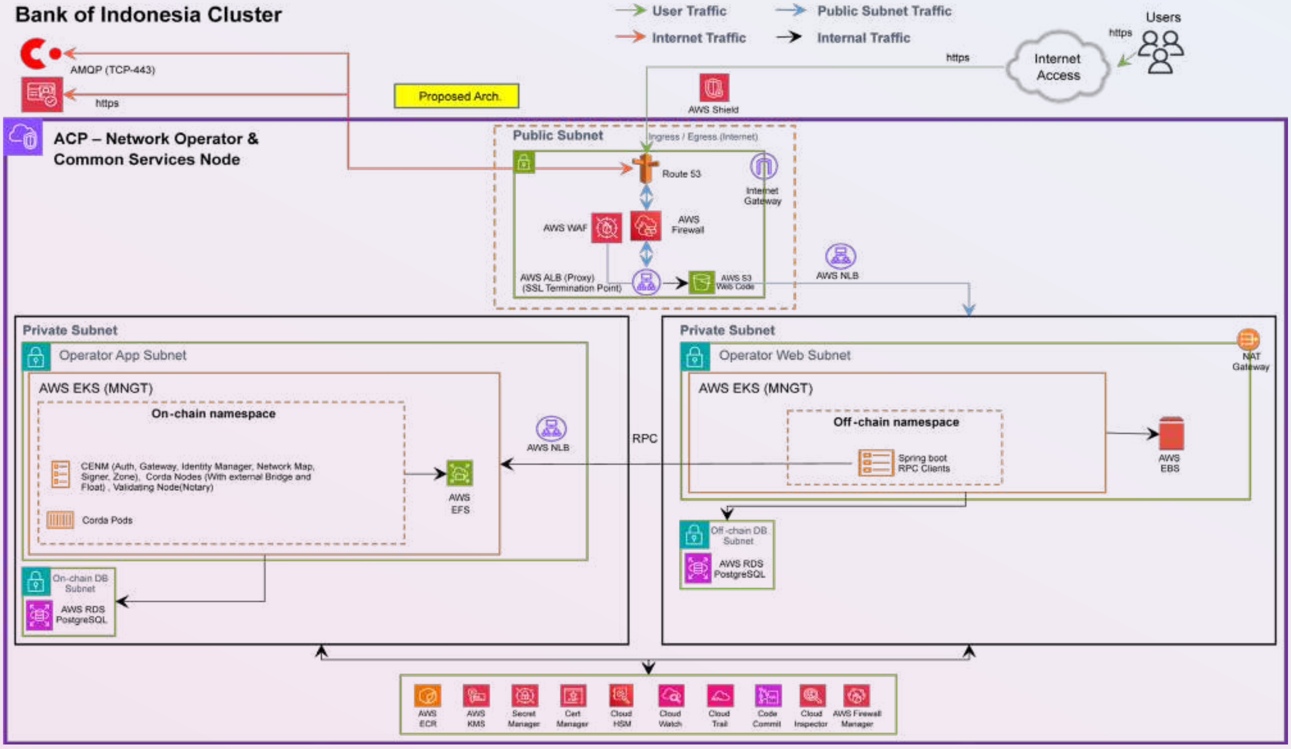
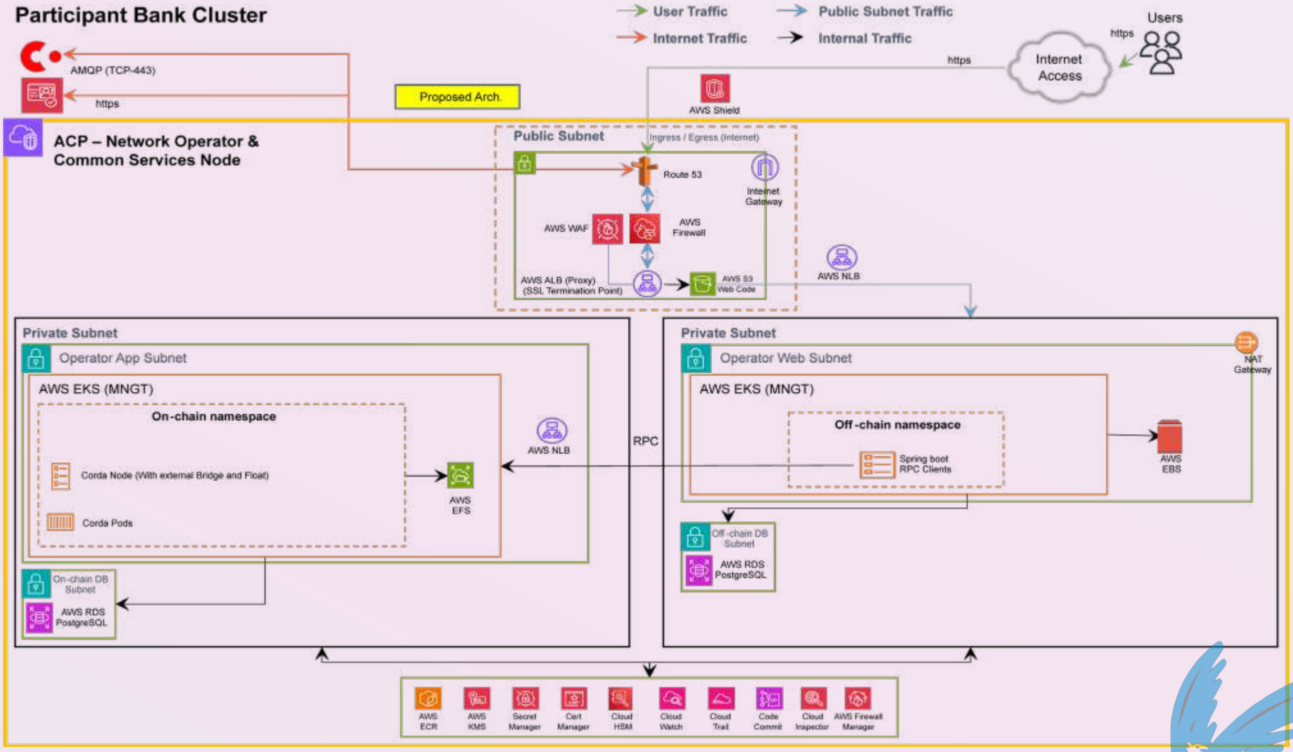


Figure 23. Participant's R3 Corda Cluster Configuration on AWS Infrastructure



In Kaleido Hyperledger Besu solution, there are 4 (four) entities: Bank Indonesia, Bank 1, Bank 2, and Bank 3. This configuration employs a single Kubernetes cluster, with a Kubernetes Namespace separating the entities within it. The cluster configuration for Kaleido Hyperledger Besu is shown in Figure 24.

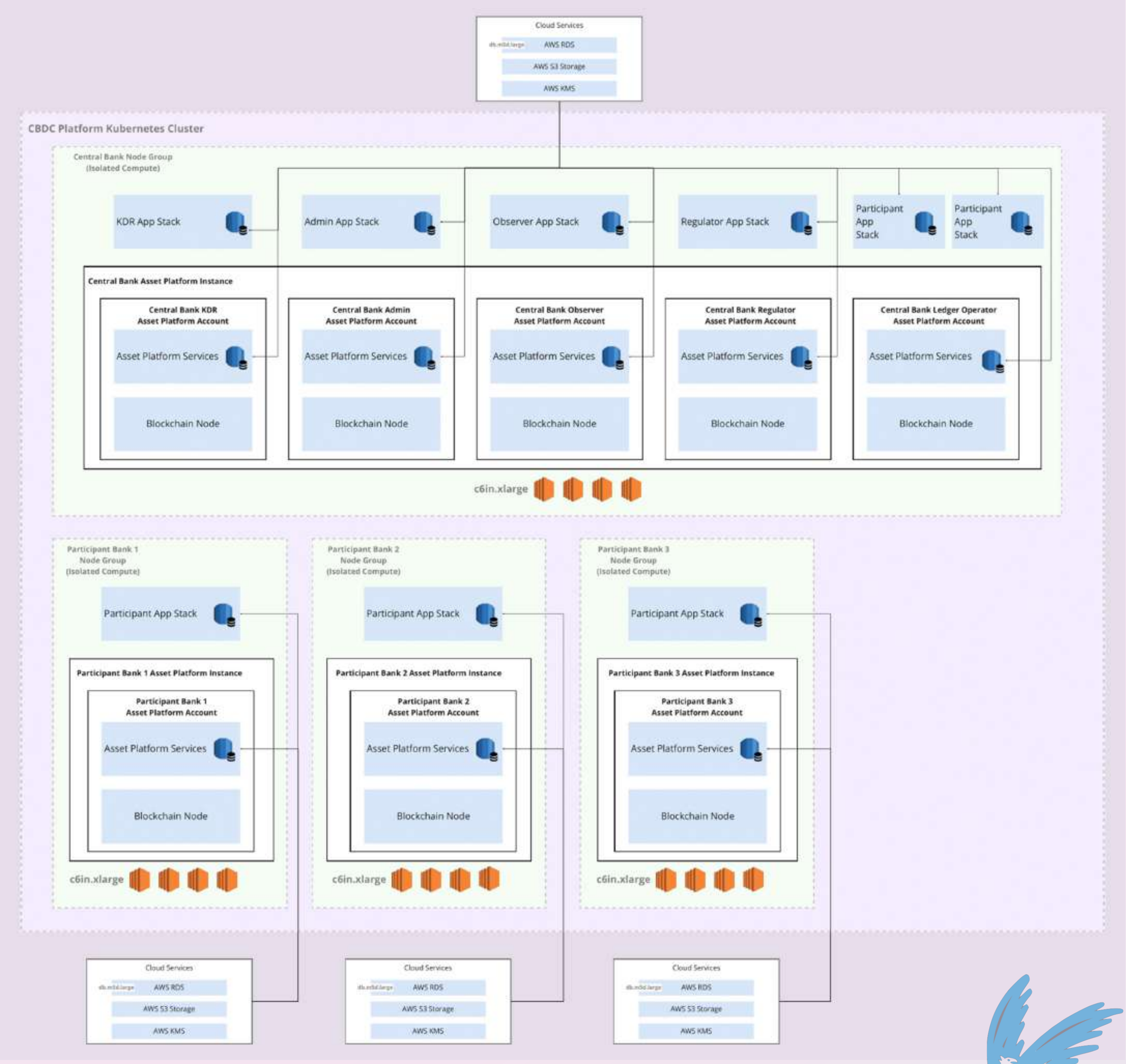
2. Smart Contract

Smart contracts are computer programs that operate on blockchain technology, offering several unique capabilities: programmability, composability, and tokenization. Programmability refers to the ability to automatically execute, control, or document events and actions according to predetermined rules, eliminating the need for human intervention.

Composability allows multiple smart contracts to interact with each other, enabling the bundling of multiple transactions into one. Tokenization facilitates the creation and management of various digital assets, including both the Rupiah Digital and the digital securities.

The use of smart contracts introduces new features such as access restrictions, cryptography, and the separation of on-chain and off-chain data. These features are tested in this PoC to enhance the current transaction privacy model. In the long term, as transaction data accumulates and the demand for improved transaction methods increases, smart contracts can be further developed to meet these evolving needs.

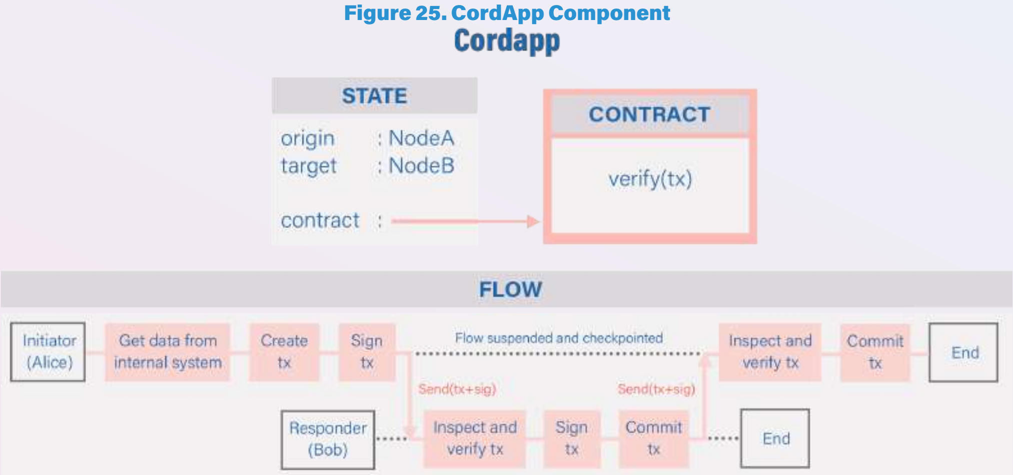
Figure 24. Kaleido Hyperledger Besu Cluster Configuration of Bank Indonesia's and Participant's Node on AWS Infrastructure


Cloud Services
db.m5d.large
AWS RDS
AWS S3 Storage
AWS KMS
CBDC Platform Kubernetes Cluster
Central Bank Node Group (Isolated Compute)
KDR App Stack
Admin App Stack
Observer App Stack
Regulator App Stack
Participant App Stack
Participant App Stack
Central Bank Asset Platform Instance
Central Bank KDR Asset Platform Account
Central Bank Admin Asset Platform Account
Central Bank Observer Asset Platform Account
Central Bank Regulator Asset Platform Account
Central Bank Ledger Operator Asset Platform Account
Asset Platform Services
Blockchain Node
c6in.xlarge
Participant Bank 1 Node Group (Isolated Compute)
Participant Bank 2 Node Group (Isolated Compute)
Participant Bank 3 Node Group (Isolated Compute)
Participant App Stack
Participant Bank 1 Asset Platform Instance
Participant Bank 1 Asset Platform Account
Participant Bank 2 Asset Platform Instance
Participant Bank 2 Asset Platform Account
Participant Bank 3 Asset Platform Instance
Participant Bank 3 Asset Platform Account
Asset Platform Services
Blockchain Node
c6in.xlarge
Cloud Services
db.m5d.large
AWS RDS
AWS S3 Storage
AWS KMS

In R3 Corda, a smart contract resides within a CorDapp (Corda Distributed Application). As depicted in Figure 25, a CorDapp is a file with jar extension containing classes written in Java or Kotlin, which typically include:

1. **State**: Contains data and facts that will be agreed upon by all parties;
2. **Contract**: Contains rules that regulate the parties involved in a business process and the transactions that can be carried out;
3. **Flow**: Contains flows of a business process and how transaction data is modified or updated.

Figure 25. CordApp Component

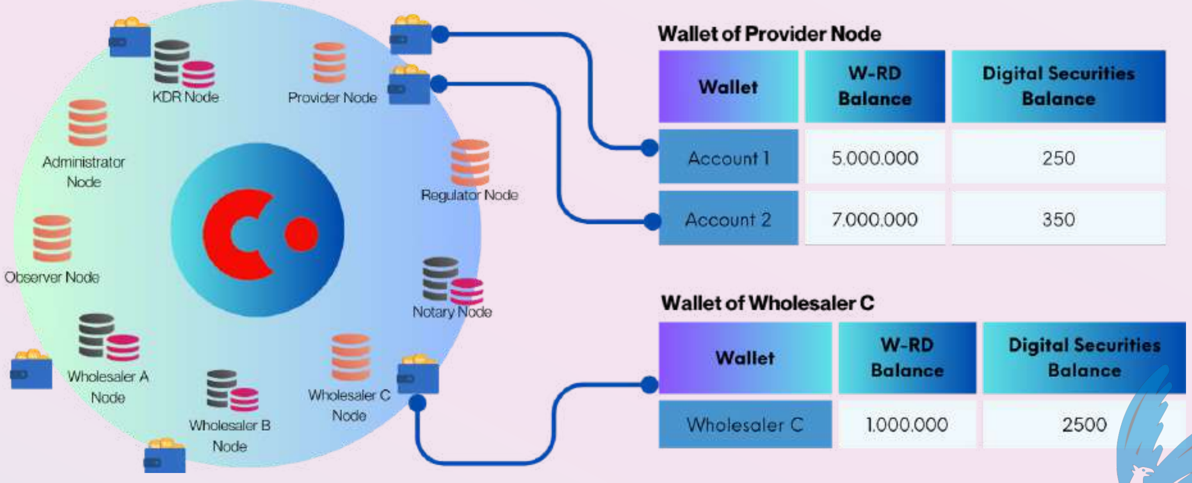


R3 Corda supports the issuance and management of digital tokens using the Token SDK, which facilitates tokenization, including the Rupiah Digital and the digital securities tokens. Each token is governed by smart contracts that control its status and data, and manage the MTO process from issuance to settlement according to specified business processes.

R3 Corda does not implement a global ledger. Instead, its architecture utilizes bilateral/point-to-point data sharing. In R3 Corda, only approved parties can join the network, and only relevant parties have access to transaction information, as illustrated in Figure 26. Both platforms implement data separation using on-chain and off-chain storage. Transaction records, such as transaction ID, sender-receiver details, and transaction amounts, are stored on-chain, while other data, such as participant profiles, are stored off-chain.

Kaleido Hyperledger Besu supports smart contracts written in Solidity or any other programming language that can be compiled into Ethereum Virtual Machine (EVM) bytecode. These smart contracts are deployed onto the blockchain and executed within the EVM. The execution of a smart contract function occurs when a new transaction is written into a block within the DLT network. Kaleido Hyperledger Besu provides a contract management service that facilitates the deployment and customization of open-source smart contract standards on EVMs, such as ERC20, ERC721, and ERC1400. The ERC20 standard is used as the basis for the Rupiah Digital token, while ERC1400 is utilized for digital securities tokens. Kaleido Hyperledger Besu stores all transaction details (transaction ID, sender, recipient, timestamp, etc.) on-chain in encrypted form, ensuring that only authorized parties can access the transaction details.

Figure 26. Rupiah Digital and Digital Securities Illustration at Wholesale Wallets R3 Corda



Wallet of Provider Node

Wallet	W-RD Balance	Digital Securities Balance
Account 1	5.000.000	250
Account 2	7.000.000	350

Wallet of Wholesaler C

Wallet	W-RD Balance	Digital Securities Balance
Wholesaler C	1.000.000	2500

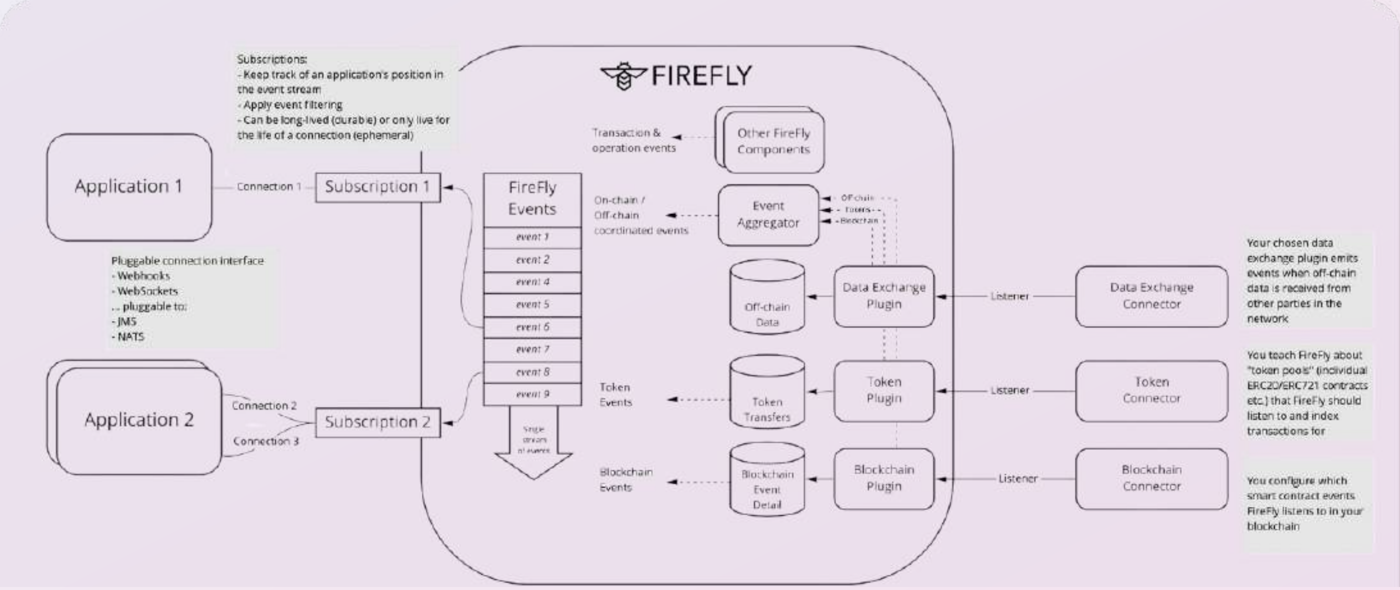
3. Messaging Components In R3 Corda and Kaleido Hyperledger Besu

Event-driven architecture (EDA) is a software development approach where system components interact through the exchange of events. An event signifies a state change within the system, such as user input, data updates, or notifications from an external system. This pattern contrasts with the traditional request/response architecture, where services must wait for a reply before proceeding to the next task.

In EDA, components or services communicate asynchronously by reading or sending events, allowing them to react to changes flexibly and independently. Messaging is a crucial component in EDA, facilitating the sending and receiving of events.

R3 Corda employs the Advanced Message Queuing Protocol (AMQP) 1.0 via Transport Layer Security (TLS) 1.2 between nodes. This is currently implemented using Apache Artemis, a message broker built on top of the MQ protocol. R3 Corda uses Artemis for communication across the DLT network, such as when executing transactions between nodes. Similarly, Kaleido Hyperledger Besu utilizes the FireFly Event Bus, a messaging system developed by Kaleido, enabling applications to receive events from all back-ends connected to FireFly, as illustrated in Figure 27.

Figure 27. Firefly Event Bus (Hyperledger Firefly, 2024)


Subscriptions:
- Keep track of an application's position in the event stream
- Apply event filtering
- Can be long-lived (durable) or only live for the life of a connection (ephemeral)
FIREFLY
Application 1
Connection 1
Subscription 1
Pluggable connection interface
- Webhooks
- WebSockets
... pluggable to:
- JMS
- NATS
Application 2
Connection 2
Connection 3
Subscription 2
FireFly Events
event 1
event 2
event 4
event 5
event 6
event 7
event 8
event 9
Single stream of events
Transaction & operation events
Other FireFly Components
On-chain / Off-chain coordinated events
Event Aggregator
Off-chain
Tokens
Blockchain
Off-chain Data
Data Exchange Plugin
Listener
Data Exchange Connector
Your chosen data exchange plugin emits events when off-chain data is received from other parties in the network
Token Events
Token Transfers
Token Plugin
Listener
Token Connector
You teach FireFly about "token pools" (individual ERC20/ERC721 contracts etc.) that FireFly should listen to and index transactions for
Blockchain Events
Blockchain Event Detail
Blockchain Plugin
Listener
Blockchain Connector
You configure which smart contract events FireFly listens to in your blockchain

Applications that subscribe to these events use protocols such as websocket and webhook. Additionally, plugins can connect to other transport protocols, including NATS, Kafka, and Java Message Services (JMS) Server.

4. Integration of the wRD platform with BI-RTGS

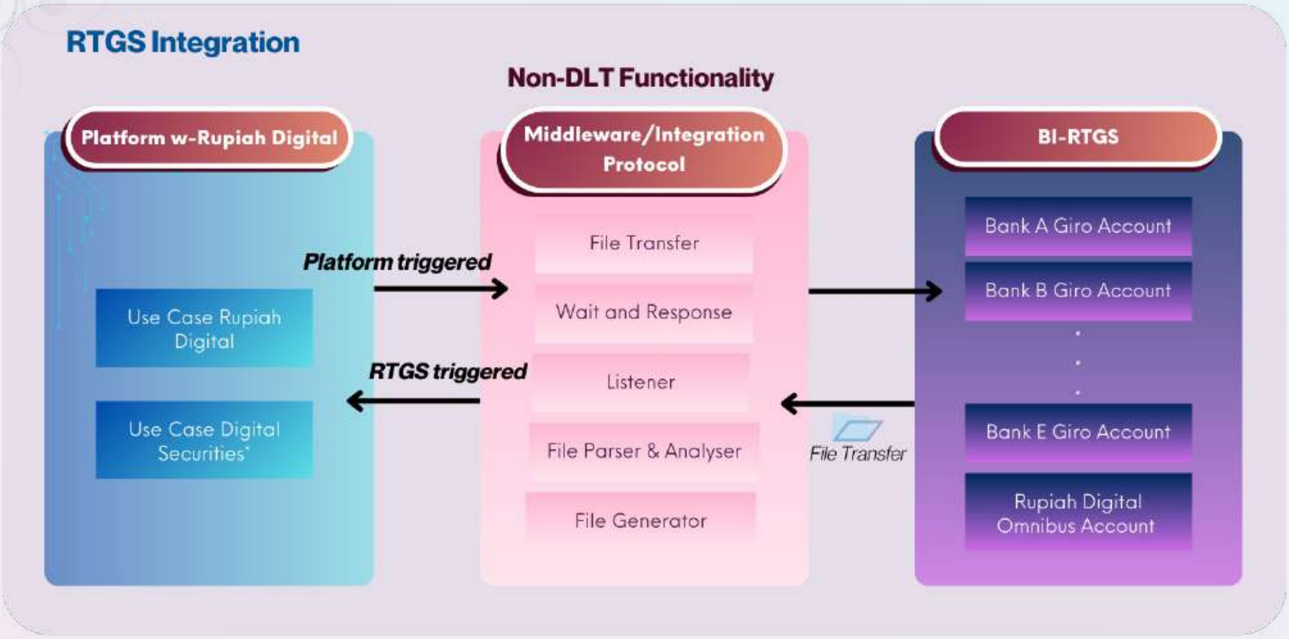
R3 Corda and Kaleido Hyperledger Besu, in general, have built-in interoperability features that enable the wRD platform to communicate with other payment systems, such as BI-RTGS, through standard communication protocols. This capability directly supports the creation of an integrated, interoperable, and interconnected (3i) digital ecosystem.

In the PoC, both solutions were connected to the BI-RTGS using standard communication protocols and message formats defined by the existing BI-RTGS messaging standard. The wRD platform demonstrated that message formats and communication protocols could be configured to meet user requirements. Adjustments from the current message format standard to the ISO 20022 standard are feasible, leveraging the Bank Indonesia 3i standard of integration, interoperability and interconnection.

The mapping of the current message format to the ISO 20022 format was carried out in the PoC and will serve as a reference point for future developments. Bank Indonesia chose ISO 20022 because it is a globally recognized communication standard for financial transactions, including payments, remittances, and other transactions that support financial inclusion.

For R3 Corda solutions, a parser and file generator were developed, compatible with the current standard format, as illustrated in Figure 28. The application, built using Java Spring Boot, processes BI-RTGS message files and triggers an R3 Corda API in response. This application also generates message files for the emulated BI-RTGS systems, which are then uploaded into AWS S3. This approach simulates the existing file messaging exchanges in BI-RTGS.

Figure 28. R3 Corda Based PoC Solution Design: BI-RTGS Integration



The BI-RTGS Bridge was developed to connect the Kaleido Hyperledger Besu platform with the BI-RTGS system, handling business scenarios of issuance and redemption. Data exchange with BI-RTGS, using the standard format, is conducted through a user interface (web app).

The BI-RTGS Bridge is developed using HTML and JavaScript, connected to the Firefly service via websocket. Transaction triggers are executed by sending data in standard format through a form on the web app. Subsequently, this data becomes an event sent through websocket to be executed as an on-chain transaction on the DLT.

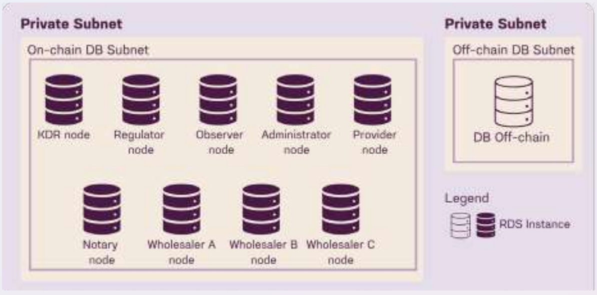
APPENDIX

D. IMPLEMENTATION DETAILS OF THE DATA LAYER

1. Relational Database Management on R3 Corda

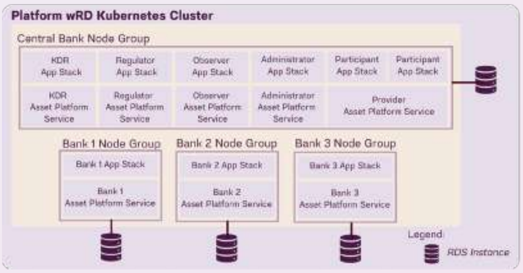
R3 Corda utilized 10 (ten) instances of AWS RDS: 9 (nine) for different on-chain databases and 1 (one) dedicated to managing 8 (eight) off-chain databases, as illustrated in Figure 29.

Figure 29. Database Design on R3 Corda



2. Relational Database Management on Kaleido Hyperledger Besu

Figure 30. Database Design on Kaleido Hyperledger Besu


Platform wRD Kubernetes Cluster
Central Bank Node Group
KDR App Stack
Regulator App Stack
Observer App Stack
Administrator App Stack
Participant App Stack
Participant App Stack
KDR Asset Platform Service
Regulator Asset Platform Service
Observer Asset Platform Service
Administrator Asset Platform Service
Provider Asset Platform Service
Bank 1 Node Group
Bank 1 App Stack
Bank 1 Asset Platform Service
Bank 2 Node Group
Bank 2 App Stack
Bank 2 Asset Platform Service
Bank 3 Node Group
Bank 3 App Stack
Bank 3 Asset Platform Service
Legend
RDS Instance

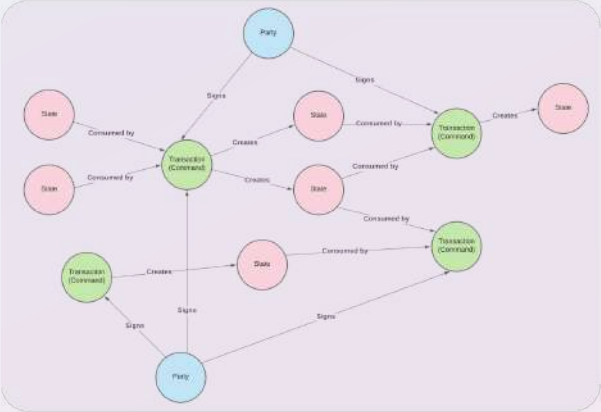
Kaleido Hyperledger Besu utilizes 4 (four) AWS RDS instances, with each instance connected to its corresponding Asset Platform and the middle-layer App Stack. Participants who own nodes manage their own databases and Asset Platforms.

3. R3 Corda: Directed Acyclic Graph (DAG)

Graph data consists of nodes, or points, interconnected by edges. Nodes represent entities or instances of data, while edges represent the relationships between nodes. Together, connected nodes and edges form graphs, a model that illustrates the interconnectedness of data.

A directed acyclic graph (DAG) is a specific type of graph characterized by 2 (two) main properties: 1) Each edge has a single direction, from an origin node to a destination node, and 2) There are no cycles, meaning no nodes form a loop. A more precise illustration can be seen in the following image.

Figure 31. Directed Acyclic Graph on R3 Corda

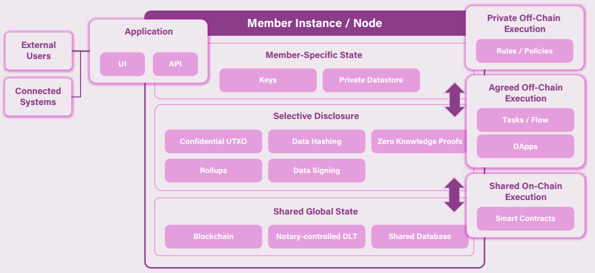


The image depicts various entities forming interconnected nodes, each representing a single transaction. For instance, a Transaction (Command) signed by a party processes a state and generates a new state. This transaction remains indirectly connected, producing a new state that can be traced back to its origin.

4. Kaleido Hyperledger Besu: Asset Platform and Blockchain

In addition to blockchain, Kaleido Hyperledger Besu has a data modeling layer that is divided into 3 (three) segments, as depicted in Figure 32.

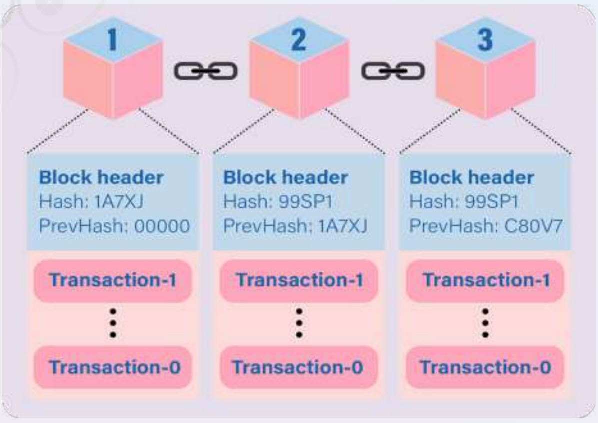
Figure 32. Kaleido's Asset Platform Digital Data Layer (Kaleido, 2024)



The top layer is the Member-Specific State, which contains specific data from network participants, such as Public and Private Keys. The second layer contains additional data modeling to store confidential transaction data that remains connected to global data.

At the bottom layer, known as the Shared Global State, a distributed ledger forms a fundamental component of Kaleido's technology. In the current PoC, the selected blockchain stores transaction data that is shared globally.

Figure 33. Blockchain on Kaleido Hyperledger Besu



Blockchain technology is distinguished by its unique characteristic of storing data in a connected block structure. As illustrated in the Figure 33, 1 (one) block comprises 2 (two) categories of information: header blocks and transaction data. The header block functions as a chain linking one block to the previous block. Each block can contain zero to *n* transactions, with the maximum number of transactions determined by the network configuration.

Using a DLT structure such as blockchain, transactions can be traced back to the creation of the first block. Transactions can be referenced by their index within a block and traced through the hash of the previous block stored in the block header.

5. Confidential UTXO Implementation

The implementation chosen for the PoC is the Confidential Unspent Transaction Output (UTXO). In this approach, the amount and owner data of a token are stored off-chain in the Member-Specific State. The blockchain transaction data only stores the ID of the token being transacted.

APPENDIX

E. IMPLEMENTATION DETAILS OF THE CONSENSUS LAYER

1. Consensus Mechanism in R3 Corda

The consensus mechanism in R3 Corda can be divided into 2 (two) main components: transaction validation and transaction uniqueness.

i. Transaction Validation
Transaction validation ensures that all conditions required for a transaction are met (e.g., sufficient balance, participants acting within their authority). This process is performed by smart contracts (when executed) and the transaction participants. Every transaction must comply with the smart contract terms. Before sending the transaction to the notary (explained in section ii: Transaction Uniqueness), the participants must sign the transaction, indicating it has been validated. Before signing, participants review the transaction to ensure it adheres to the smart contract terms and meets all necessary requirements for validity.

ii. Transaction Uniqueness
Transaction uniqueness prevents double-spending by verifying that each transaction input has not been used in another transaction (ensuring uniqueness). This verification is performed by the notary. Once the transaction is signed by all relevant participants, it is sent to the notary. After the notary confirms the transaction's uniqueness, it is considered final. This finality ensures that the transaction cannot be canceled or altered.

2. Consensus Mechanism in Kaleido Hyperledger Besu

QBFT is a proof of authority (PoA) consensus algorithm recommended for private networks in Kaleido Hyperledger Besu. In QBFT, participants designated as validators (referred to as trusted validators) are authorized to validate transactions and take turns in block creation within the network. A supermajority (more than 2/3) of the trusted validators who are not assigned to block creation must sign the transactions before the "created block" can be added to the blockchain.

Figure 35. Consensus Mechanism in Kaleido Hyperledger Besu

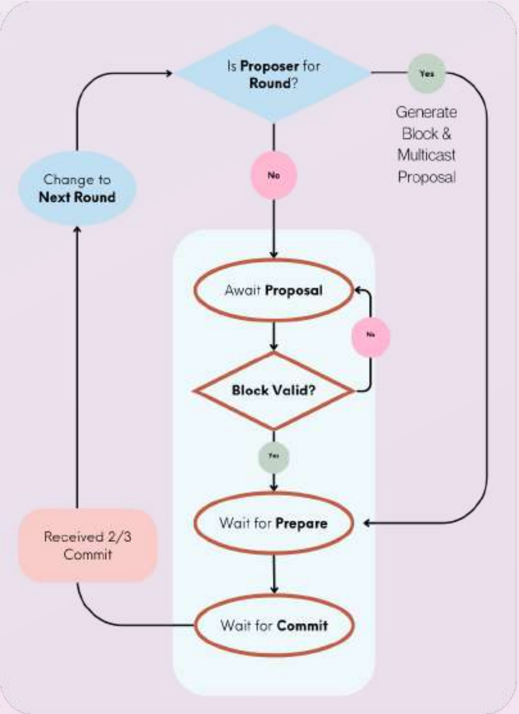
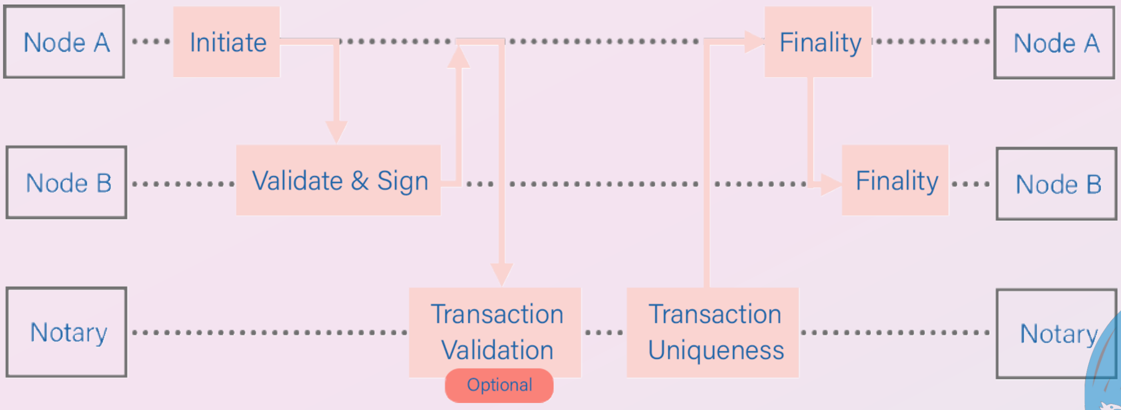


Figure 34. Consensus Mechanism in R3 Corda



Furthermore, QBFT is designed to tolerate Byzantine failures, meaning it can handle up to f "faulty" nodes, provided the total number of nodes n meets the condition $n \geq 3f + 1$. This ensures that the network will continue to reach consensus as long as the number of failed trusted validators does not exceed the tolerated threshold.

3. Findings: Consensus

When adding a block to a DLT, each node in the system must reach an agreement. This is accomplished in the consensus layer. Most consensus algorithms today fall into 3 (three) categories: i) proof-based, ii) BFT-based, and iii) DAG-based.

i. **Proof-based**

Consensus with proof-based algorithms is the most commonly used in public/permissionless DLTs. Proof of work in Bitcoin and proof of stake in Ethereum are well-known proof-based consensus mechanisms that provide high levels of security, scalability, and decentralization in trustless systems. However, proof-based consensus, especially traditional proof of work, requires a significant amount of energy and has low throughput and transaction confirmation speed. Despite this, innovations and modifications in proof-based methods continue with the aim of achieving better performance while maintaining the same level of security.

ii. **BFT-based**

Consensus with vote/Byzantine Fault Tolerance (BFT)-based algorithms is generally used in permissioned DLTs. BFT-based consensus is achieved through a series of deterministic communications between nodes. Contrary to proof-based, BFT-based has better performance but tends to be lower in decentralization (BFT-based tends to be more centralized).

iii. **DAG-based**

Consensus with DAG-based algorithms is used by distributed ledgers that employ graph structures rather than blocks, as typically used in blockchain. In DAG-based systems, transactions form nodes in a graph that refer to each other, creating a series of graphs. This graph structure allows transactions to occur in parallel, resulting in high scalability and throughput. However, DAG-based systems tend to have lower security. Some DAG-based systems also use the concept of trusted validators, which reduces decentralization.

In conclusion, there is no "one-size-fits-all" consensus. Therefore, it is necessary to delve into the specific needs of each case to determine which consensus is most suitable.

APPENDIX

F. IMPLEMENTATION DETAILS OF THE NETWORK LAYER

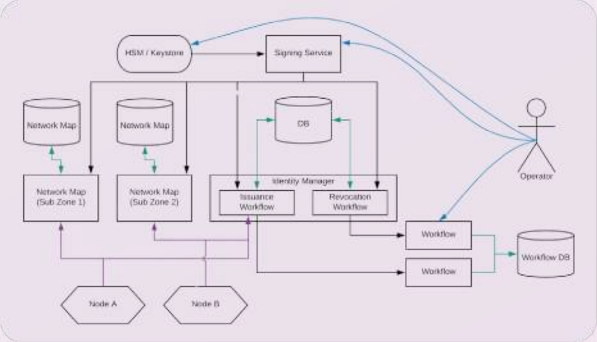
1. Illustration of the Use of CENM

Corda Enterprise Network Manager (CENM) manages and operates the R3 Corda DLT network. CENM provides a set of functions that can be used by operators to manage DLT networks, including node configuration, network map management, and certificate authority services.

CENM is supported by 3 (three) main components to carry out its functions, including:

1. **Identity Manager**
   The identity manager performs 2 (two) main functions to manage the identity of nodes in the R3 Corda network: 1) Issuance of node identities through the issuance of certificates that associate legal names with public keys. 2) Revoking the certificate when needed. The Certificate Issuance and Revocation service in Identity Manager supports using plugins[35] to model the approval process workflow for certificate issuance and revocation.

Figure 36. Illustration of the Use of CENM (Corda, 2024)



2. **Network Map**
   The Network Map serves as a location service for nodes once they obtain the identity assigned by CENM. In addition, by joining the network, a node agrees on a set of parameters that define the rules for reaching a consensus on the zone. One of the most important is the list of trusted notary services.

   A zone can host several consensus rule sets, each forming a different sub-zone within the main zone.

3. **Signing Service**
   The Signing Service is responsible for signing several things: Identity Certificates, Revocation lists, Network Parameters, and Network Maps. R3 recommends storing each key in Hardware Security Modules (HSMs) to keep that critical security by adding a configuration to the Signing Service.

2. Permissioned Network Kaleido Hyperledger Besu

There are 3 (three) networks that connect the Kaleido Hyperledger Besu nodes: the blockchain network, the private transaction network, and the InterPlanetary File System (IPFS). The blockchain network on Kaleido Hyperledger Besu operates using a permissioned network with 2 (two) types of access controls: node-based and account-based. Node-based access control manages a node's ability to connect to the network, while account-based access control governs the onboarding process, account freezing, and the limitation of transaction activities within the network.

In the blockchain network, there are 2 (two) levels of access control: local and on-chain. Local access controls are stored on individual nodes and contain a whitelist of nodes approved for communication. This level of control primarily focuses on protecting nodes connected to the network. On the other hand, on-chain access controls are stored in smart contracts and regulate the roles of individual accounts in performing transactions on the network.

To meet privacy standards, Kaleido Hyperledger Besu employs a private data manager, which connects to the private transaction network using mutual TLS protocols for secure point-to-point data transmission.

The InterPlanetary File System (IPFS) network facilitates file exchanges between nodes.

[35] Plugins are software components that add specific features or functions to a computer program.

APPENDIX

G. LIQUIDITY MANAGEMENT AND PRIVACY CONCEPTS FOR ADVANCED EXPLORATION

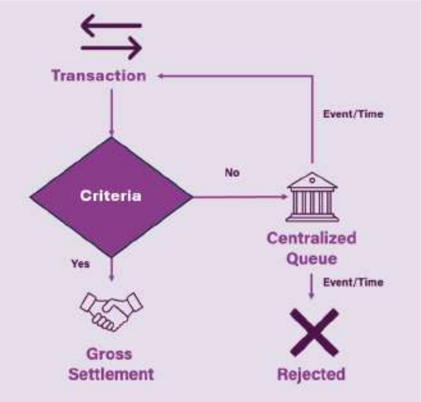
1. Liquidity Management: Liquidity Saving Mechanism

In the implementation of the Rupiah Digital proof of concept (PoC), both the R3 Corda and Kaleido Hyperledger Besu solutions adopted gross settlement mechanisms equipped with queueing mechanisms to simplify and reduce the need for a complex liquidity-savings mechanism (LSM). The queueing mechanism is implemented in a decentralized manner, where participants are responsible for managing their own queues. A transaction enters the queue if it does not meet the transaction criteria: 1) Low Priority, and 2) Sufficient Balance.

The R3 Corda solution processes queues using a First In, First Out (FIFO) approach, meaning that the earliest transaction in the queue is processed first once the participant's balance is sufficient to cover the transaction. On the other hand, the Kaleido Hyperledger Besu solution applies a First Available, First Out (FAFO) method for queue processing, where transactions with sufficient balance are processed first.

There are aspects of the queueing mechanism for LSM that can be further explored, as illustrated in the diagram below. In general, the queue management process remains consistent with the PoC implementation results. The criteria applied can be tailored to the business process, ensuring that transactions meeting these criteria are settled on a gross basis. The primary difference lies in the queue management approach, which involves a centralized queue.

Figure 37. Queue Management Flow for Further Exploration



Unlike the PoC implementation that distributes queue management among participants, a centralized queue relies on a single entity, such as the observer node, to manage the queue. In this case, the observer node, which is aware of each participant's transactions, is delegated to manage the queue and resolve gridlocks. When multiple participants experience gridlocked transactions, they can submit these transactions to the centralized queue, encapsulated as an event. The centralized queue then waits for additional transactions that can be resolved within a predefined time limit. If this time limit is exceeded, the transactions are canceled to prevent ongoing gridlock.

2. Privacy: Zero Knowledge Proof

In the BI-RTGS system, only the transaction parties have information about their own transaction data. There are several DLT solutions that can accommodate this policy. R3 Corda, which is built on a need-to-know principle using a directed acyclic graph (DAG), directly meets the privacy criteria set by Bank Indonesia. On the other hand, Kaleido Hyperledger Besu, which utilizes EVM blockchain technology, adopts Ethereum's global state[36] model with a transparent and "trustless" ledger design. Due to its public blockchain foundation, EVM inherently provides transparency between participants. Privacy concepts are added on top of the public blockchain layer of EVM with various solutions depending on the specific requirements. In the proof of concept (PoC), in addition to on-chain transaction data, Confidential UTXO with Notary, which fundamentally resembles the working method of R3 Corda, was also explored. Confidential UTXO comprises off-chain components and a UTXO pattern layered on top of EVM. Integrated privacy solutions using Zero-Knowledge Proofs (ZKP) will also be explored in further detail below.

The privacy criteria tested in the PoC are: 1) Only the sender and receiver should be aware of the transaction, and 2) Other parties should not be able to detect the transaction being added to a block from any particular party. To meet the first criterion, Kaleido Hyperledger Besu leverages a combination of Besu nodes processing encrypted data and a private data manager that sends decrypted data on a peer-to-peer basis. However, since the blockchain

[36] Global state model is a model in which all system components have access to the same set of data.

generates an event for each transaction, the details of the encrypted transactions in the block can still be seen through event subscriptions, thereby failing to meet the first criterion in this model.

The privacy model explored in the PoC is Confidential UTXO utilizing a Notary, which conceptually aligns with R3 Corda. However, this model requires an enterprise version of the EVM blockchain and additional processes to ensure transactions occur. The difference between R3 Corda and Kaleido Hyperledger Besu in this model lies in the connectivity between nodes, which is point-to-point in R3 Corda and distributed in Kaleido Hyperledger Besu. Both have their respective strengths and weaknesses.

Confidential UTXO (whether in R3 Corda or Kaleido Hyperledger Besu) uses a Notary to validate the balance update of participants in a transaction. However, the centralized role of the Notary introduces a single point of failure, leading to the proposal of an alternative solution, Zero-Knowledge Proof (ZKP), which has emerged within the EVM community. The ZKP privacy model can meet both privacy criteria (points 1 and 2) while maintaining the multi-validator concept within the blockchain network. This model is relatively new and continues to evolve in industry practices.

The ZKP method under consideration still uses the UTXO structure to store participants' tokens. Validators will validate transactions without knowing the contents of those transactions. To ensure that the tokens added comply with the rules, verification is stored in smart contracts relying on the ZKP principle.

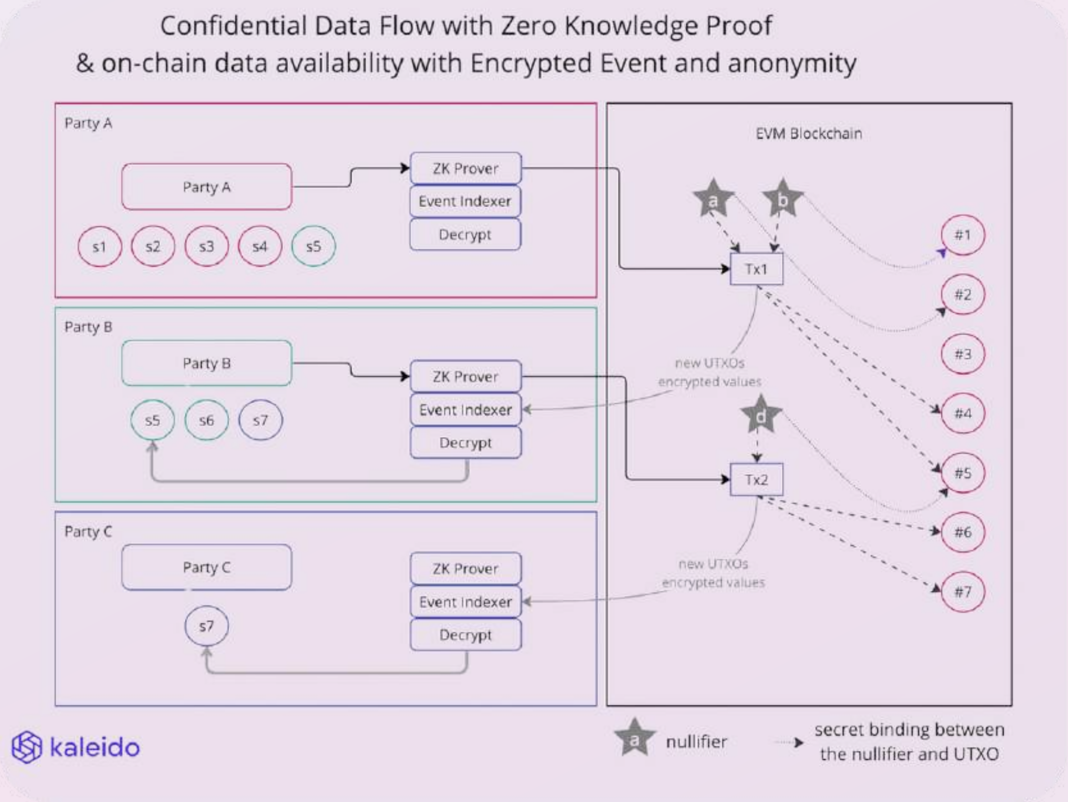
In Figure 38, the fund transfer conducted by the Bank relies on an additional component, the ZK Prover, to generate components 'a' and 'b', which are the encryption of tokens 1 and 2 respectively, known only to the sender. The sender will create new components that are known only to the receiver and observer, allowing both parties to know the value of the transaction that occurred.

With this solution, Party B cannot determine the number of tokens and their respective values used by Party A. Party B only knows the new tokens received.

According to experiments conducted by Kaleido, this process adds approximately 2 seconds to each transaction. Additionally, there are components that need to be added according to the variables that require verification and the parties involved.

An essential component of this solution is the zero-knowledge circuit, implemented through a combination of mathematical operations. This component generates an output in the form of a hash of the data, which is then processed into a block.

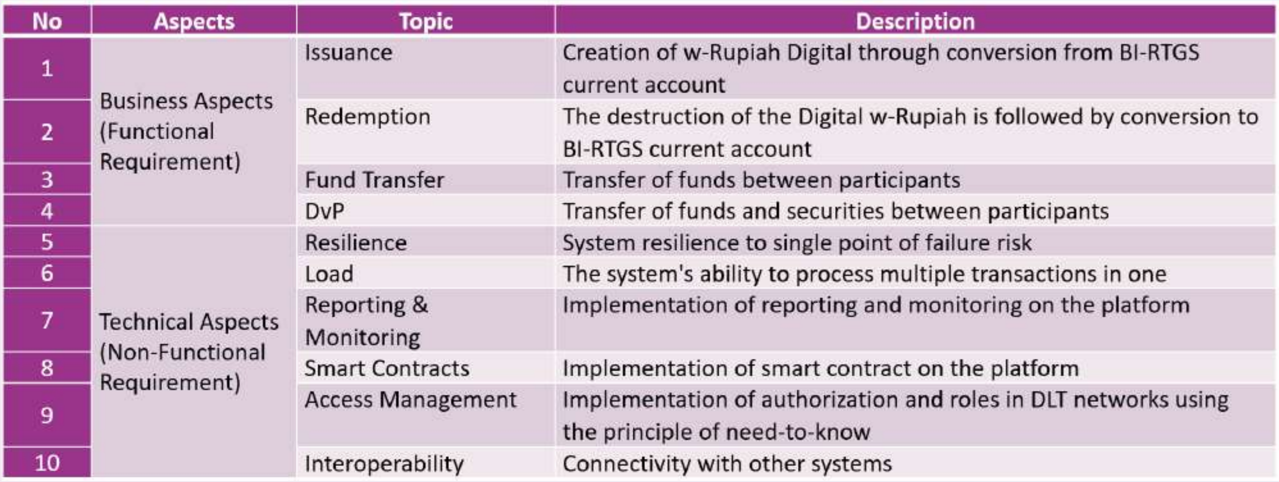
Figure 38. Kaleido's Privacy Model Concept for Further Exploration



APPENDIX

H. POC SCENARIO TOPICS

Table 4. PoC Scenario Topics



No	Aspects	Topic	Description
1	Business Aspects (Functional Requirement)	Issuance	Creation of w-Rupiah Digital through conversion from BI-RTGS current account
2		Redemption	The destruction of the Digital w-Rupiah is followed by conversion to BI-RTGS current account
3		Fund Transfer	Transfer of funds between participants
4		DvP	Transfer of funds and securities between participants
5	Technical Aspects (Non-Functional Requirement)	Resilience	System resilience to single point of failure risk
6		Load	The system's ability to process multiple transactions in one
7		Reporting & Monitoring	Implementation of reporting and monitoring on the platform
8		Smart Contracts	Implementation of smart contract on the platform
9		Access Management	Implementation of authorization and roles in DLT networks using the principle of need-to-know
10		Interoperability	Connectivity with other systems

APPENDIX

I. LOAD TEST

1. Scope and Results of Load Test

The load test results were obtained using the Locust Dashboard and AWS CloudWatch. Due to the limitations and time constraints of the PoC, the load test primarily focused on meeting the threshold consistent with the typical traffic of wholesale payment systems, approximately 30 transactions per second (tps). Both technologies successfully met this threshold, with R3 Corda recording 37 tps and Kaleido Hyperledger Besu achieving 39 tps. It is important to note that further exploration with additional time and resources is necessary to fully assess the maximum capabilities of both technologies. Additionally, the load test results are influenced by multiple factors, including the type of distributed ledger technology (DLT) used, as well as other elements such as middleware, infrastructure capacity, and configuration settings.

2. R3 Corda and Kaleido Hyperledger Besu Load Configuration when Performing Load Test

In the proof of concept (PoC), the R3 Corda network comprises 1 (one) Bank Indonesia node cluster and 3 (three) wholesaler bank clusters. The Bank Indonesia cluster includes observer node, KDR node, provider node, regulator node, administrator node, non-validating notary node, and network map node. Each wholesaler bank cluster consists of 1 (one) wholesaler node. Due to the non-validating nature of the notary, it is not required to validate transactions, resulting in improved performance.

Similarly, the Kaleido Hyperledger Besu network consists of 1 (one) Bank Indonesia node cluster and 3 (three) wholesaler bank clusters. However, in the Kaleido Hyperledger Besu network, the Bank Indonesia cluster does not include notary or network map nodes. Instead, the wholesaler bank clusters serve as validators. Kaleido Hyperledger Besu also employs a combination of off-chain and on-chain processing when executing logic on the network, which can positively impact performance.

For load testing, the minimum configured AWS cloud infrastructure was utilized, as depicted in Figures 39 and 40. The on-premise configuration was not explored in the PoC. In the future, infrastructure configurations should be designed according to specific performance requirements, whether on-premise or cloud-based.

Figure 39. R3 Corda Infrastructure on AWS For Wholesale Participant Clusters

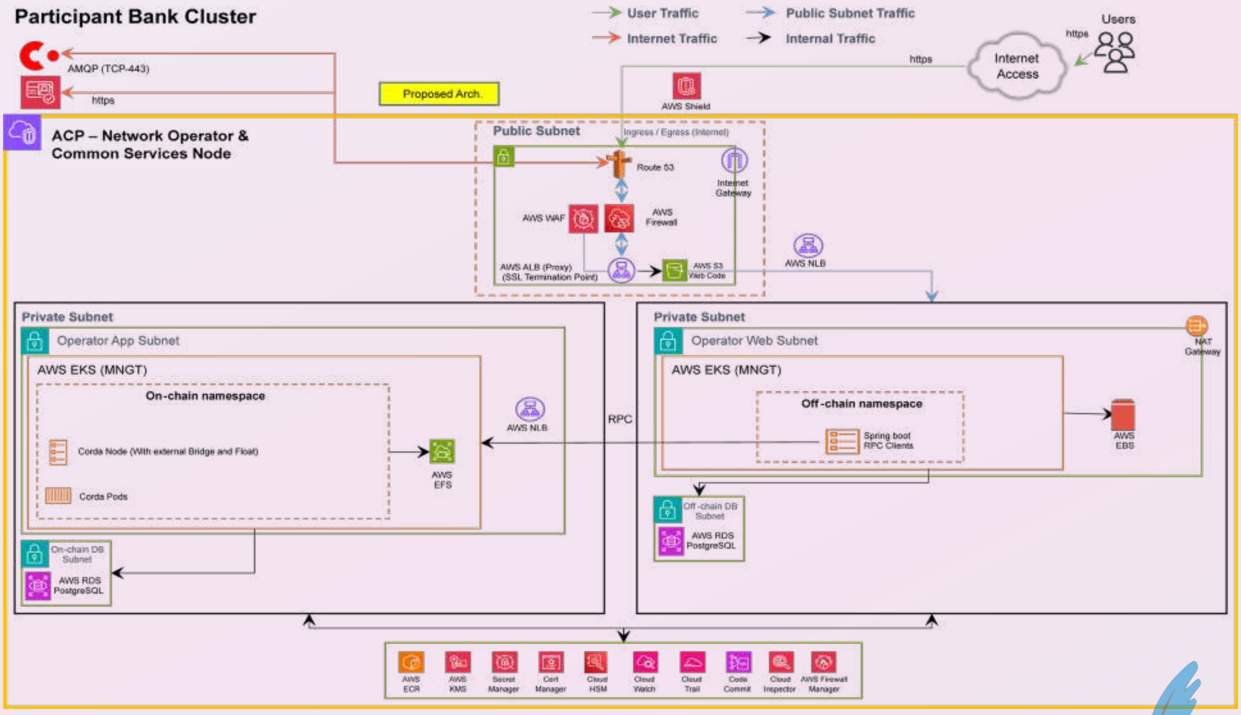
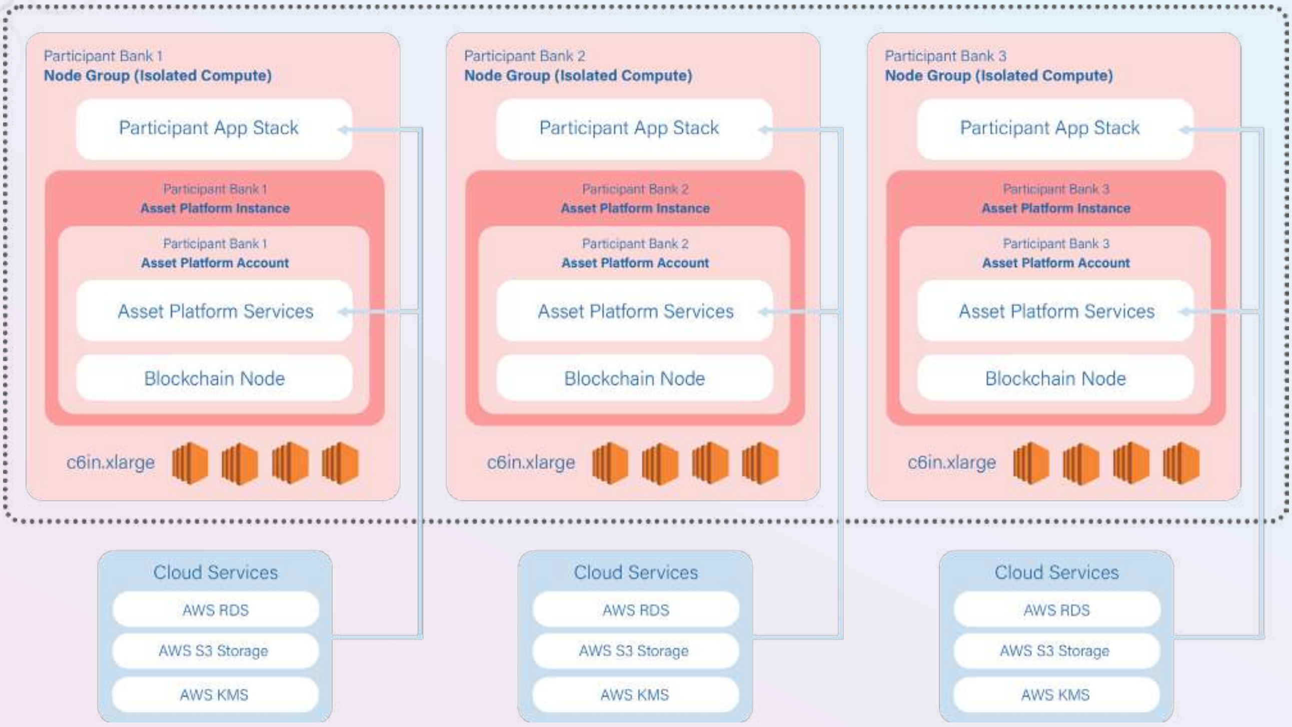


Figure 40. Kaleido Hyperledger Besu Infrastructure on AWS For Wholesale Participant Clusters



Both platforms require further optimization to handle the potential for increased transaction loads. This can be done in synergy across various components ranging from network design and hardware specs to refinement of consensus methods, application architectures, and potential scalability solutions (such as channels, data sharding, and others).

LIST OF AUTHORS

Coordinator:
Endang Trianti (Assistant Governor/DPID),
Dicky Kartikoyono (Assistant Governor/DKSP)

Contributor:
Rohadi Triatmono (Executive Director/DPID),
Ryan Rizaldy (Director/DKSP),
Yudi Muliawirawan Sugalih (Deputy Director/DPID)

Writer Team:
Setyo Kuncoro, Bagas Aji Pratama, Kevin Eza Rizky, Timothy Thamrin Andrew H. Sihombing, Sirria Panah Alam, Dewi Septina Br Pelawi, Bijak Antusias Sufi, Faradilla Azranur, Dian Nofitri, Annisa Muzdalifa

Technical Team:
Workstream 1 Project Garuda:
Novi Maryaningsih, Kusuma Ayu Kinanti, Nenden Endah Sari, Akhmad Ginulur Pangersa, Moh. Nuryazidi, Yudha Wastu Prawira, Ivan Devara, Najibullah Ulul Albab, Abhirama Budiawan, Adinda Diyah Ayu Permata Sari, Ridha Nur Huzaifah, Ruth A Cussoy Intama, Afaf Munawwarah, Angga Puspa Hapsari, Yoga Aroyandi

Workstream 2 Project Garuda:
Setyo Kuncoro, Bagas Aji Pratama, Kevin Eza Rizky, Timothy Thamrin Andrew H. Sihombing, Sirria Panah Alam, Dewi Septina Br Pelawi, Bijak Antusias Sufi, Faradilla Azranur, Dian Nofitri, Annisa Muzdalifa, Ngadino, Muhammad Arif Sultoni, Prihantojo, Istianto Utomo, Suryo Pranoto Utomo, Johannes Andrew Kristiandi

Workstream 3 Project Garuda:
Lisa Rienelda Irsal, Faried Caesar Nugroho, Charvin Lim, Berly, Renold Abdi

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BANK INDONESIA
Jalan M.H. Thamrin No.2, Jakarta – 10350, Indonesia