The future is here

Project Ubin: SGD on Distributed Ledger

A report developed with the contributions of Bank of America Merrill Lynch, BCS Information Systems, Credit Suisse, DBS Bank, HSBC, J.P. Morgan, Mitsubishi UFJ Financial Group, OCBC Bank, R3, Singapore Exchange and UOB Bank

Acknowledgements

Deloitte and the Monetary Authority of Singapore would like to thank the following organisations who have contributed to the research of this publication:

- Bank of America Merrill Lynch
- BCS Information Systems
- Credit Suisse
- DBS Bank Ltd
- The Hongkong and Shanghai Banking Corporation Limited
- J.P. Morgan
- Mitsubishi UFJ Financial Group
- OCBC Bank
- R3
- Singapore Exchange
- United Overseas Bank

Sections

Foreword

The Monetary Authority of Singapore (MAS) is pleased to present the report “Project Ubin: SGD on Distributed Ledger”. This report will serve as an introduction to Distributed Ledger Technology (DLT), and provide an understanding of the prototype developed in Project Ubin for inter-bank payments using DLT.

Project Ubin demonstrated the commitment of MAS and the industry to co-create concrete use cases for technologies such as DLT. We believe that central banks like MAS can play a bigger role beyond just providing research funding: collaborative projects such as Project Ubin support the creation of open Intellectual Property and foster collaboration between industry players, creating a vibrant, collaborative, and innovative ecosystem of financial institutions and FinTech companies.

Some Project Ubin participants have since embarked on projects that are inspired by this collaboration. We hope that the report will further encourage other financial institutions to explore and experiment with the use of DLT, and the report lists potential use cases which will serve as a useful starting point.

We would like to take this opportunity to acknowledge the contributions of Project Ubin participants in developing the working prototype on DLT for inter-bank payments and contributing to the project report, and the team from Deloitte in the production of this report.

We hope that you would gain a better understanding of DLT from the report, and be inspired to explore and further evaluate the use of DLT within your institution.

Sopnendu Mohanty
Co-Chair, Project Ubin
Chief FinTech Officer
Monetary Authority of Singapore

Ng Nam Sin
Co-Chair, Project Ubin
Assistant Managing Director
Monetary Authority of Singapore

Executive summary

DLT is at the centre of a massive push for innovation across the financial services industry. While DLT is by no means a one-size-fits-all solution, it has the potential to drastically alter the way we do business and interact with one another. The technology is also known as the "Internet of Value", as it increases the efficiency, security and transparency of transactional activities.

Deloitte has been an active player in this emerging ecosystem, conducting research, exploring use cases, designing prototypes to test hypotheses and partnering with technology platform vendors to collaborate on pilots. It has created numerous use cases across themes such as cross-border payments, smart identity, trade finance and loyalty, with over 800 practitioners across its global network involved in these efforts, staying constantly up-to-date on the latest developments while demonstrating the 'art of possible' to the broader industry.

A group of banks in Singapore, with the support of MAS, Singapore's central bank and financial regulatory authority, have also been developing a payment system prototype using DLT in which bank users can exchange currency with one another without lengthy processing times, expensive processing fees, or intermediaries. R3 – a consortium specialising in DLT – has partnered with the group on the initiative, known as Project Ubin. This project represents a significant opportunity for Singapore's ecosystem to establish leadership in the area of DLT research and development, in line with Singapore's broader goal of becoming a Smart Financial Centre.

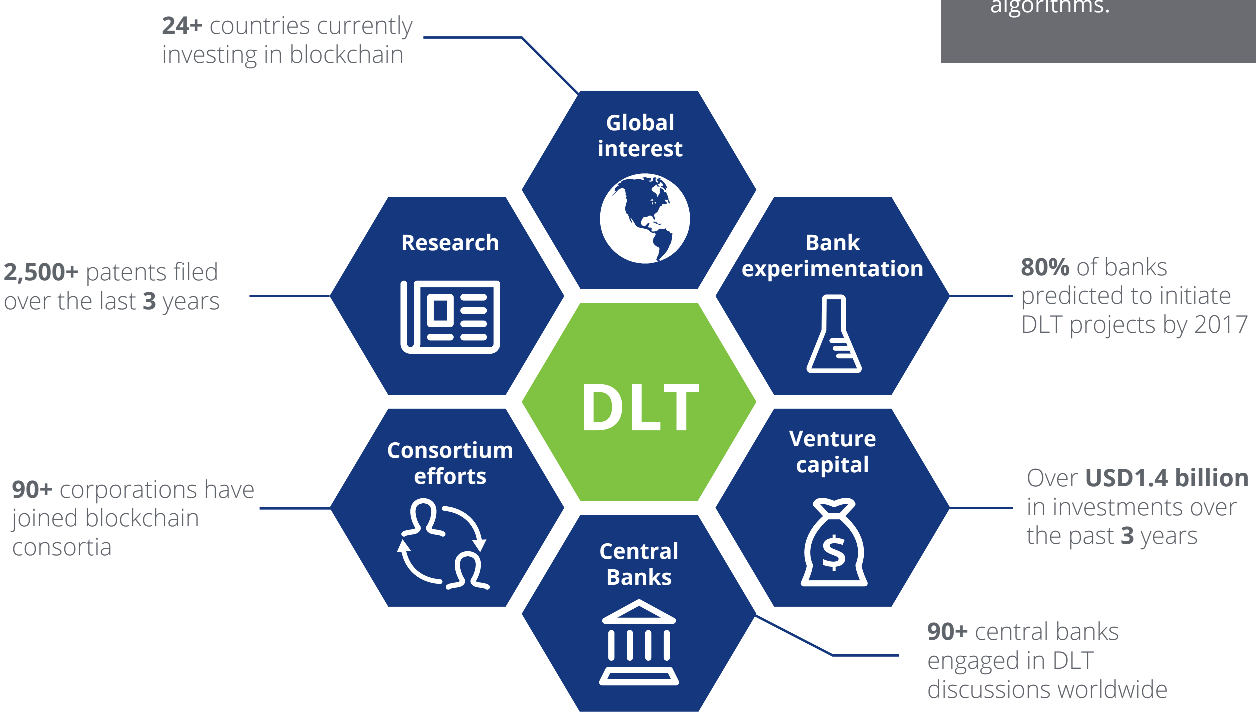
In this whitepaper, we provide a brief overview of DLT along with how Deloitte is pioneering innovation in the market, while outlining Project Ubin, which places a tokenized form of the Singapore Dollar (SGD) on a DLT. Singapore may be the first major financial centre in Asia to fully explore the benefits of DLT across a broad set of transformative applications.

Distributed Ledger Technology

Over the past year, there has been much buzz in the marketplace about DLT (see Figure 1). The 2016 report entitled, "The future of financial infrastructure," produced by the World Economic Forum in collaboration with Deloitte, predicted that 80% of banks will initiate DLT projects in 2017. Due to the significant cost, risk and friction of current financial services infrastructure, organisations in search of a more viable alternative have found hope in DLT to potentially disrupt the way we conduct transactions and contracts.

Key takeaways
- DLT has seen high traction in the global market with over USD1.4 billion of investments made in the last 3 years.
- DLT was made possible by 3 technology innovations: Peer-to-peer networks, public key cryptography, and consensus algorithms.

Figure 1: Global traction in DLT[1]



Based on Deloitte's research, the following three innovations helped to lay the groundwork for the invention of DLT:

1. **Peer-to-peer networks:** In a peer-to-peer model, every peer in the network is a server and client, both supplying and consuming resources. This may facilite, for example, the creation of a currency without a privileged third party, amongst other types of decentralised financial interactions.

2. **Public key cryptography:** Public key cryptography is a method for verifying digital identity with a high degree of confidence, enabled by the use of private and public keys. Cryptography enables the individual identification and exchange of Bitcoin among users.

3. **Consensus:** Consensus algorithms that ensure agreement between parties on a network can help validate the data's authenticity as well as transactions and control when it can be written into the system. This capability prevents double spending by ensuring chronogical recording of data.

2.1 What is DLT?

DLT is a type of database that is spread across multiple sites, countries or institutions. It is decentralised in nature, eliminating the need for an intermediary to process, validate or authenticate transactions. Each party (e.g., individual, organisation or group) is represented by their computer, called a node, on the network. Each node keeps its own copy of all transactions on the network, and nodes work directly with one another to check a new transaction's validity through a process called consensus. Each of these transactions is encrypted and sent to every node on the network to be verified and grouped into timestamped blocks of transactions. Blockchain is one such type of distributed ledger (DL) that has gained notoriety as the core technology behind Bitcoin.

For example, let's say that John initiates a transaction to pay Sally $20 through a DLT-based solution. A copy of that transaction is sent to all the other nodes on the network, and each of these nodes would then verify that its copy of the ledger is the same as the others to ensure that the transaction is valid. Each transaction has a unique signature, called a hash, that includes a reference to the previous transaction as well as a digital signature from the node initiating the transaction. This hash gives the nodes on the network a common signature with which to validate the transaction. Nodes on the network called miners compete to solve complex algorithms to write batches of valid transactions, such as John and Sally's $20 exchange, to a block. This block is a timestamped group of transactions that is chained to previous blocks, forming an immutable, or tamper-resistant "block-chain" of historical transaction data.

DLT has several unique and valuable characteristics that over time could transform a wide range of industries (see Figure 2).

Key takeaways
- DLT allows for decentralised processing, validation and authentication of transactions.
- DLT has several unique and valuable characteristics that over time could transform a wide range of industries.

Figure 2: Characteristics of DLT[2]

Distributed ledger
The peer-to-peer distributed network records a public history of transactions. DLT is distributed and highly available. DLT retains a secure source of proof that the transaction occurred.

Irreversibility
DLT contains a certain and verifiable record of every single transaction ever made. This mitigate the risk of double-spending, fraud, abuse, and manipulation of transactions.

Censorship resistant
The crypto-economics built into DLT model provide incentives for the participants to continue validating blocks, reducing the possibility of external influencers to modify previously recorded transaction records.

2.2 What are the benefits of DLT?

There are many intrinsic benefits of DLT, which make it a disruptive force across many industries (see Figure 3). First and foremost, it allows for the disintermediation of processes that once required centralised third parties. For example, since nodes work directly with one another, when John transferred Sally $20, their transaction did not go through a third party such as a bank; it went directly from John to Sally and was validated by all of the nodes on the network (instead of a centralised bank). Disintermediation also minimises the time it takes to clear transactions, and the costs associated with transferring assets. Removing third parties can make networks less susceptible to certain types of cyberattacks, as there is no central point of failure to be targeted. Additionally, the loss of one node does not pose a threat to the larger network.

Transactions stored on a DL use digital signatures, which make them tamper-resistant. This can help prevent some types of fraud and can help ensure the integrity of the data.

Although DLs can create immediate value for two participants, there is a network effect, and larger networks with more participants create more efficiency. The value of the network depends on the number of nodes participating – the greater the number of people using it, the more valuable the network becomes.

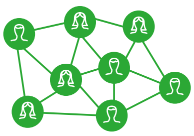
DLT also enables Smart Contracts, which are virtual agreements encoded on the network that are automatically executed based on logical conditions. Referring to our example again, let's now imagine that John issued a Smart Contract with instructions to send Sally $20 if the stock for Company X reaches $1.20 earnings per share. The Oracle – a trusted data feed to a Smart Contract, which may be needed when data is not intrinisically available on the ledger – validates the logical conditions of a Smart Contract. It watches the earnings per share value and triggers the Smart Contract when the earnings per share of Company X hit $1.20. As soon as the condition is met, it will automatically trigger a $20 transaction to Sally. This offers an extremely powerful benefit to many different industries by enabling the automation of complex business processes (often with multiple untrusting parties) with the use of logical conditions and rules.

Key takeaways

- Digital signatures enable DLT transactions to be tamper and fraud resistant.
- Many DLTs enable the use of Smart Contracts which are agreements encoded on the network that can be automatically executed when certain predefined conditions are met.

Figure 3: Benefits of DLT

1 Disintermediate



In a peer-to-peer model, every peer in the network is a server and client, thus eliminating the middlemen in processes between users.

Enables the facilitation of transactions without a central, privileged third party even in the absence of trust.

2 Secured by cryptography

Public key cryptography is a method for verifying digital identity with a high degree of confidence, enabled by the use of private and public keys.

Allows for increased security and protection of data and identity in the system.

3 Smart Contracts & Oracles

Smart Contracts are virtual agreements encoded on the DLT that can be automatically reconciled based on logical conditions.

Enables the secure automation of complex, logical agreements and the business processes using data gathered by Oracles.

4 Immutable

Data on the DLT is immutable, and is thus resistant to double-spending, fraud, censorship and hacking efforts.

Creates a more secure, transparent network and creates new avenues for regulators.

5 Real-time settlement

DLT allows for near real-time settlement of transactions, removing friction and reducing risk.

Enables transactions to be made in near real-time between users on the network.

6 Trustless

DLT is based on cryptographic proof, allowing any two parties to transact directly with each other without a trusted third-party.

Allows two or more trustless parties to transact directly with each other.

2.3 When Is DLT the answer?

As with every new technology, experiments are needed to determine the feasibility of the solution in solving a set of problems. DLT is not the answer to all problems. There are a handful of requirements that, when met in part or in full, should indicate whether DLT will sufficiently address a client's needs, such as shared data, architecture or infrastructure, absence of trust and the opportunity for disintermediation.

Conversely, there are several factors that, when present, may indicate that technologies other than DLT would be needed to meet client needs (e.g., technical reliability, system operators and users). As the degree of trust in system participants and confidence in system infrastructure rises, non-DLT based technologies should also be considered in parallel. To evaluate the appropriate DLT use cases, a number of key value drivers have been identified (see Figure 4).

Figure 4: Key value drivers for the identification of appropriate DLT use cases[1]

Operational simplification
DLT reduces/eliminates manual efforts required to perform reconciliation and resolve disputes

Regulatory efficiency improvement
DLT enables real-time monitoring of financial activity between regulators and regulated entities

Counterparty risk reduction
DLT challenges the need to trust counterparties to fulfil obligations as agreements are codified and executed in a shared, immutable environment

Clearing and settlement time reduction
DLT disintermediates third parties that support transaction verification/validation and accelerates settlement

Liquidity and capital improvement
DLT reduces locked-in capital and provides transparency into sourcing liquidity for assets

Fraud minimisation
DLT enables asset provenance and full transaction history to be established within a single source of truth

2.3 DLT use cases

A few initial DLT use cases have been identified, based on their potential for disruption and innovation to processes that are otherwise time consuming, expensive and prone to fraudulent activities (see Figure 5).

Figure 5: DLT use cases[2]

Trade finance

Blockchain eases the existing pain points of buyers, sellers and financial institutions while opening the ecosystem to new non-traditional players.

Cross-border payments

Blockchain can transfer payment across currencies almost instantly for a fraction of today's cost and provide access to the unbanked in remote areas.

Digital identity

Blockchain can create an auditable source of information shared and verified across a network of organisations (e.g., KYC compliance).

Clearing and settlement

Blockchain shows promise to drive efficiency in the clearing and settlement process of digital assets through the use of coloured coins.

Provenance

Blockchain offers an immutable and irreversible source of information that can track the true ownership of a product across the supply chain.

Multi-party aggregation

Blockchain can be used as a shared master data repository for common industry information allowing members to query the data.

Record keeping

Blockchain provides a method for collectively recording and notarising any type of data, whose meaning can be financial or otherwise.

Re-insurance

Contractual terms and obligations can be programmed directly into the blockchain, maximising adherence (e.g., final contract, signatures, claims & premiums processing).

Project Ubin

SGD-on-ledger

We have introduced the concept of an SGD-on-ledger to distinguish it from existing forms of digital central bank money such as the deposits that banks hold at the MAS which are used to make payments via MEPS+.

To use a physical analogy, the SGD-on-ledger is a specific use coupon that is issued on a one-to-one basis in exchange for money. The coupons have a specific usage domain – in our case for the settlement of interbank debts – but no value outside of this. One is able to cash out by exchanging the coupons back into money later.

One may think of these as the coupon booklets at fun fairs: visitors can purchase them to be spent on games and food within the fairgrounds only.

SGD-on-ledger has three useful properties that make it suited to our prototype.

First, unlike money in bank accounts, we do not receive interest on the on ledger holdings. The absence of interest calculations reduces the complexity of managing the payment system.

Second, to ensure full redeem-ability of the SGD-on-ledger for money, each token is fully backed by an equivalent amount of SGD held in custody. This means that the overall money supply is unaffected by the issuance of the on ledger equivalents since there is no net increase in dollar claims on the central bank.

Third, SGD-on-ledger are limited use instruments and can be designed with additional features to support the use case – such as security features against misuse.

3.1 Objectives and scope

3.1.1 Context

On 16 November 2016, MAS announced that it was partnering with R3 – a blockchain-inspired technology company and consortium of the world's largest financial institutions – on the production of a proof-of-concept (PoC) to conduct inter-bank payments facilitated by DLT. This endeavour, known as Project Ubin, is a digital cash-on-ledger project run in partnership between MAS and R3, with the participation of Bank of America Merrill Lynch, Credit Suisse, DBS Bank, The Hongkong and Shanghai Banking Corporation Limited, J.P. Morgan, Mitsubishi UFJ Financial Group, OCBC Bank, Singapore Exchange, United Overseas Bank, as well as BCS Information Systems as a technology provider.

The aim of Project Ubin is to evaluate the implications of having a tokenized form of the SGD on a DL, and its potential benefits to Singapore's financial ecosystem.

MAS is Singapore's central bank and financial regulatory authority. MAS acts as a settlement agent, operator and overseer of payment, clearing and settlement systems in Singapore that focus on safety and efficiency.

As part of its role, it operates an electronic payments and book-entry system, the New MAS Electronic Payment System (MEPS+). MEPS+ is a Real-Time Gross Settlement (RTGS) system that supports large-value local currency interbank funds transfers and the settlement of script less Singapore Government Securities (SGS) between MEPS+ participants, subject to the availability of funds and securities.

MAS undertakes this role as a trusted third party and actively engages banks in the Singapore market, as well as with public and private sector bodies such as the Singapore Clearing House Association (SCHA) and The Association of Banks in Singapore (ABS).

MEPS+ is a system that enables real-time and irrevocable transfer of funds and SGS. Key features include:

- Use of SWIFT message formats to increase interoperability
- Parameterised queue management, which provides participants with better liquidity and settlement management
- Automated collateralised intraday liquidity facilities, that enable participants (particularly banks with low liquidity) to settle more payments quicker
- Automated gridlock resolution, which detects and resolves multi-party payment gridlocks to prevent or reduce payment queues and to increase overall efficiency of payments flow

All participating banks are contractually bound to operate in compliance with the MEPS+ operating rules and regulations. This presented an excellent opportunity for MAS to collaborate with the banks and assess the value that blockchain could bring to this existing relationship.

Project Ubin is a multi-phase project. Phase 1, which ran for six weeks from 14 November 2016 to 23 December 2016, served as the foundation to assess the feasibility and implications of DLT, and to identify the elements required for future enhancements.

3.1.2 Background

Project Ubin was conceived as an opportunity for Singapore to take a leading role in the research on central bank currency on a DL and Central Bank Digital Currencies (CBDCs).

A similar project, Project Jasper, was carried out in Canada between March and June 2016 in partnerships between R3, the Bank of Canada, Payments Canada and five R3 member banks in the Canadian market (Bank of Montreal, Canadian Imperial Bank of Commerce, Royal Bank of Canada, Scotiabank and TD Canada Trust).

Project Jasper's goals were to:

- **Build a proposal** for a model for Bank of Canada issued digital currency, including issuance, transfer, settlement and destruction;
- **Leverage rapid prototyping** to test and validate business; operational, and technical hypotheses; modelling the on-ramp/off-ramp access points to the central bank ledger; and
- **Collaborate** and publish a report on findings and the broader implications of central bank issued digital currencies.

Project Ubin leverages the significant experience of R3 and its members in the Canadian market. Specifically, the architecture, code and lessons learned from Project Jasper were considered and applied to the Singapore context for Project Ubin.

Key takeaways

- In 2016, MAS partnered with R3, a leading blockchain consortium, to launch Project Ubin for developing a proof-of-concept to conduct inter-bank payments through DLT (Phase 1).
- Project Ubin's objective was to evaluate the implications of a tokenized SGD on a distributed ledger with potential benefits to Singapore's financial ecosystem.
- In Phase 1, the project leveraged on the MAS MEPS+ system to enable real-time fund transfers to issue funds on a DLT. Project Ubin's next phases will explore improvements in domestic and cross-border securities transactions.

3.1.3 Scope

For current operations, while MEPS+ supports SGD-denominated domestic transactions, cross-border transactions interact with international systems and face additional risks and inefficiencies such as the following outlined in Figure 6.

Figure 6: Additional risks and inefficiencies from cross-border transactions

Replacement risk	Settlement risk	Inefficient funding costs	Reconciliation costs
Counterparty cancels or delivers late	Counterparty defaults	Parties on both sides of a transaction tend to pre-fund accounts early and excessively on a 'worst case' provisional basis	Multi-way reconciliation required across payments and securities to understand real-time stock position

R3 and MAS believe that DLT offers the potential to:

- Improve domestic securities transactions, offering Delivery-vs-Payment (DvP) settlement in cases where it is not already available
- Significantly improve cross-border payments (Payment-vs-Payment) and securities transactions (DvP)

In order to achieve the hypothesised benefits, widespread adoption of DLT would be needed. The industry requires answers to the perceived technical challenges of getting: interoperability between platforms, selective identification of relevant parties, appropriate levels of privacy, proven ability to scale and various systems upgrades over time.

If these challenges can be solved as part of this project in the near future, MAS can create "atomic" transactions for the first time for cross-border fixed income products with payments directly on central bank money. This would enable true DvP where security and corresponding payment switches ownership simultaneously at the deepest technical level. This could remove the occurrence of late payments and payment failures. Certainty around delivery and near real-time, same-day (t+0) delivery also becomes viable. These could make both domestic as well as cross-border transactions more attractive from both a technology and end user experience standpoint. Furthermore, the reduction in counterparty risk may drive a reduction in collateral requirements in some circumstances.

Project Ubin was thus designed to research and validate the hypothesis, and drive the potential benefits towards reality through evaluations across business, technology and economic factors.

Key takeaways

- Project Ubin's ultimate goal is to reduce risk and costs for cross-border settlements of payments and securities.
- Cross-border operations require international cooperation on standards, the ability to identify payers and payees, and systems of adequate scale.
- Project Ubin will be implemented in phases, starting with a DLT for domestic payments. Subsequent phases will explore cross-border payments in a single currency, settling different currencies and culminate with risk free cross currency securities settlements.

Figure 7: Evaluation of business, technology and economic factors of Project Ubin

Business case

- Would DLT enable the Singapore financial services industry to become safer and more efficient by reducing risks and costs across domestic as well as cross-border use cases?
- Can DLT provide Singapore's financial ecosystem a global competitive advantage?

Technology feasibility

- How does DLT compare with existing technology capabilities?
- Do the DLT capabilities provide significant advantages for financial ecosystem use cases in comparison to prevalent existing technologies?

Economic viability

- What are the economic implications of digitising central bank currency on DLT?
- Would DLT enable broader electronic access to the Central Bank's balance sheet?
- If so, what are the economic implications of a central bank digital currency with widespread participation?

3.2 Phase 1 prototype capabilities and findings

As the overall scope of the project is broad in nature, objectives were divided into multiple phases. A collaborative environment with traditionally competing participants across MAS was set up to deliver the two-fold objectives of Phase 1 (Figure 8).

Figure 8: Objectives of Project Ubin Phase 1

Build a PoC for a domestic payments system for inter-bank obligations on a DL, denominated in balances backed by central bank deposits	The prototype should include: • A DL to track participant balances • Real-time creation, transfer and destruction of participant balances on the DL • Sustain "always-on," round-the-clock balance transfers on the DL • Integration of the DL to existing central bank settlement infrastructure
Identification of non-technical implications of implementing DLT in production environment	• What impact does cash-on-ledger have on monetary policy and market rules? • Does cash-on-ledger impact money supply and systemic risk or Principles for Financial Market Infrastructure (PFMI) criteria? • Which regulatory and risk related implications should be considered?

In order to deliver these objectives in the relatively short period of time, MAS instituted two work streams:

1. The **technical workstream** to focus on building PoC; and
2. The **research workstream** to document adjacent potential implications of implementing DLT.

3.2.1 Technical workstream

As suggested earlier, the Project Ubin Phase 1 prototype was adapted using several components from existing project implementations undertaken by R3 (Project Jasper) and BCS Information Systems (BCSIS Blockchain PoC).

3.2.2.1 Design considerations and requirements

Amongst the three models that were being considered for the prototype, a "continuous depository receipt" model was selected for Phase 1. Please refer to Table 1 for detailed account terminology that shows the different accounts that may be held by a MEPS+ participant, including a new "Depository Receipts (DR) Cash Custody account" was created for Project Ubin to back the DR in the DL.

Key takeaways

- The prototype was developed with linkage to MEPS+ RTGS and Current Account Systems, enabling automated management of collateral that backs the outstanding float of SGD-on-ledger.
- The prototype was tested for the ability to transact 24/7, resilience against single points of failure, and timeliness of settlements.

Table 1: Different accounts that may be held by a MEPS+ participant

MEPS+ account	Description
CAS account	• This stores balances overnight and is considered part of the Minimum Cash Balance (MCB) regulatory requirement. • It is the "home" for Bank A's money, when the money is not being used for payments. • Typically, this account is kept at its minimum required level, with excess moved in the morning to the RTGS account to support RTGS transfers, and returned in the evening.
RTGS account	• This is for RTGS (wholesale, operating hours only) transfers between banks, typically debited and credited all day long during MEPS+ operating hours. • Typically, this is funded from the CAS account in the morning and drained back to the CAS account in the evening. • In Project Ubin, this account was used to transfer money to and from the DR Cash Custody account.
Fast and Secure Transfers (FAST) Cash Custody account	• This is a custody account used to back interbank FAST (retail, round-the-clock) payments. • Typically, it remains funded, and is not funded and drained on a daily basis. • Cash custody accounts are not technically collateral accounts as ownership remains under the holders. • This was not used for Project Ubin, but serves as a point of reference for the new cash custody account.
DR Cash Custody account (created for Project Ubin)	• This is a new account created for Project Ubin, and acts like the FAST Cash Custody account, but backs DRs on the DL. • The balance in the account is periodically adjusted to match the outstanding amounts of DR owed to the account holder.

The prototype draws its main features from the R3 Jasper Project. However, Project Ubin's functionality follows a "continuous depository receipt model" with three major differences for the Singapore context:

1. **In MEPS+, DR Cash Custody accounts are individual (per bank) rather than comingled as an omnibus account.**
   - As cash custody accounts are owned by the individual banks, the deposits they hold are not true collateral and rebalancing of the accounts to match the DLT wallet balances after the point of any one participant's bankruptcy is contestable.
   - For the purpose of the current project, however, it is assumed that they can act as collateral under a participation contract.

2. **Banks can individually pledge and redeem at will during operating hours of MEPS+, not limited to start of day and end of day activities. Additionally, Banks can hold depository receipt balances on the DL overnight.**
   - There are no interest rate implications as current accounts in MEPS+ are zero-interest, and DL accounts are zero-interest.
   - Regulatory reserves capital in the form of MCB is impacted unless the balances in the DR Cash Custody accounts are included in the MCB calculations. This is a consideration as it will have impacts on policy decision.

3. **DL transfers are round-the-clock and are not limited to the operating hours of MEPS+.**

Hence, prior to building a new PoC in a different market, several design considerations must be addressed. These considerations have been captured and used as building blocks for the realisation of a new cross-border payment prototype, and later refined in parallel with the evolution of the monetary model.

Overall, it is possible to identify three main types of design considerations (Figure 9): pre-requisites for the idealisation of the PoC; business requirements; and non-functional requirements. It is important to note that these building blocks are not to be considered as separate and individual as they are, in fact, complementary and necessary sub-parts of Project Ubin's final architecture.

Key takeaways

- A "continuous depository receipt" model was selected for Phase 1 that allows banks to exchange cash collateral for Depository Receipts (DR) on the distributed ledger.
- The distributed ledger network (Ethereum-based blockchain) was designed to interface with existing MEPS+ and RTGS systems, which allowed for a working integrated transfer prototype.
- A new DR Cash Custody account was created in MEPS+ for Project Ubin which backs DRs on the Distributed Ledger. The balance in the account is periodically adjusted to match the outstanding amounts owed to the account holder.
- Banks can individually pledge and redeem at will during operating hours of MEPS+, while transactions on the distributed ledger can be conducted round-the-clock and independent from the operations of MEPS+.

Figure 9: Three types of design considerations

Pre-requisites

If Project Ubin proves to be successful, the SGD would represent the first Asian digitalised currency, an important milestone that requires additional levels of careful planning. Factors that are of the utmost priority include the architecture and interaction model, identification of the Genesis File's owner and infrastructure set up, including key management decisions and Smart Contracts verification.

Business requirements

The pre-requisites highlight various delicate features of the prototype infrastructure. Know-Your-Customer (KYC) investigation; permission setting; money pledging; money confirmation; money transfer; money redeeming as well as transaction cancellation; balance and transaction status checking; and general reporting are all examples of the functional aspects that need to be adapted in to Project Ubin's design.

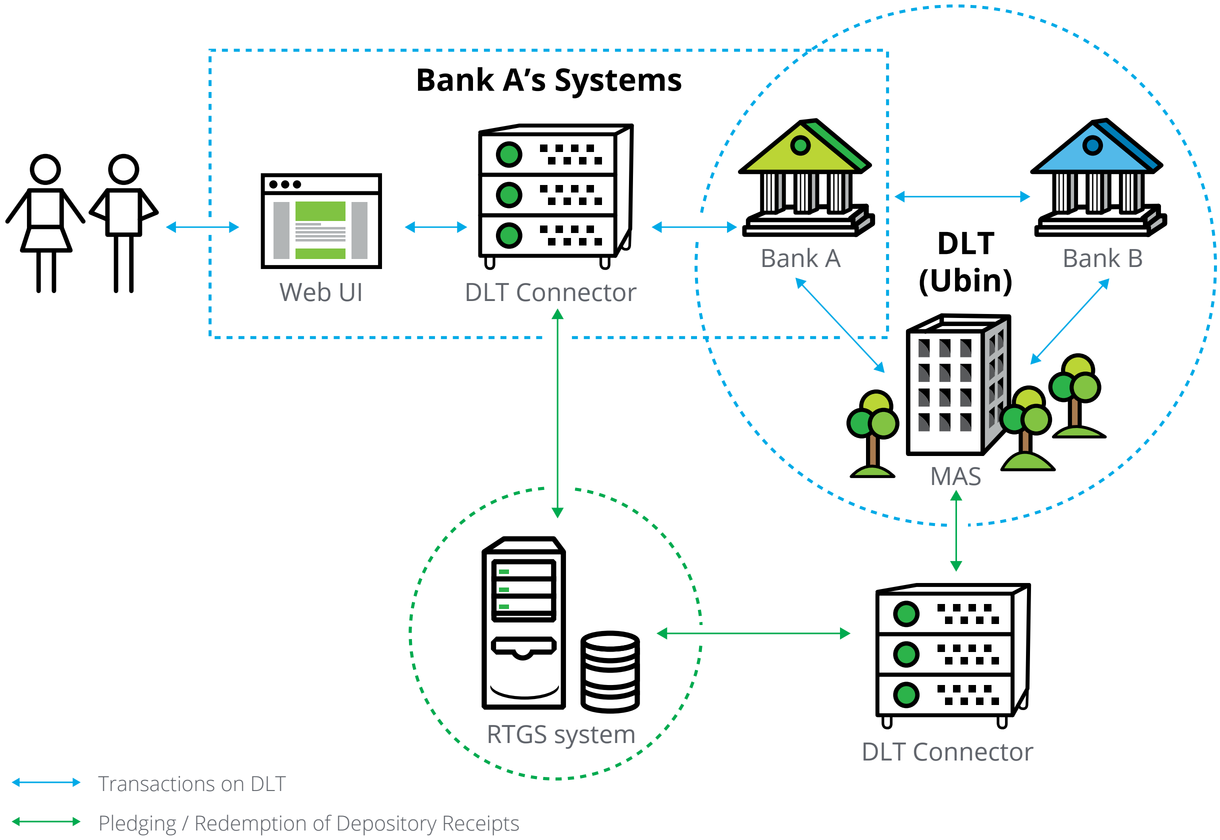
Non-functional requirements

Factors such as transaction validation; transaction ordering; transactions per second vs block per second; and resiliency should also be subject to verification as part of the prototype.

3.2.2.2 Architecture

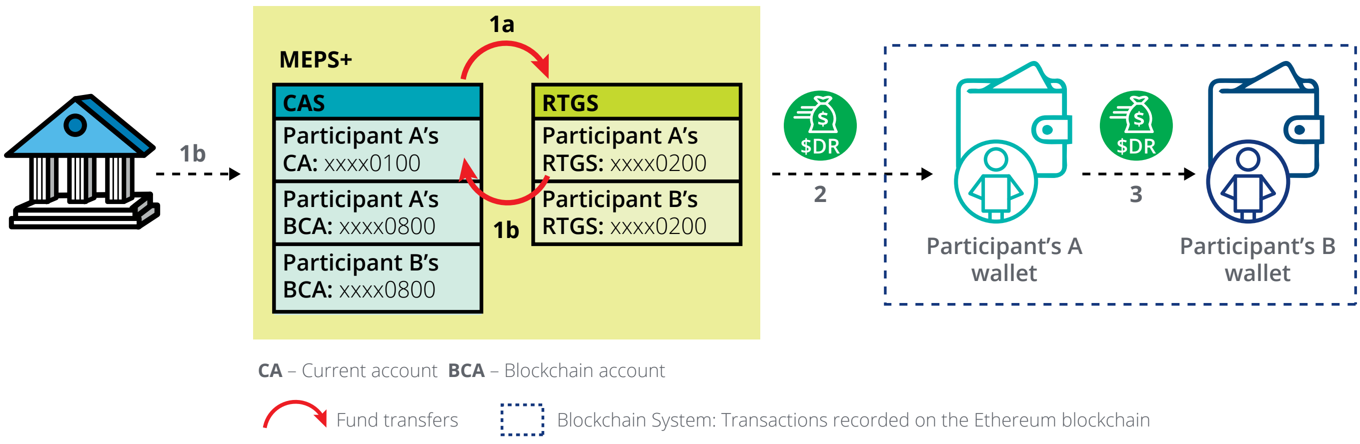
A high-level view of Project Ubin's architecture between different banking systems and users demonstrates how various parts of Project Ubin's architecture interact with one another to create transactions on DL and to pledge or redeem DR (see Figure 10).

Figure 10: High-level architecture of Project Ubin



The process diagram of Project Ubin's Phase 1 reveals two separate systems that can be linked to increase money transfer efficiency between different accounts (see Figure 11). The MEPS+ which is generally used to process high-value and urgent SGD interbank transfers and the RTGS system are strategically integrated in this environment as it makes the money-flow more straightforward. On the blockchain end, Ethereum allows value transfer between participant's online wallets. The connection between the aforementioned systems is enabled by money transfers that are incorporated into DR. As a result, fund transfers in the MEPS+ become value transfers in the Ethereum blockchain.

Figure 11: Project Ubin's process diagram – Part 1



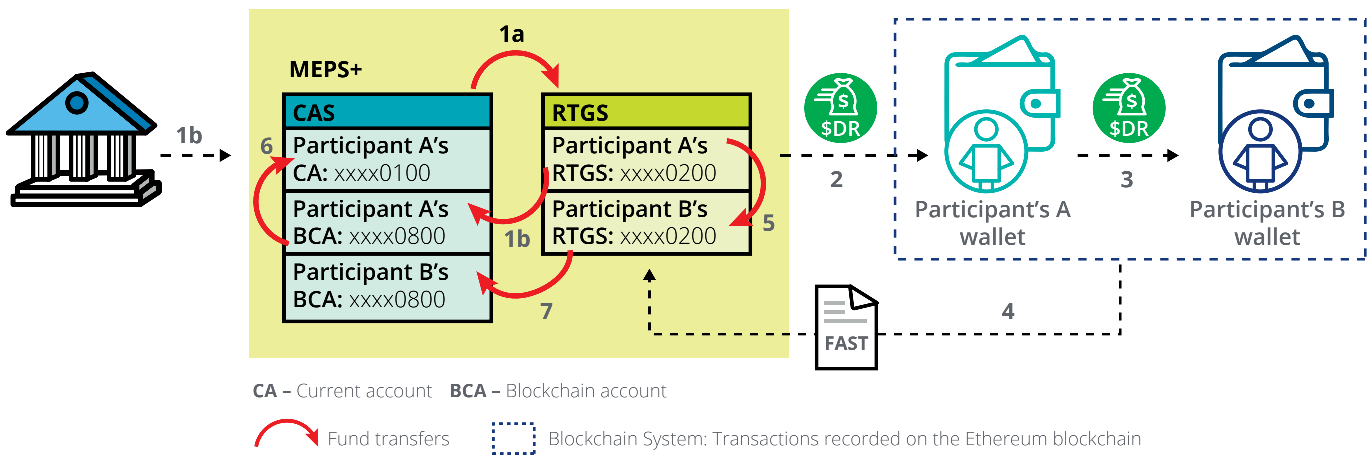
Project Ubin's Phase 1 process begins in the MEPS+ where participants' account balance checks are carried out by the system. If the participant's account balance shows a surplus of funds when compared to the MCB, the transfer of funds is allowed.

1. At the start of the day, pledge collateral process and sweeping of funds will begin.
   - **Sweeping of funds:** Funds in excess of Participant A's MCB will be swept into its RTGS account.
   - **Pledge collateral process:** Participant A sends top-up request to MEPS+ to top-up its Blockchain (BCA) account. Funds from Participant A's RTGS account will be transferred to Participant A's 0800 account via the top-up process for G3. Funds in Participant A's 0800 account will be the cash collateral in exchange for DR issued. At this stage, MAS has to verify the validity of the collateral in order to proceed with the DR issuance.

2. MAS will issue the DR to Participant A's wallet via transaction agent Smart Contract. That is, if there is SGD 300 in the 0800 account, there is 300 worth of DR in Participant A's wallet. As mentioned above, DR is used as a connection between the two systems. The next steps occur in the Ethereum blockchain.

3. Participant A will transact with other participants' wallets on the DR platform. For example, let's assume that only one transaction happens in which participant A will issue SGD 30 DR to Participant B (see Figure 12).

Figure 12: Project Ubin's process diagram – Part 2



4. Participant A's wallet can exchange value with other participants' wallets (in this case, Participant B) within the Ethereum network. Subsequently, the blockchain system will send a FAST net settlement file to RTGS. Therefore, the focus is moved to the MEPS+ system again.

5. Assuming sufficient funds in participant A's RTGS account, the SGD 30 will be debited from Participant A's RTGS account and credited into Participant B's RTGS account. It is worthwhile to mention that MEPS+ only allows transfer of funds.

6. Participant A's 0800 account will be debited by SGD 30 accordingly (withdrawal process for G3), with the result that Participant A's 0800 account will reflect SGD 270.

7. Funds from Participant B's RTGS account will be transferred to Participant B's 0800 account via the top-up process for G3.

8. At end of day, Participant A's 0800 account will be adjusted (either zeroed out or topped up).

The prototype was staged into three main delivery areas:

1. **Establishment of a DL network**
   The DL network consisted of two MAS nodes running Ethereum and MQ Client with the genesis block created by one of the MAS nodes and eight bank nodes running Ethereum, MQ Client, and Common Payment Gateway (CPG).

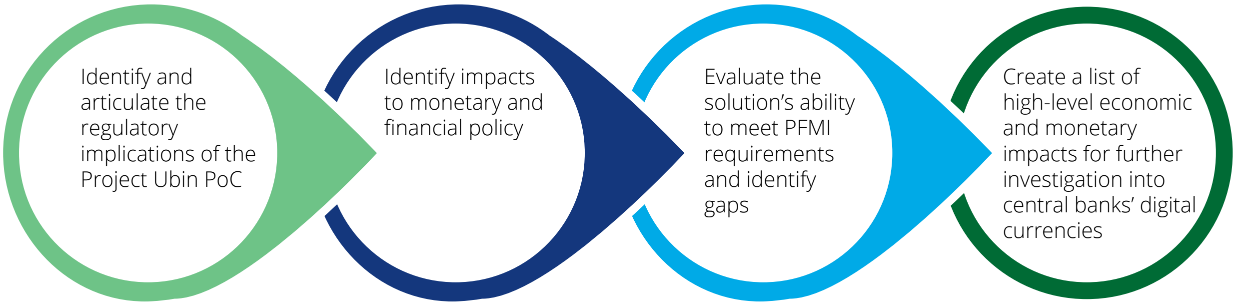
2. **Development of Smart Contracts and tools**
   Even though Project Ubin's implementation was inspired by the model in Project Jasper, its monetary model differed significantly in that new Smart Contracts were written to support the model. A dashboard was also created to provide visibility into the balances and transactions occurring on the Ethereum blockchain. This was run on MAS' servers and connected to MAS' nodes.

3. **Connectivity of the DL network to MEPS+**
   The DL network was connected to a development instance of MAS' real-time gross settlement systems, MEPS+, using a SWIFT Simulator. This was done to automate and synchronise the DR balances in the DL with the RTGS and DR Cash Custody accounts in MEPS+.

3.2.3 Research workstream

Subject matter experts were engaged in order to fulfil the overall mission of the research stream for Project Ubin outlined in Figure 13.

Figure 13: Project Ubin research workstream's mission



3.2.4 Summary of findings

Project Ubin's Phase 1 was successful as it has brought together a wide range of parties (including non-R3 member banks, R3 member banks, SGX and BCSIS as a technology provider). Participants worked collaboratively towards the following outcomes over a short, six-week duration.

Figure 14: Findings of Project Ubin Phase 1

Technical workstream	Research workstream
• A working interbank transfer prototype on a private Ethereum network was built. • The Ubin Phase 1 prototype evolved Project Jasper's monetary model, and a new Smart Contract codebase was developed. • In addition, BCSIS successfully conducted end-to-end integration between the private Ethereum network and MEPS+ test environment via their CPG.	• The research workstream built a solid foundation of questions and initial points of view across topics ranging from monetary policy to legal and operational concerns for taking this prototype to production.

3.2.5 Observations and lessons learnt

Credit risk

Project Ubin's Phase 1 model was designed so that credit exposures do not arise between participants when payments are transferred. Participants pledge cash into a custody account held at the central bank. MAS then creates an equal value in Digital SGD on the DL and sends each bank an amount of Digital SGD equal to the amount they pledged. Once banks receive their Digital SGD transfers from the central bank, they are free to make transfers to each other or back to the central bank. The exchange of Digital SGD on the DL occurs without credit risk for participants because:

- Transfers of Digital SGD are transfers of a binding claim on the central bank's currency.
- Participants do not face credit risk associated with claims on the central bank's currency because the central bank is not subject to default (i.e., no concerns regarding bankruptcy remoteness of cash collateral).

An appropriate legal structure is required to ensure that the transfer of Digital SGD is equivalent to a full and irreversible transfer of the underlying claim on the central bank's currency. This would ensure that there is no credit risk associated with the creation, distribution, use or redemption of Digital SGD. The current iteration of Project Ubin that utilises cash custody accounts, and thus remains subjected to an element of credit risk as the ownership of the cash custody accounts remains with the holder, and hence are not truly bankruptcy remote. A true collateral account type within the MEPS+ CAS system may have to be developed to enable a design that is more compatible with the PFMIs related to credit risk.

An additional consideration for future phases is the creation of a Digital SGD "money market" that would allow banks to borrow Digital SGD from other banks without posting cash with MAS. Such an option may help to optimise liquidity requirements in the market but the credit risk implications of any increased functionality for Digital SGD payments (unsecured loans) would have to be evaluated.

Liquidity risk

During Project Ubin's Phase 1, banks fund their expected payments on a gross basis with payments and hence there is virtually no liquidity risk in the DL. Even the failure or outage of the largest participant would not prevent remaining participants from completing their desired payments.

In the future, it is possible that the DL could coexist as a permanent facility alongside a conventional payment platform such as MEPS+. In such a world, banks would have to decide on an allocation of liquidity to each system. This introduces the risk that one facility or the other will not be adequately funded. It is also possible that the greater transparency of the DL (to the extent that this is preserved in future implementations beyond Phase 1, which is fully transparent) may offer advantages for liquidity management, allowing participants to substitute and optimise pledged collateral with greater efficiency. We should consider whether advanced liquidity management techniques might introduce new risks.

The extensions of the Project Ubin Phase 1 model that introduce credit risk (e.g., Digital SGD money market) would also have implications for liquidity risk that would need to be evaluated, including considerations of the role of the central bank in reducing the liquidity risk in the system. In order for the central bank to act as a liquidity provider, it would need to generate Digital SGD on its own behalf and lend it to participants.

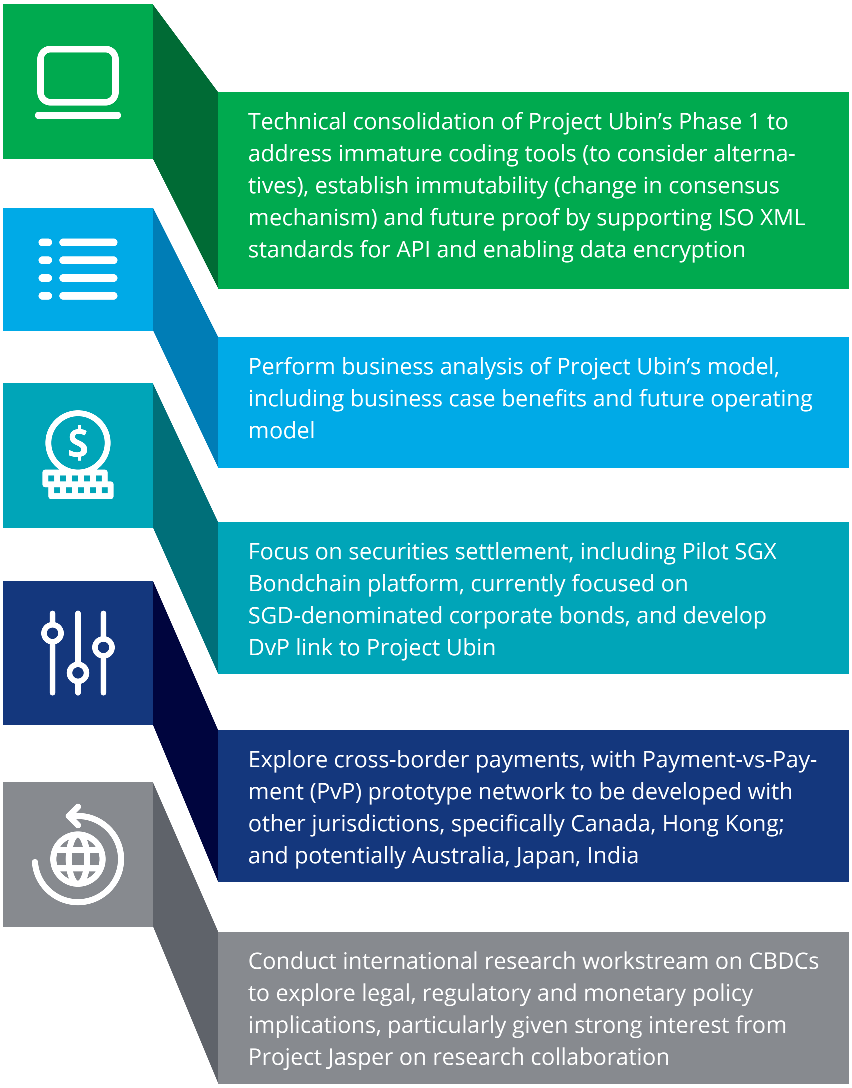
We need to consider all the issues that may arise from this "lender-of-last-resort" function by reviewing some of the key observations and lessons learnt (see Figures 15 and 16).

Figure 15: Observations

Figure 16: Lessons learnt

The figure below summarises the five distinct objectives for future phases of Project Ubin based on feedback received from project participants.

Figure 17: Objectives for future phases of Project Ubin



Section takeaways

- In 2016, MAS partnered with R3, a leading blockchain consortium, to launch Project Ubin for developing a proof-of-concept to conduct inter-bank payments through DLT (Phase 1).
- Project Ubin's objective was to evaluate the implications of a tokenized SGD on a distributed ledger with potential benefits to Singapore's financial ecosystem.
- The project leverages on MAS's MEPS+ system that enables real-time transfer of funds and Singapore Government Security.
- Project Ubin explores DLT's potential to improve domestic securities transactions (DvP: domestic-vs-payment) and also cross-border payments (PvP: payment-vs-payment).
- A "continuous depository receipt" model was selected for Phase 1 that allows banks to exchange cash collateral for Depository Receipts (DR) on the distributed ledger.
- The distributed ledger network (Ethereum-based blockchain) was designed to interface with existing MEPS+ and RTGS systems, which allowed for a working integrated transfer prototype.
- Implications around credit and liquidity risk and challenges with Ethereum needs to be further evaluated.
- Future phases would focus on future operating model of Project Ubin, further technical analysis, focus on securities settlement by developing DvP and Cross-border payments (PvP).

Project Ubin: Future focus

Project Ubin's Phase 1 was just the first step towards understanding the potential of the technology and its implications. As outlined in the broad overview, the envisioned key benefits are in cross-border securities and payments. For Phase 2 of the project, the participants will be focusing on the following areas:
1. DvP track: Evaluate the usage of DLT for SGS (led by SGX)
2. PvP track: Continue to work on domestic payment system and with overseas central banks and operators on potential cross-border PvP opportunities (led by MAS)

Continuing the workstream delivery approach from Phase 1, we expect the research and technical work streams to shift in focus (see Table 2).

Section takeaways
- Phase 2 of Project Ubin would focus on: DvP track which would evaluate the usage of DLT for SGS and PvP track which would continue work on domestic payment system and potential cross-border PvP opportunities.
- An additional workstream would evaluate the value proposition of DLT for ecosystem participants and suggest a target operation model. This would inform as well as influence the industry for DLT adoption.

Table 2: Future objectives for Project Ubin

Technical workstream	Research workstream
Whilst the Project Ubin Phase 1 prototype was built on a private Ethereum DL, some concerns were raised about the characteristics of this specific technology in an enterprise and business context.	The outputs of Project Ubin's Phase 1 research workstream provide direction for additional research posed by CBDCs in Singapore and cross-border financial markets. The team plans to validate policy questions around the vision of SGD as a CBDC and its impact on monetary policy.
As an exercise to familiarise the vendor with the candidate DLT platform(s) and understand their characteristics, it can redevelop the Project Ubin Phase 1 Monetary Model onto these platforms a side-by-side while the technical workstream reviews the comparison of characteristics provided by the vendors under consideration.	A consultation paper articulating various CBDC scenarios should be provided to Project Ubin participants to ensure that DLT can comply with Singapore and International Payment Standards and Guidelines. This will provide market participants with visibility on the potential direction in this space and will enable Singapore to demonstrate thought leadership as the world continues to move to digital transactions.
	Following the consultation paper, topics to research include those related to market impact and systemic risks from CBDCs, interaction between SGD as a CBDC and the existing legal framework and SFMI and how CBDC participants should operate.

As technical implementations that span enterprises are influenced by the target operating models of the ecosystem and individual participants, MAS has proposed instituting an additional business workstream to focus on:
- Understanding the value proposition of DLT and CBDCs for ecosystem participants
- Suggesting a target operating model for the industry

Both of the above focus areas will enable business case and funding discussions for financial institutions in Singapore, and a target operating model design will inform as well as influence the industry for DLT adoption.

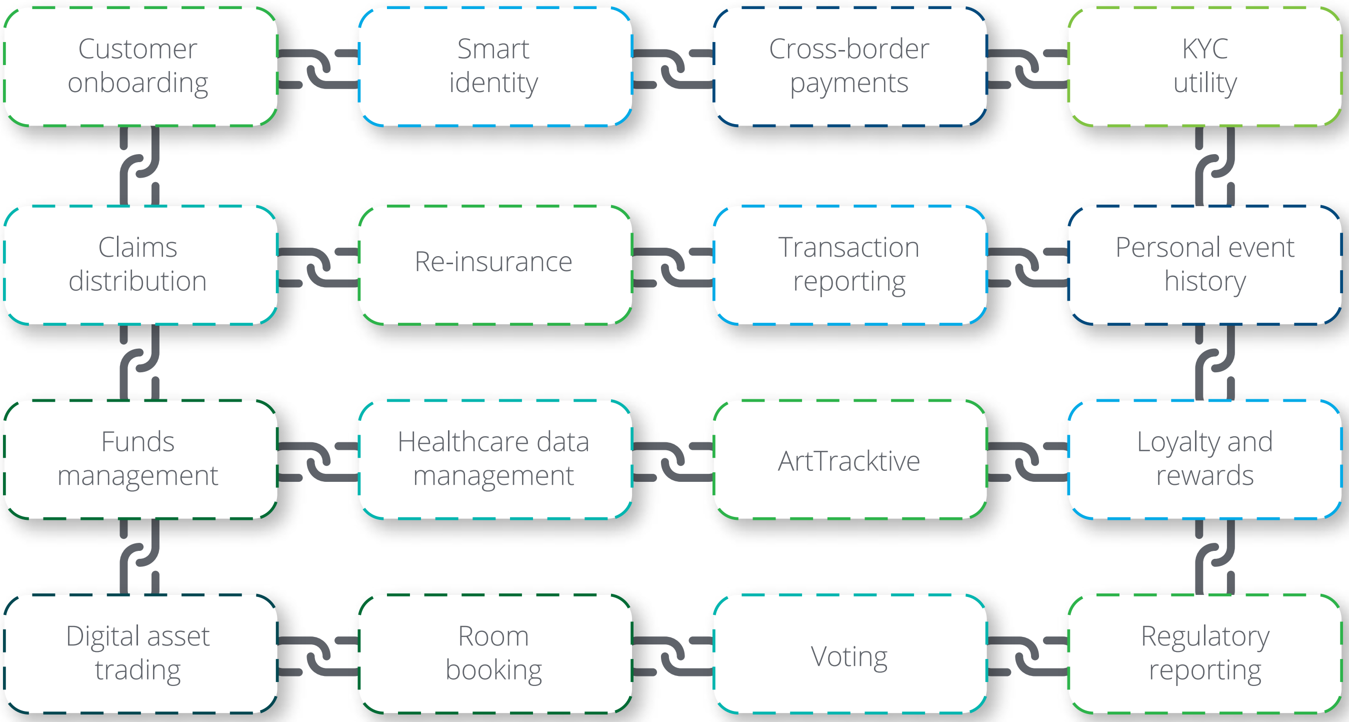
Deloitte's Blockchain expertise

Deloitte is positioned as one of the leaders in the rapidly-developing blockchain space, with over 800 practitioners globally specialising in blockchain technology and working to develop strategy, documentation, research, prototypes and solutions for clients. Deloitte's Blockchain practice is backed by a global network of Blockchain Labs in Europe, Asia and North America, with the ability to virtually expand anywhere in the world through "pop-up" labs that route expertise where it is needed at any given time. This blockchain expertise is supported by rich experience in delivering solutions using traditional, agile and hybrid-agile methodologies to integrate innovative solutions with legacy infrastructure.

With extensive experience in large-scale technology development and implementation projects across nearly every key industry, Deloitte is leveraging that experience to provide cutting edge blockchain solutions to clients.

Deloitte has actively been investing in building prototypes to gain hands-on experience with blockchain technology and to bring use-case accelerators to clients. Globally, Deloitte has built over thirty blockchain PoCs and prototypes for industries including Consumer & Industrial Products, Financial Services, Life Sciences & Health Care, as well as other cross-industry applications.

Figure 18: Examples of Deloitte's blockchain PoCs and prototypes



“Financial institutions have the power and ability to take blockchain live in production environments. To get there, companies will need to move away from experimenting with proof-of-concepts and implement solutions in ready to use production mode. Helping organisations achieve this vision is one of the foundational reasons for the setup of Deloitte’s Blockchain Labs.”

– Eric Piscini, Deloitte’s Global Blockchain Leader

One of Deloitte’s most notable prototypes is the cross-border payments application. In the current payment ecosystem, cross-border payments are marred with expensive and uncertain transaction fees, long processing times and, often, opportunity for fraud. With DLT, the reliance on some intermediaries, such as correspondent banks and notaries, can be reduced (since every actor on the network can transact directly with one another), which can dramatically accelerate transaction times. In addition, DLT handles the validation, verification and fulfilment of the payment in (near) real-time without the need for costly fees, thus increasing efficiency and driving cost savings. Another key consideration is that the identity of the user making the transaction is verified, streamlining KYC processes and leading to greater fraud prevention. The prototype integrates Ripple and Stellar blockchain platforms to enable a Person-to-Person (P2P) transactions across geographies. DLT offers significant benefits to both P2P and Business-to-Business (B2B) payments in terms of cost savings, increased efficiency, and improved security. Cross-border payments have plenty of room for innovation, and the future looks bright for DLT within this use case.

Appendix

Appendix A: Monetary model option

Start of day batch (Pledge): Participant banks pledge central bank money by instructing the central bank to transfer a balance from their current accounts into a new special omnibus collateral account. An equivalent balance is created on a DL in the central bank's account and sent to the DL accounts of individual banks.

Intraday transactions: Banks can perform DL payments between each other during operating hours only.

End of day batch (Redeem): Banks transfer their DL balances back to the central bank's DL account. The central bank then releases the balance from the special omnibus collateral account to the banks' current accounts in proportion to the DL balances redeemed.

Three models were considered for implementation, and a "Continuous DR" model was selected for Phase 1.

Option 1: The cryptocurrency model
In this option, balances tracked on the DL would be a new token which is a direct liability of the central bank and an asset to the banks. In effect, MAS would be issuing new money in a new form, expanding the money supply. Expanding the money supply was not an objective of Phase 1 so this model was not selected.

Option 2: The daily depository receipt model (Jasper Model)
This model represents the case when DR are created and destroyed on the DL on a daily basis, backed by money in a special omnibus collateral account. This was the Project Jasper model.

Start of day – Pledge (batch process)

Before				Step 1				Step 2			
MEPS+		DL		MEPS+		DL		MEPS+		DL	
Bank A RTGS	100	Bank A	0	Bank A RTGS	**90**	Bank A	0	Bank A RTGS	90	Bank A	**10**
Bank B RTGS	100	Bank B	0	Bank B RTGS	**80**	Bank B	0	Bank B RTGS	80	Bank B	**20**
Bank C RTGS	100	Bank C	0	Bank C RTGS	**70**	Bank C	0	Bank C RTGS	70	Bank C	**30**
Omnibus collateral	0	Central Bank	0	Omnibus collateral	**60**	Central Bank	**60**	Omnibus collateral	60	Central Bank	**0**

Intraday (working hours) – Continuous transfers on DL

Before				Step 1				Step 2			
MEPS+		DL		MEPS+		DL		MEPS+		DL	
Bank A RTGS	90	Bank A	10	Bank A RTGS	90	Bank A	**5**	Bank A RTGS	90	Bank A	5
Bank B RTGS	80	Bank B	20	Bank B RTGS	80	Bank B	**25**	Bank B RTGS	80	Bank B	**15**
Bank C RTGS	70	Bank C	30	Bank C RTGS	70	Bank C	30	Bank C RTGS	70	Bank C	**40**
Omnibus collateral	60	Central Bank	0	Omnibus collateral	60	Central Bank	0	Omnibus collateral	60	Central Bank	0

End of day – Redeem (batch process)

Before				Step 1				Step 2			
MEPS+		DL		MEPS+		DL		MEPS+		DL	
Bank A RTGS	90	Bank A	5	Bank A RTGS	90	Bank A	**0**	Bank A RTGS	**95**	Bank A	0
Bank B RTGS	80	Bank B	15	Bank B RTGS	80	Bank B	**0**	Bank B RTGS	**95**	Bank B	0
Bank C RTGS	70	Bank C	40	Bank C RTGS	70	Bank C	**0**	Bank C RTGS	**110**	Bank C	0
Omnibus collateral	60	Central Bank	0	Omnibus collateral	60	Central Bank	**60**	Omnibus collateral	**0**	Central Bank	0

From a central bank balance sheet perspective, there is no monetary inflation as the central bank's liabilities are simply re-categorised from "cash balances" to "depository receipts," as illustrated below.

Assets		**Liabilities**	
a) Foreign assets	100	d) Currency in circulation	100
b) Domestic assets		e) Government deposits	100
– Loans to banks	100	f) Banks balances	
– Government securities	100	– Cash balances	25
		– **Depository receipts**	**25**
c) Other assets	100	g) Capital, reserves	50
		h) Borrowing from other banks	100
Total Assets (A)	**400**	**Total Liabilities (L)**	**400**

This model was considered and iterated, resulting in Option 3.

Option 3: The continuous depository receipt model (Project Ubin Model)
This is similar to the Jasper Model (Option 2) but differs in three important aspects:

1. In MEPS+, DR Collateral Cash Custody accounts are individual (per bank) rather than comingled as an omnibus account. As cash custody accounts are owned by the individual banks, the deposits they hold are not true collateral and rebalancing of the accounts to match the DL wallet balances after the point of any one participant's bankruptcy is contestable. For the purpose of the current project, however, we have assumed that they can act as collateral under a participation contract.

2. Banks can individually pledge and redeem at will during operating hours of MEPS+, not limited to start of day and end of day activities. Banks can hold depository receipt balances on the DL overnight.
   - There are no interest rate implications as current accounts in MEPS+ are zero-interest, and DL accounts are zero-interest.
   - However, regulatory reserves capital in the form of Minimum Cash Balance (MCB) is impacted, unless the balances in the "DR Collateral Cash Custody" accounts are included in the MCB calculations. This would need to be considered for policy decision.

3. DL transfers can happen round-the-clock and are not limited to the operating hours of MEPS+.

A significant technical difference is that DR balances are created directly in Bank DR accounts in one step, and not created in the central bank's DR account and then transferred. This differs from the Jasper model where the Central Bank had a DR account on the DL specifically for the creation, dissemination and destruction of the depository receipts.

For the project, MAS had a RTGS account and a DR Cash Custody account in MEPS+, and a DR account on the DL – but acting as a participant, rather than acting as a supervisor. The MAS account is not shown in the diagrams below for simplicity, but if it were to be, it should be treated the same way as any other participant bank.

This model mirrors the FAST Collateral Cash Custody account setup for the existing FAST payment system, so participants are familiar with the paradigm, and technology in MEPS+ exists to support this.

Pledge process

Banks pledge collateral cash by requesting a balance transfer from their RTGS accounts to their DR Collateral Cash Custody accounts in MEPS+. This results in the creation of an equivalent balance in their DR accounts on the DL. Any bank can pledge at any time during MEPS+ operating hours.

Pledge Process example 1
(Bank A pledges 10, during MEPS+ opening hours)

Before				After			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	100			Bank A RTGS	**90**		
Bank B RTGS	100			Bank B RTGS	100		
Bank C RTGS	100			Bank C RTGS	100		
Bank A DR Collateral Cash Custody	0	Bank A	0	Bank A DR Collateral Cash Custody	**10**	Bank A	**10**
Bank B DR Collateral Cash Custody	0	Bank B	0	Bank B DR Collateral Cash Custody	0	Bank B	0
Bank C DR Collateral Cash Custody	0	Bank C	0	Bank C DR Collateral Cash Custody	0	Bank C	0

Pledge Process example 2
(Bank B pledges 40, Bank C pledges 5 during MEPS+ operating hours)

Before				After			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	90			Bank A RTGS	90		
Bank B RTGS	100			Bank B RTGS	**60**		
Bank C RTGS	100			Bank C RTGS	**95**		
Bank A DR Collateral Cash Custody	10	Bank A	10	Bank A DR Collateral Cash Custody	10	Bank A	10
Bank B DR Collateral Cash Custody	0	Bank B	0	Bank B DR Collateral Cash Custody	**40**	Bank B	**40**
Bank C DR Collateral Cash Custody	0	Bank C	0	Bank C DR Collateral Cash Custody	**5**	Bank C	**5**

Transfer process

Banks initiate balance transfers, or payments, on DL at any time, i.e., always-on.

Continuous 24/7 DL transfer process example
(Bank B pays Bank C 5 in the DL)

Before				After			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	90			Bank A RTGS	90		
Bank B RTGS	60			Bank B RTGS	60		
Bank C RTGS	100			Bank C RTGS	100		
Bank A DR Collateral Cash Custody	10	Bank A	10	Bank A DR Collateral Cash Custody	10	Bank A	10
Bank B DR Collateral Cash Custody	40	Bank B	40	Bank B DR Collateral Cash Custody	40	Bank B	**35**
Bank C DR Collateral Cash Custody	5	Bank C	5	Bank C DR Collateral Cash Custody	5	Bank C	**10**

Redemption process

A number of solutions for the redemption process were considered and are described in Appendix B. The chosen redemption process for Phase 1 was that all participant cash custody accounts would be rebalanced to match DL accounts every time a bank called a redemption. The arguments are detailed in Appendix B, and the process is outlined below.

Pledge Process example 2
(Bank B pledges 40, Bank C pledges 5 during MEPS+ operating hours)

Before				Redeem step 1				Redeem step 2			
MEPS+		DL		MEPS+		DL		MEPS+		DL	
Bank A RTGS	90			Bank A RTGS	90			Bank A RTGS	90		
Bank B RTGS	60			Bank B RTGS	60			Bank B RTGS	60		
Bank C RTGS	95			Bank C RTGS	95			Bank C RTGS	**110**		
Bank A DR Collateral Cash Custody	10	Bank A	5	Bank A DR Collateral Cash Custody	**5**	Bank A	5	Bank A DR Collateral Cash Custody	5	Bank A	5
Bank B DR Collateral Cash Custody	40	Bank B	35	Bank B DR Collateral Cash Custody	**35**	Bank B	35	Bank B DR Collateral Cash Custody	35	Bank B	35
Bank C DR Collateral Cash Custody	5	Bank C	15	Bank C DR Collateral Cash Custody	**15**	Bank C	15	Bank C DR Collateral Cash Custody	**0**	Bank C	**0**

Appendix B: Redemption options

A number of options for the redemption of DRs were considered.

Option 1: Let Collateral Cash Custody accounts go negative

Option 1: Let Collateral Cash Custody accounts go negative
Redeem process (Bank C redeems 15)

Before				After			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	90			Bank A RTGS	90		
Bank B RTGS	60			Bank B RTGS	60		
Bank C RTGS	95			Bank C RTGS	110		
Bank A DR Collateral Cash Custody	10	Bank A	5	Bank A DR Collateral Cash Custody	10	Bank A	5
Bank B DR Collateral Cash Custody	40	Bank B	35	Bank B DR Collateral Cash Custody	40	Bank B	35
Bank C DR Collateral Cash Custody	5	Bank C	15	Bank C DR Collateral Cash Custody	-10	Bank C	0

Letting DR Collateral Cash Custody accounts go negative would allow a Bank's RTGS account to increase while the DR Collateral Cash Custody account becomes negative by the same amount. This is not unlimited: the maximum overdrawn limit of any DR Collateral Cash Custody account is the sum of the balances in the DR Collateral Cash Custody accounts of the rest of the system, which can only be funded from RTGS accounts.

Limit scenario: All Bank RTGS accounts are pledged to become DL balances

Before				Create maximum DL balances			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	100			Bank A RTGS	0		
Bank B RTGS	100			Bank B RTGS	0		
Bank C RTGS	100			Bank C RTGS	0		
Bank A DR Collateral Cash Custody	0	Bank A	0	Bank A DR Collateral Cash Custody	100	Bank A	100
Bank B DR Collateral Cash Custody	0	Bank B	0	Bank B DR Collateral Cash Custody	100	Bank B	100
Bank C DR Collateral Cash Custody	0	Bank C	0	Bank C DR Collateral Cash Custody	100	Bank C	100

Limit scenario: All redeemed by one party (Bank C)							
All transfer DL balances to Bank C				**Bank C redeems**			
MEPS+		**DL**		**MEPS+**		**DL**	
Bank A RTGS	0			**Bank A RTGS**	0		
Bank B RTGS	0			**Bank B RTGS**	0		
Bank C RTGS	0			**Bank C RTGS**	**300**		
Bank A DR Collateral Cash Custody	100	**Bank A**	0	**Bank A DR Collateral Cash Custody**	100	**Bank A**	0
Bank B DR Collateral Cash Custody	100	**Bank B**	0	**Bank B DR Collateral Cash Custody**	100	**Bank B**	0
Bank C DR Collateral Cash Custody	100	**Bank C**	**300**	**Bank C DR Collateral Cash Custody**	**-200**	**Bank C**	**0**

There are three important items to note:

1. The sum of Bank C's (RTGS account + DR Collateral Cash Custody account) remains constant (300 in this case).

2. The sum of all DR Collateral Cash Custody accounts cannot go zero. This is because we do not allow negative balances in the DL, and the sum of DR Collateral Cash Custody accounts must equal the sum of DL balances.

3. This does not create the ability for aggregate money supply to increase.

In the Project Ubin model, DR Collateral Cash Custody accounts cannot be overdrawn, i.e., balances must remain positive.

Option 2: Limit redemption amount
In this option, the amount a bank can redeem is limited to the amount in their DR Collateral Cash Custody account. Therefore, the DR Collateral Cash Custody account always remains positive.

Option 2: Limit redemption amount
Redeem process (Bank C can only redeem 5)

Before				After			
MEPS+		**DL**		**MEPS+**		**DL**	
Bank A RTGS	90			**Bank A RTGS**	90		
Bank B RTGS	60			**Bank B RTGS**	60		
Bank C RTGS	95			**Bank C RTGS**	**100**		
Bank A DR Collateral Cash Custody	10	**Bank A**	5	**Bank A DR Collateral Cash Custody**	10	**Bank A**	5
Bank B DR Collateral Cash Custody	40	**Bank B**	35	**Bank B DR Collateral Cash Custody**	40	**Bank B**	35
Bank C DR Collateral Cash Custody	5	**Bank C**	15	**Bank C DR Collateral Cash Custody**	**0**	**Bank C**	**10**

This would mean that Bank C would need to make DL payments to release or spend the value of the any balance accumulated in the DL above the original collateral cash amount pledged.

In the above scenario, DRs on the DL clearly haves less utility than MEPS+ money as it is more constrained. This implies difference in values between DL balance (limited utility) and an equivalent MEPS+ balance (broader utility), suggesting that banks would prefer not to use DL money.

However, there is some utility in DL money as it can circulate outside of MEPS+ hours, whereas MEPS+ money cannot. This is similar to FAST.

This value discrepancy can also be eliminated if DL accounts were created to mirror all MEPS+ accounts, and hence central bank balances would effectively be indistinguishable from DL balances; in other words, port everything to a DL.

This is an interesting avenue for future research.

Option 3: Continuous Collateral Cash Custody account rebalance

The option of keeping DR Collateral Cash Custody accounts synchronised with DL accounts by rebalancing the DR Collateral Cash Custody accounts every time a DL transaction was made was also considered.

Option 3: Continuous Collateral Cash Custody account rebalance
Intraday Bank B pays Bank C 5

Before				After			
MEPS+		DL		MEPS+		DL	
Bank A RTGS	90			Bank A RTGS	90		
Bank B RTGS	60			Bank B RTGS	60		
Bank C RTGS	100			Bank C RTGS	100		
Bank A DR Collateral Cash Custody	10	Bank A	10	Bank A DR Collateral Cash Custody	10	Bank A	10
Bank B DR Collateral Cash Custody	40	Bank B	40	Bank B DR Collateral Cash Custody	**35**	Bank B	**35**
Bank C DR Collateral Cash Custody	5	Bank C	5	Bank C DR Collateral Cash Custody	**10**	Bank C	**10**

This option was rejected because:

1. DL is intended as a round-the-clock system and the CBL operates only during MEPS+ operating hours. Thus, either the DL would have to stop outside working hours, or there would be an overnight de-synchronisation.

2. The "per transaction" process would limit the throughput of the DL to the throughput of MEPS+, and create additional technical overhead of locking databases in MEPS+, which in high volumes could be disruptive to the other operations of MEPS+.

Option 4: Collateral Cash Custody account rebalance upon redemption
This option acknowledges that the DR Collateral Cash Custody accounts do not need to continuously match the DL accounts and is similar to Option 3, except that collateral cash rebalancing only happens when a bank initiates a redemption.

Redeem Option 4: Collateral Cash Custody rebalance upon redemption
Bank C redeems 15 after some intraday transactions

Before (mismatch)				Redeem step 1 (rebalance)				Redeem step 2 (CBL transfer)			
MEPS+		**DL**		**MEPS+**		**DL**		**MEPS+**		**DL**	
Bank A RTGS	90			**Bank A RTGS**	90			**Bank A RTGS**	90		
Bank B RTGS	60			**Bank B RTGS**	60			**Bank B RTGS**	60		
Bank C RTGS	95			**Bank C RTGS**	95			**Bank C RTGS**	**110**		
Bank A DR Collateral Cash Custody	10	**Bank A**	5	**Bank A DR Collateral Cash Custody**	**5**	**Bank A**	5	**Bank A DR Collateral Cash Custody**	5	**Bank A**	5
Bank B DR Collateral Cash Custody	40	**Bank B**	35	**Bank B DR Collateral Cash Custody**	**35**	**Bank B**	35	**Bank B DR Collateral Cash Custody**	35	**Bank B**	35
Bank C DR Collateral Cash Custody	5	**Bank C**	15	**Bank C DR Collateral Cash Custody**	**15**	**Bank C**	15	**Bank C DR Collateral Cash Custody**	**0**	**Bank C**	**15**

This reduces the technical overhead on MEPS+ databases, and reflects the reality that redemptions can only be made during MEPS+ hours, hence there is no possibility or need for continuous collateral cash rebalancing.

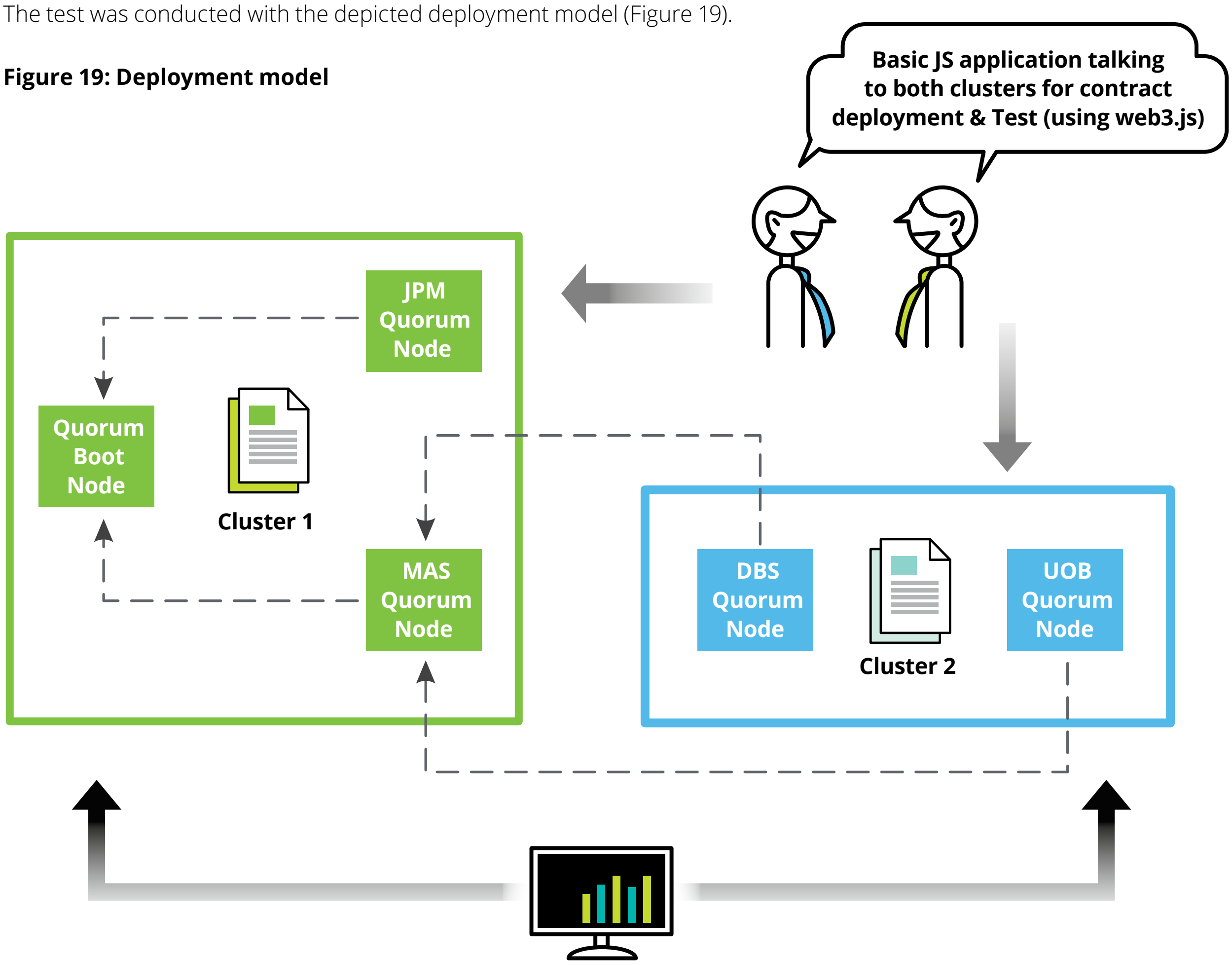
This option was eventually chosen as the redemption model for Project Ubin Phase 1.

Appendix C: Deployment of Project Ubin contracts on Quorum

There was interest in testing the privacy model of Quorum, a permissioned implementation of Ethereum supporting data privacy, in order to understand how Quorum handles/improves on the base Ethereum model to manage privacy and improve throughput.

The test was conducted with the depicted deployment model (Figure 19).

Figure 19: Deployment model



- Two clusters with five nodes as depicted in the diagram were set up for the test.
- A simple JavaScript (JS)-based application using web3.js was used for testing the contracts deployed.
- Quorum has a developer toolkit called cakeshop, which has a network monitoring dashboard. This was used to monitor the throughput, block creation rate and to drill down to transaction level details.
- The Smart Contracts deployed were simplified versions of the contracts used for Project Ubin since the objective was primarily to test privacy. All the modifiers (except *only Owner*) were removed from the contract code.

The images below depicts some of the test results of the PoC which highlight the privacy aspects:

Figure 20: Pledge transaction executed from MAS node for the participating banks

All stash balances visible to MAS node.

```
Zekun@ALTARF  ~/prog/quorum-examples/examples/7nodes  master ●  node quorum.js --cluster 1 --node 1 --exec bal
JPM
0x1932c48b2bf8102ba33b4a6b545c32236e342f34
{ [String: '10000'] s: 1, e: 4, c: [ 10000 ] }
DBS
0x1349f3e1b8d71effb47b840594ff27da7e603d17
{ [String: '10000'] s: 1, e: 4, c: [ 10000 ] }
UOB
0x9d13c6d3afe1721beef56b55d303b09e021e27ab
{ [String: '10000'] s: 1, e: 4, c: [ 10000 ] }
```

Figure 21: Node 2 configured for JPM and JPM stash balance visible from node 2

Balance of other stashes is shown as 0.

```
Zekun@ALTARF  ~/prog/quorum-examples/examples/7nodes  master ●  node quorum.js --cluster 1 --node 2 --exec bal
JPM
0x1932c48b2bf8102ba33b4a6b545c32236e342f34
{ [String: '10000'] s: 1, e: 4, c: [ 10000 ] }
DBS
0x1349f3e1b8d71effb47b840594ff27da7e603d17
{ [String: '0'] s: 1, e: 0, c: [ 0 ] }
UOB
0x9d13c6d3afe1721beef56b55d303b09e021e27ab
{ [String: '0'] s: 1, e: 0, c: [ 0 ] }
```

Figure 22: Transfer transaction executed by JPM for $300 to DBS

Balance check from node 2 (JPM node) displays the real balance of node 2 and net position of JPM with respect to node 3 (DBS node).

```
Zekun@ALTARF  ~/prog/quorum-examples/examples/7nodes  master ●  node quorum.js --cluster 1 --node 2 --exec bal
JPM
0x1932c48b2bf8102ba33b4a6b545c32236e342f34
{ [String: '9700'] s: 1, e: 3, c: [ 9700 ] }
DBS
0x1349f3e1b8d71effb47b840594ff27da7e603d17
{ [String: '300'] s: 1, e: 2, c: [ 300 ] }
UOB
0x9d13c6d3afe1721beef56b55d303b09e021e27ab
{ [String: '0'] s: 1, e: 0, c: [ 0 ] }
```

Figure 23: From node 3 (DBS node) real balance of node 3 and net position with respect to JPM displayed in balance check

```
Zekun@ALTARF  ~/prog/quorum-examples/examples/7nodes  master ●  node quorum.js --cluster 2 --node 3 --exec bal
JPM
0x1932c48b2bf8102ba33b4a6b545c32236e342f34
{ [String: '-300'] s: -1, e: 2, c: [ 300 ] }
DBS
0x1349f3e1b8d71effb47b840594ff27da7e603d17
{ [String: '10300'] s: 1, e: 4, c: [ 10300 ] }
UOB
0x9d13c6d3afe1721beef56b55d303b09e021e27ab
{ [String: '0'] s: 1, e: 0, c: [ 0 ] }
```

Figure 24: MAS node displays the real balance for all participating nodes

```
Zekun@ALTARF  ~/prog/quorum-examples/examples/7nodes  master ●  node quorum.js --cluster 1 --node 1 --exec bal
JPM
0x1932c48b2bf8102ba33b4a6b545c32236e342f34
{ [String: '9700'] s: 1, e: 3, c: [ 9700 ] }
DBS
0x1349f3e1b8d71effb47b840594ff27da7e603d17
{ [String: '10300'] s: 1, e: 4, c: [ 10300 ] }
UOB
0x9d13c6d3afe1721beef56b55d303b09e021e27ab
{ [String: '10000'] s: 1, e: 4, c: [ 10000 ] }
```

Further, in base Ethereum, the transaction data is serialised and stored on-chain, which can be decoded by any participating node possessing the contract application binary interface (ABI). In Quorum, the actual payloads containing the confidential balance details are stored off-chain, strongly encrypted, and only a hash of that information is represented on-chain. Only the intended nodes can retrieve and decrypt the actual payloads. This is depicted in Figure 25.

Figure 25: Intended nodes in Quorum can retrieve and decrypt actual payloads

The key observations from the tests carried out were:

- Quorum extends the base Ethereum protocol to support private transactions. Only nodes that have been made privy to a transaction will have access to the transaction payload. All other nodes will not be able to view the transaction payload.
- Quorum replaces the proof-of-work consensus model with a voting-based model. Each node in the Quorum network can be assigned a role (block maker, voter and observer). There can be several block maker nodes in the network, however, at any given time only one block maker will make blocks. This is decided based on random timeout. The voter nodes validate the block data and vote. The entire consensus mechanism is managed in a Smart Contract and hence is easily upgradeable.
- Throughput was observed to be higher compared to the base Ethereum protocol.
- Overall deployment was simple and easy. The team could bring up a new cluster node on public cloud in five minutes.

Quorum Wiki can be referenced for additional information.

Glossary of terms

ABI	Application Binary Interface
ABS	The Association of Banks in Singapore
API	Application programming interface
B2B	Business-to-Business
BCSIS	BCS Information Systems
CBDCs	Central Bank Digital Currencies
CPG	A Common Payment Gateway is used by banks for connectivity to FAST, and has been enhanced as a general purpose interface layer to other payment infrastructures, including the Ubin DLT architecture
DL	Distributed Ledger
DLT	Distributed Ledger Technology
DR	Depository Receipts
DvP	Delivery-vs-Payment
FAST	Fast and Secure Transfers is an electronic funds transfer service that allows a secure and almost immediate transfer of Singapore Dollar (SGD) funds between accounts held in the participating banks in Singapore
JPM	J.P. Morgan
JS	JavaScript
KYC	Know-Your-Customer
MAS	Monetary Authority of Singapore
MCB	Minimum Cash Balance
MEPS+	MAS Electronic Payment System
MQ Client	IBM WebSphere Message Queue (MQ) is used to interface between CPG, MEPS+ and banks' internal systems
P2P	Person-to-Person
PFMI	Principles for Financial Market Infrastructure
PoC	Proof-of-Concept
PvP	Payment-vs-Payment
RTGS	Real-Time Gross Settlement
SCHA	Singapore Clearing House Association
SGD	Singapore Dollar
SGS	Singapore Government Securities
SGX	Singapore Exchange
SWIFT Simulator	MEPS+ uses the SWIFT network for some communications. As this is not available in the development environment, a simulator is used in place to simulate the SWIFT network for the transfer of messages to MEPS+

Endnotes

1 World Economic Forum, **The Future of Financial Infrastructure** [Paper], http://www3.weforum.org/docs/WEF_The_future_of_financial_infrastructure.pdf, accessed 2/26/2017

2 Deloitte Analysis and Industry Insights

Contacts

Authors

Darshini Dalal
Blockchain Lab Lead
Deloitte US
ddalal@deloitte.com

Stanley Yong
Specialist Leader of Innovation Acceleration
Monetary Authority of Singapore
stanley_yong@mas.gov.sg

Antony Lewis
Director of Research, Singapore
R3
antony.lewis@r3.com

Contributors

Eric Piscini
Global Blockchain Leader
Deloitte US
episcini@deloitte.com

Mayank Singhal
Senior Consultant
Deloitte US
maysinghal@deloitte.com

Mohit Mehrotra
Southeast Asia Leader
Monitor Deloitte
momehrotra@deloitte.com

Ho Kok Yong
Financial Services Industry Leader
Deloitte Southeast Asia
kho@deloitte.com

Vikas Gupta
Consulting Senior Manager
Monitor Deloitte
vgupta@deloitte.com

Toh Wee Kee
Assistant Director
Monetary Authority of Singapore
toh_wee_kee@mas.gov.sg

Xiaomin Zhang
Global Banking & Markets Technology Delivery Executive
Bank of America Merrill Lynch
Xiaomin.zhang@baml.com

Ho Boon Kiat
Technical Project Manager, Delivery & Support Group
BCS Information Systems
hoboonkiat@bcsis.com

Leslie Chan
Vice President, Business Transformation
Credit Suisse
leslie.chan.2@credit-suisse.com

Lim Heng Hai
Project Manager
DBS Bank Ltd
henghailim@dbs.com

Sathya Ram
Head of Innovation Lab
The Hongkong and Shanghai Banking Corporation Limited
sathya.ram@hsbc.com.sg

Naveen Mallela
Technology Director
J.P. Morgan
naveen.mallela@jpmchase.com

Michael Truter
Deputy General Manager
Mitsubishi UFJ Financial Group
mike_truter@sg.mufg.jp

Andrew Koay
Vice President, Group Technology Architecture
OCBC Bank
andrewkoay@ocbc.com

Kelvin Tan
Head, FinTech & Data
Singapore Exchange
kelvin.tan@sgx.com

Srivatsan Pillai
Senior Vice President, Digitial Architecture
UOB Bank
srivatsan.pillai@uobgroup.com

Additionally, the Monetary Authority of Singapore would like to express its gratitude to Danielle Andrzejewski, Forrest Colyer, John Hallahan and Vikas Singla from Deloitte for their support of this publication.

Deloitte.