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MAS
Monetary Authority of Singapore

Delivery versus Payment on Distributed Ledger Technologies

Project Ubin

A report developed with the contributions of
MAS, SGX, Anquan Capital, Deloitte and Nasdaq

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Foreword

Project Ubin: A Singapore story

Project Ubin is a collaborative project by Singapore's financial services industry to explore the use of Distributed Ledger Technology (DLT) for the clearing and settlement of payments and securities. Launched in 2016 by the Monetary Authority of Singapore (MAS) and The Association of Banks in Singapore (ABS), the project is named after Pulau Ubin, a remote island and rural oasis that is home to Singapore's last *kampongs* or villages.

In many ways, Project Ubin symbolises the spirit of collaboration among the stakeholders in our Fintech ecosystem. It has brought together Singapore Exchange (SGX) and other financial institutions, along with business leaders, academia, and technology partners, who have supported MAS and ABS in identifying and pursuing common interests in the real-world applications of DLT to benefit the industry and consumers.

Following Project Ubin Phases 1 and 2, the goal here is to take the collaborative energy and innovation to the next level, by fostering a strong stewardship for the potential of central bank-issued digital currencies (CBDC) and reimagining real-time gross settlement architectures and their interoperability with separate securities ledgers.

Together with MAS, SGX is pioneering this new phase of Project Ubin to utilise DLT to develop Delivery versus Payment (DvP) for the settlement of tokenised assets. Project Ubin DvP seeks to achieve interledger interoperability and finality of DvP, starting with Singapore Government Securities (SGS) for central bank-issued cash-depository receipts (CDRs) on separate ledgers. To explore possible DvP models, our technology partners developed prototypes to connect different DLT platforms: Quorum, Hyperledger Fabric, Ethereum, Anquan, and Chain, each with varying capabilities and features. At this point in time, we would also like to acknowledge the contributions of Anquan Capital, Deloitte, and Nasdaq, our technology partners for Project Ubin DvP.

The contracts that define the roles of participants in Project Ubin Phase 2 were extended for the buyer-side transfer of CBDC and seller-side transfer of tokenised assets, starting with SGS on a trade-by-trade basis. Post-trade processes were simplified and settlement cycles compressed, while DvP contracts were designed for the enhanced protection of investors.

We hope that the successful completion of Project Ubin DvP will pave the way for wider adoption of DLT-based settlement of tokenised assets. While we faced many challenges along this journey, this is an opportunity to share our learnings to encourage further experimentation in Singapore's FinTech ecosystem and bring greater benefits to all.

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Executive summary

The DvP-on-DLT project is an extension of Project Ubin. This project seeks to achieve interledger connectivity and settlement finality for SGS with CDRs on separate DLTs.

To examine possible DvP settlement models and interledger interoperability, prototypes of different DLTs with varied capabilities and features were developed. These prototypes allow the transfer of tokenised assets such as SGS and CDRs on a trade-by-trade basis.

We observed that this setup provides the flexibility to compress settlement cycles and simplify post-trade settlement processes. The industry has taken actions to move from T+3 to T+2, shortening the settlement cycle and thereby reducing underlying risk exposures. DLT could potentially be an enabler for the industry to eventually compress the settlement cycle even further.

In addition, smart contracts for DvP could enable the consistent and coherent implementation of rights and obligations that will increase investor confidence and reduce compliance costs in the market.

The solution design of prototypes also enables a Recognised Market Operator (RMO) to maintain a central role to monitor and facilitate market functionalities. Given that investor security is of paramount importance, the solution possesses the following key design features:

- Account controls with multiple signature conditions
- Contract locks utilising secure secrets
- Time boundaries established for asset recovery
- Dispute resolution through arbitration

This paper will explore how DvP settlement finality, interledger interoperability, and investor protection may be realised using specific solution designs. In addition, it will highlight some future considerations for DvP-on-DLT and its impact on capital markets.

Later on, this paper will also take a look at the private and public blockchain platforms employed by the appointed technology partners – Anquan Capital, Deloitte, and Nasdaq – to create the prototypes used in this project.

Distributed Ledger Technology in capital markets

Blockchains are essentially implementations of DLT. A DLT is a virtual network built on contracts that consistently and coherently defines the rights and obligations of its participants[1]. In doing so, it may replace the need for an authority to enforce rules, disseminate information, and make decisions. Instead, DLT participants – each represented by a computer (node) on the network – simultaneously share, update, verify, and reach consensus on transactions.

In addition, data involved in these activities is protected by cryptography, and is therefore immutable[2], lowering the threat of cybercrime. With round-the-clock uptime, the ability of a network to live across multiple locations (sites, countries, or institutions), and the shouldering of complex tasks by computer code, it is easy to see why DLT has many business applications. Indeed, the effects of DLT on capital markets could potentially be game-changing (see Figure 1).

While DLT holds the promise of reducing some of inefficiencies embodied in the current market infrastructure, much rigorous testing remains to be done before DLT proves itself to be the de facto solution.

Figure 1: The impact of DLT on the capital markets value chain

Pre-trade	Trade	Post-trade	
Activities			
Research analytics and risk management	Order execution and matching	Clearing and settlement	Custody and asset servicing
Current pain points in capital markets			
Information flow lag time	Operational hours restricted to business hours and batch settlement[3]	Counterparty risk, opportunity and financing costs	Costly and there is a need for manual processing and reconciliation
Benefits of DLT in capital markets			
Transparent and automated verification of asset ownership	24/7 access to markets and trading	Elimination of counterparty risk and reduced costs	Elimination of the need to safekeep assets with immutable transaction records
Improved confidence in market analysis based on immutable data history	Alignment for cross-border settlement capabilities	Speedier, seamless asset recovery enabled by smart contracts	Reduced operational costs using blockchain for automated reconciliation

Distributed, not decentralised
Although the "D" in DLT stands for Distributed, it should not be mistaken for a decentralised system. The fact is that every aspect of DLT – including contracts, standards, protocols, databases, and algorithms – are all centric implementations. While in some cases, blockchain allows for disintermediation, in others, it allows the efficient and effective process automation that creates new value for customers and businesses.

1 An individual, organisation or group.
2 Cannot be altered, manipulated, or tampered with.
3 Transactions are consolidated for each business day and then cleared at one time.

What is DvP?

Simply put, a DvP transaction is one where the cash payment for a purchased security occurs prior to, or upon, its delivery, much akin to two counterparties (traders) meeting at an agreed time to exchange the agreed assets. With the transfer of one asset conditioned to the transfer of the other, counterparties are protected from principal risk, that is, the risk of the seller of a security failing to receive payment despite fulfilling delivery, or the risk of the buyer of a security failing to receive delivery despite fulfilling payment.

DvP advancements in global capital markets

In this section, we take a look at some case studies of global financial institutions applying technology (DLT and non-DLT) to capital markets, particularly in securities settlement: a process otherwise known as DvP[4].

It is worth noting that DvP need not be instantaneous, and may be achieved through time-sensitive arrangements built into settlement mechanisms, where participants[5] are given a reasonable timeframe to fulfil their trade obligations. For instance, imagine walking into a fast food restaurant, ordering a meal over the counter and paying for it only when it is placed in front of you. That is DvP at work.

In March this year, the European Central Bank (ECB) and the Bank of Japan (BOJ) published a report on a joint research project known as STELLA[6]. It detailed their[7] attempt to evaluate DvP settlement on a single ledger and across two different ledgers using DLT. The following findings were derived:

1. DvP settlement can be successfully achieved without any connection between the ledgers.
2. The design and construct of the DLT solution has a direct bearing on the participants' exposure to principal and counterparty risks. To ensure fair settlement, asymmetric time boundaries were designed for the release of cash payment and delivery of securities.
3. To achieve finality, the transfer of assets must be made irrevocable upon completion of the transaction.
4. The mitigation of risk exposures during the DvP process is essential to safeguard investors' interests and ensure a fair and orderly market.

The STELLA report has showcased experimental results and conceptual analysis of DvP success across single ledger and cross-ledger situations. In this report, we will explore the market feasibility of DvP-on-DLT with respect to i) current market structures and practices, ii) overarching regulatory framework that governs post-trade settlement processes such as arbitration, and iii) potential to enhance investor security and confidence.

In recent years, the Australian Securities Exchange (ASX) embarked on a review of the capabilities and readiness of the current Australian Clearing House Electronic Subregister System (CHESS) to tackle challenges posed by future technologies. Its findings cited two key issues: duplication of records, and an inefficient reconciliation process between the client and clearing house[8].

In response, ASX proposed an implementation roadmap to replace the current CHESS settlement system with a DLT-based clearing system in 2018, with plans to go live by 2021[9]. This move by ASX will support the commercial application of DLT in securities settlement to not only enable efficient trade settlement and reconciliation, but also drive down operational costs. Savings garnered could then be passed on to investors through lower trading costs, which would in turn boost market participation and trading volume.

4 As defined by MAS in "Rules and Market Practices of the Singapore Government Securities Market", DvP requires that "unless otherwise mutually agreed to between the buyer and seller, settlement shall be on the basis of payment against delivery of the security transacted".

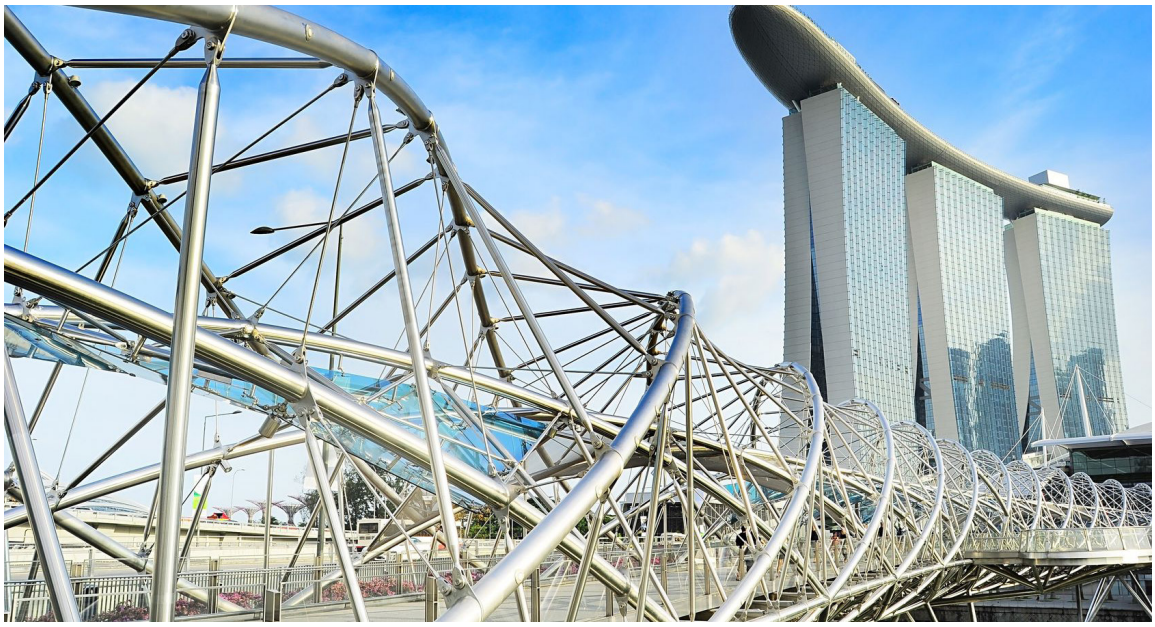
5 Buyers or sellers of a security involved in a transaction.

6 Adapted from "Securities settlement systems: delivery-versus-payment in a distributed ledger environment". European Central Bank and Bank of Japan. 2018. [https://www.ecb.europa.eu/pub/pdf/other/stella_project_report_march_2018.pdf]

7 Assisted by R3, IBM and DG Lab.

8 Retrieved from "CHESS Replacement: New Scope and Implementation Plan". ASX. September 2018. [https://www.asx.com.au/documents/public-consultations/response-to-chess-replacement-consultation-feedback.pdf]

9 Retrieved from "CHESS Replacement: ASX is replacing CHESS with distributed ledger technology (DLT) developed by Digital Asset". ASX. [https://www.asx.com.au/services/chess-replacement.htm]



Solely on the subject of DvP, it has been observed that there has been a growing preference for shorter settlement periods over long-held industry norms. This trend is largely fueled by concerns over the risks linked to lengthy, inefficient post-trade practices that were uncovered by the 2009 financial crisis. In fact, many regulators and stock exchanges have looked into their own settlement cycles over the last 10 years to reassess their risk exposures. The European Central Counterparty members (EuroCCP)[10], Hong Kong[11], Japan[12], Singapore[13], to name a few, have either initiated studies to examine or have completed the migration from T+3 to T+2.

Furthermore, a 2014 study[14] conducted by the U.S. Depository Trust & Clearing Corporation (DTCC) recommended the compression of trade settlement cycles for equities, municipal and corporate bonds, and unit investment trusts, from T+3 to T+2. DTCC also explored the possibility of shortening the settlement cycle further to T+1 as a future consideration to enhance investor protection (by reducing counterparty and principal risks). In other words, T+2, challenging as it is to accomplish, is far from ideal.

Regardless of their reasons for pursuing DLT implementations or speedier DvP – or a combination of both – the common sentiment among financial institutions is clear: system inefficiencies have a direct bearing on the amount of risks and costs one is subjected to. In the face of these inefficiencies, DLT has emerged as a technology with the potential to enable Singapore to transform into the leading global financial centre in Asia.

10 Retrieved from "T+2 settlement cycle announcement". European Central Counterparty. 11 June 2014. [https://euroccp.com/2014/06/11/t2-settlement-cycle-announcement]

11 Retrieved from "HKEX to introduce T+2 finality on 25 July". Hong Kong Exchanges and Clearing Limited. 7 July 2011. [http://www.hkex.com.hk/news/news-release/2011/110707news?sc_lang=en]

12 Retrieved from "Move to T+2 settlement in Japan". Japan Securities Dealers Association. [http://www.jsda.or.jp/shiraberu/minasama/t2_en_cyukan_201603.pdf]

13 Retrieved from "SGX proposes to make securities settlement and clearing safer and aligned with global practices". Singapore Exchange Limited. 29 November 2017. [http://infopub.sgx.com/FileOpen/20171129_SGX_proposes_to_make_securities_settlement_and_clearing_safer.ashx?App=Announcement&FileID=480254]

14 Retrieved from "New DTCC Paper Details Benefits of Move to T+2 Settlement Cycle in U.S.". DTCC. 30 April 2014. [http://www.dtcc.com/news/2014/april/30/new-dtcc-details-benefits-of-move-to-t-2-settlement-cycle-in-us]

Project Ubin

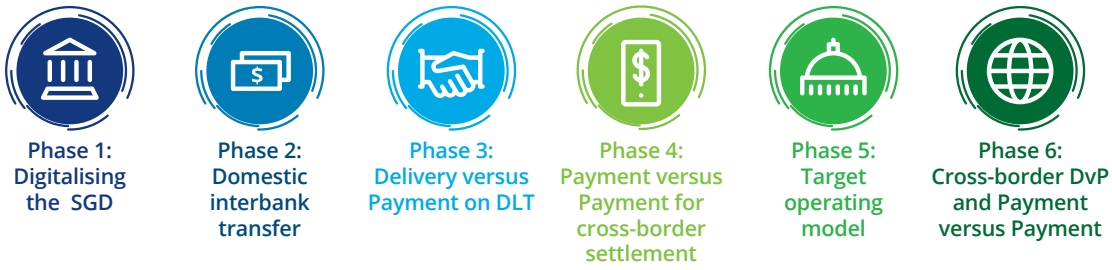
On 16 November 2016, MAS announced that it was partnering R3, a blockchain-inspired technology company and consortium of the world's largest financial institutions, to produce a proof-of-concept to test the efficacy of DLT in facilitating interbank payments.

This endeavour, known as Project Ubin, revolved around the core idea of having a central bank digital currency – a tokenised form of the Singapore Dollar (SGD) – on ledger. The project was named Ubin, after the name of a Singapore island that supplied much of the granite that was used to pave the Singapore-Johor Causeway that provided the foundation for bilateral trade and relations. Likewise, Project Ubin brings together industry players in a collaborative effort to shape the future of business and peoples' lives through technological innovation.

Will DLT enable Singapore's financial services industry to become safer and more efficient by reducing risks and costs at home and across borders? Can DLT provide Singapore's financial ecosystem with a global competitive advantage? What are the implications of a central bank digital currency with widespread participation? What opportunities does DLT hold for industry players, and how will roles change and evolve? These are just some of the questions that Project Ubin aims to address across six distinct phases carried out over a pre-defined timeframe (see Figure 2).

In the following section, we take a look at the previous phases of Project Ubin: Digitalising the SGD, and Domestic interbank transfer.

Figure 2: Project Ubin's six distinct phases



Phase 1: Digitalising the SGD
In this phase, MAS and R3 explored the use of a central bank digital currency – a tokenised version of the SGD – for interbank payments.

Phase 2: Domestic interbank transfer
In this phase, MAS and ABS explored DLT-enabled interbank transfers and examined specific RTGS functionalities, such as queue handling and payment gridlock resolution.

Phase 3: Delivery versus Payment on DLT (DvP-on-DLT)
In this phase, MAS and SGX collaborated to realise domestic DvP settlement on two separate blockchain platforms, which is the focus of this report.

Phase 4: Payment versus Payment for cross-border settlement
In this future phase, the objective is to assess the feasibility of cross-border DvP.

Phase 5: Target operating model
In this future phase, the objective is to evaluate the impact of DLT on existing regulatory framework and market processes.

Phase 6: Cross-border DvP and Payment versus Payment
In this future phase, the objective is to apply the learnings garnered to execute cross-border settlement of both payments and securities.

Project Ubin Phase 1: Digitalising the SGD

Phase 1 of Project Ubin[15] was conducted over six weeks from 14 November 2016 to 23 December 2016, and served to assess the technical feasibility of using a tokenised form of the SGD issued by the central bank[16] for inter-bank payments and settlement on a distributed ledger.

In this system, participant banks pledge cash into a custody account held at the central bank, MAS. MAS will then create the equivalent value in Digital SGD[17] on the distributed ledger[18], and assign them to the respective banks. Once the banks have received their Digital SGD transfers from the central bank, they are then free to make transfers (payments) to each other or the central bank.

Phase 1 concluded successfully. Interbank payments can be made possible by the integration and synchronisation of the distributed ledger with MEPS+, MAS' Real-Time Gross Settlement (RTGS) system[19]. This implies that beyond enabling round-the-clock uptime and the traceability of records, distributed ledgers also possess the ability to preserve the integrity of the data held by existing electronic payments and book-entry systems. A Digital SGD money market, where banks can lend to and borrow Digital SGD from one another without pledging cash with the central bank, is also no longer a distant possibility.

Project Ubin Phase 2: Domestic interbank transfer

Having proven that a Digital SGD could work on a distributed ledger for domestic inter-bank payments, the next logical step was to remove a hurdle common in the settlement process: payment gridlocks. Initiated by MAS and ABS, Phase 2[20] explored the use of DLT for specific RTGS functionalities, with a focus on distributing Liquidity Savings Mechanisms (LSMs)[21].

Then, there was also the need to address the privacy of transactions. Three prototypes were developed on three distinct DLT platforms: Corda, Hyperledger Fabric, and Quorum. The goal was to operationalise a fully functional DLT-based RTGS system by the end of 13 weeks.

15 More information on Project Ubin Phase 1 can be found in "Project Ubin: SGD on Distributed Ledger". Deloitte and MAS. 2017. [http://www.mas.gov.sg/~/media/ProjectUbin/Project%20Ubin%20%20SGD%20on%20Distributed%20Ledger.pdf]

16 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 focuses on safety and efficiency.

17 These are in the form of depository receipts (coupons) that are exchangeable for SGD in cash.

18 The distributed ledger network, an Ethereum-based blockchain which was designed to be compatible with current account systems and RTGS systems, allows for a working integrated transfer prototype.

19 A funds transfer system used by banks to send payments to one another on a gross settlement basis.

20 More information on Project Ubin Phase 2 can be found in "Project Ubin Phase 2: Re-imagining Interbank Real-Time Gross Settlement System Using Distributed Ledger Technologies". MAS and ABS. November 2017. [http://www.mas.gov.sg/~/media/ProjectUbin/Project%20Ubin%20Phase%202%20Reimagining%20RTGS.pdf]

21 This refers to transactions that are settled on a net basis.

RTGS systems

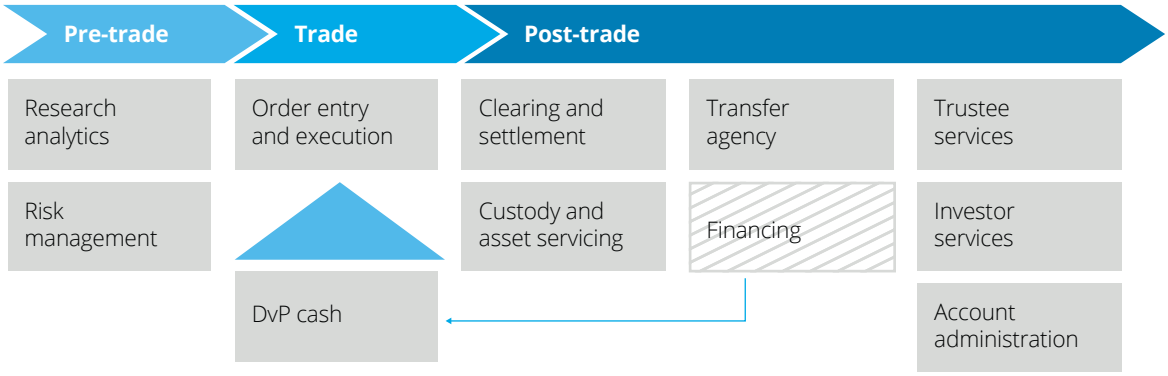
RTGS systems are funds transfer systems that process a large number of high-value transactions requiring immediate settlement. There is therefore a demand on such systems to neutralise intraday liquidity gridlocks, by means of an LSM, to move transactions along. LSMs are traditionally found on centralised systems, as is the case for most RTGS systems around the world, where the algorithms necessary for their implementation usually require a consolidated, system-wide view of all payment instructions. This sharply contrasts with the concept of a distributed LSM offered by DLT. Singapore's equivalent of an RTGS system is the MAS Electronic Payment System (MEPS+)[22], operated by MAS.

Payment gridlocks

A typical payment gridlock is a paradoxical scenario where senders and receivers are unable to settle queued payment instructions one-to-one, in a sequential manner, due to insufficient funds, despite the fact that the net liquidity held by all participants in the gridlock is sufficient for the simultaneous settlement of all transactions. If there are LSMs (private or public queue mechanisms) that can prioritise all payment instructions to trigger gridlock resolution – that is, enable incoming and outgoing amounts to coincide without any risk of a deficit – smoother settlements can be achieved and costly deadlocks[23] avoided.

The idea of a DLT-based RTGS system with an efficient LSM is especially relevant in the context of capital markets, particularly with securities trading. While digitisation has shortened trading timeframes considerably, the same cannot be said for clearing and settlement, which can stretch up to three days (T+3). This delay is partly due to existing market structure and rules that dictate that both participants be given some time to secure the underlying assets during post-trade settlement.

Figure 3: Impact on value chain



With distributed ledgers able to not only ascertain a buyer's liquidity, but also effect settlement within the trading phase itself, the time and monetary costs associated with post-trade financing may soon be a thing of the past (see Figure 3). This explains why a fully functional DLT-based RTGS system holds immense interest for industry players. Furthermore, DLT supports the use of smart contracts to automate or replace convoluted processes currently performed by clearing houses, back office systems, and registries.

Phase 2 concluded with all three prototypes confirming that an RTGS system, complete with an LSM, could be built on a distributed infrastructure. This has significant implications considering that DLT is capable of 24/7 uptime and, therefore, the restrictions of market operating hours will no longer apply. The possibility of cloud deployment and use of bespoke functionalities to handle tokenised assets further supports the case for DLT adoption.

22 MEPS+ plays an integral role in the functioning of Singapore's financial market. It processes about 25,000 transactions a day, with a total daily transaction value of up to SGD 70 billion.

23 A deadlock arises when a gridlock results in a negative net liquidity across participants and becomes impossible to resolve without the injection of additional liquidity into the system.

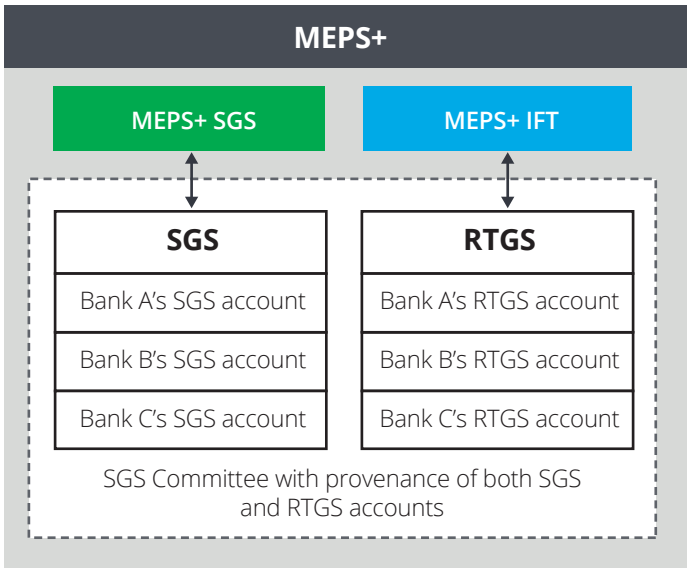
Project Ubin: Delivery versus Payment on DLT

On 24 August 2018, MAS and SGX announced their plan to realise DvP settlement of two tokenised assets across different blockchain platforms (distributed ledgers). The two tokenised assets are MAS-issued SGS and an MAS-issued central bank digital currency in the form of Digital SGD.

Current MEPS+ DvP system

MEPS+ is an RTGS system implemented and operated by MAS, comprising two subsystems: MEPS+-SGS, and MEPS+-IFT[24]. The former handles the scripless[25] settlement of MAS-issued SGS on a DvP basis, while the latter enables high-value SGD-denominated interbank funds transfers. Market participants must be registered with a central bank and an RMO, in this case, MAS, before they can engage in transactions (see Figure 4). The MAS SGS Market Committee[26] also has provenance over dispute resolution as an arbitrator.

Figure 4: MEPS+ operated by MAS



Challenges and opportunities

Systemic operational risks

In a conventional settlement system, all participating banks that require settlement services will have to be connected to central operators (clearing houses and central banks) in order to settle their transactions. A central operator represents a single point of failure in this closed loop system (systemic risk).

If DLT is a way to achieve connectivity between asset ledgers built on separate systems, we can effectively remove the systemic risk of siloed infrastructures, such as MEPS+. Distributing control to participants would in fact strengthen security resilience in the system since DLT makes the simultaneous hacking of multiple nodes extremely difficult.

Although transactional mechanisms could be replaced by DLT, the role of a central operator remains a question to be answered. Would there be a need for legal oversight over transactions and the role of the arbitrator?

24 MEPS+ interbank fund transfer system.

25 Securities trading with no physical certificate issued or exchanged, and only represented as book entries.

26 Section 3.4.3 on Amendment or Cancellation in SGS Rules & Market Practices mandates the recovery through arbitration by the SGS Market Committee.

Operating hours

The MEPS+ operates with fixed operating hours, and faces the same limitations imposed by fixed operating hours that plagues most, if not all, RTGS systems around the world. Going by current standards, it is simply unrealistic to expect round the clock trade-by-trade settlement. While clearing and settlement cycles characterised by T+2 or T+3 have become the industry norm, any delay in the settlement process fundamentally exposes trade participants to principal risks.

With DLT enabling 24/7 uptime and continuous trade-by-trade settlement facilitated by LSMs, clearing cycles of T+3 or T+2 can be compressed and their associated risks, reduced.

Compliance

Adherence to contractual obligations is difficult for the central operator (clearing house) to enforce in practice. Often, extra processes, labour, and financial resources have to be committed to ensure compliance. Additionally, the current market setup does not completely mandate provenance on the securities. For example, it typically takes a number of years for a regulator to complete an overhaul in the financial services industry, particularly with regulatory changes, changes in compliance standards, and system upgrades.

A DLT system can make use of smart contracts to contractually bind participants to operate in compliance. Although the benefits of such functionalities are appealing, we have to be prudent given the high-risk nature of the financial services industry. Would having a hybrid system combining a distributed network and a central operator work in practice? Does it include certain operational requirements to ensure that the framework is sufficiently robust to facilitate dispute resolutions?

Project objectives

While the proposed implementation of DLT in the current settlement system could very well address the inherent drawbacks of present RTGS systems, the real test lies in proving its efficacy. To do this, we need to design and create DvP-on-DLT prototypes that can accomplish the following:

- Interledger interoperability between cash and securities ledgers built on separate DLT platforms;
- Mitigation of counterparty risks in DvP by enabling recovery on cash and securities ledgers;
- Achievement of DvP settlement finality[27] with clearing members by counterparties;
- Strengthening of investor confidence and an enhanced user experience in DvP with safe and sound recovery.

In the next chapter, we will be exploring the feasibility of a DLT model that encapsulates these functionality requirements and the different approaches taken by our technology partners.

27 When transaction obligations are fulfilled through the transfer of an asset or financial instrument to another party, and the underlying contract is discharged, deeming the transaction irrevocable.

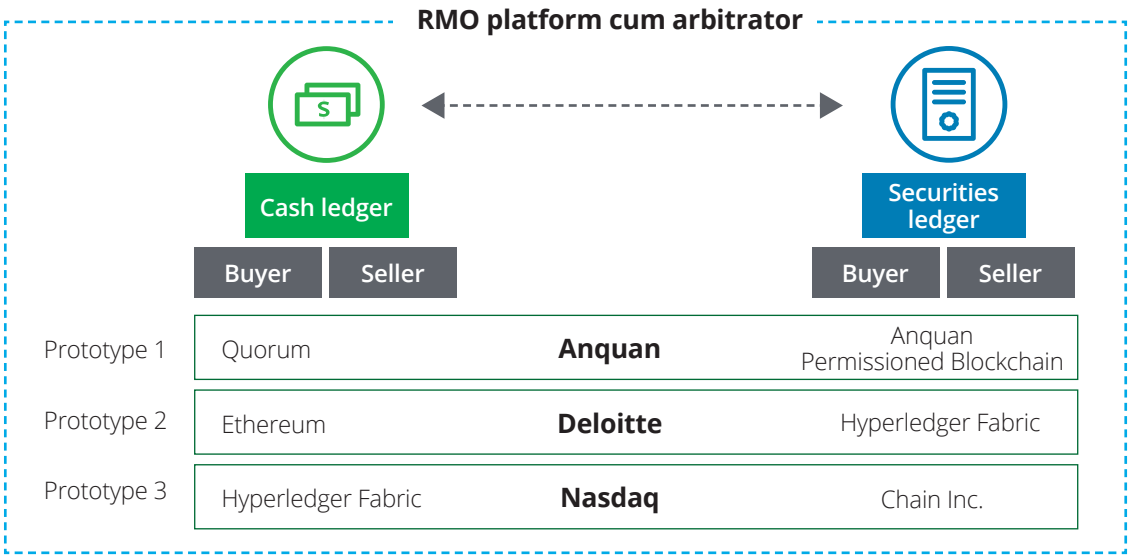
DvP settlement design on DLT

In this section, we examine the achievement of DvP settlement in an environment where cash and securities are implemented on two different blockchains. We will also highlight the specifics of our solution: participants and their roles (see Figure 5), prototype features, and a baseline settlement process flow, with examples of success and failure cases.

Platforms

Our technology partners created the prototypes on three DLT platforms: Anquan permissioned blockchain and Quorum (Anquan), Hyperledger Fabric and Ethereum (Deloitte), and Chain and Hyperledger Fabric (Nasdaq). The process flow described below is a generic one adopted by all three technology partners with slight deviations in design, including instances where transaction failures might occur, and where auto-recovery and arbitration are triggered.

Figure 5: High-level overview of solution architecture



Key participants and ledgers

- **RMO[28]:** This entity has oversight of both ledgers and dealer activities. It could also assume the role of an arbitrator that has access to two key-pairs, with a pair on each ledger: one public, and one private in escrow.
- **Buyer:** This entity is an exchange-registered trader with accounts on both the cash and securities ledger, and two key-pairs, with a pair on each ledger: one public, and one private.
- **Seller:** This entity is an exchange-registered trader with accounts on both the cash and securities ledger, and two key-pairs, with a pair on each ledger: one public, and one private.
- **Cash ledger:** This entity is the central bank-managed ledger for the tokenised Digital SGD asset.
- **Securities ledger:** This entity is an exchange-managed ledger for the tokenised SGS asset.

With their potential to reduce inefficiencies and costs, blockchains may well become a cornerstone of future financial ecosystems. Yet, there is also the potential flip side to consider: a fragmented global financial landscape borne on various blockchain protocols. Establishing connectivity between disparate blockchains is a daunting task, as each will have its own unique set of rules and protocols. Hence, achieving interledger interoperability is of profound interest for the financial industry as a whole.

28 For more information, please refer to "Review of the Recognised Market Operators Regime". Monetary Authority of Singapore. May 2018. [http://www.mas.gov.sg/~/media/MAS/News%20and%20Publications/Consultation%20Papers/2018%20May%2022%20RMO%203P/Consultation%20Paper%20on%20RMO%20Regime.pdf]

Prototype features

To achieve a DvP-on-DLT prototype that is fit for purpose, there needs to be a thorough study of real-world challenges and current market structures. The proposed system must be able to (i) aid trade participants in their fulfilment of obligations, (ii) mitigate, among others, principal and counterparty risks, (iii) allow for the conclusive state of settlement finality, and (iv) improve investor confidence.

For clarity, the terms "buyer", "seller" and "counterparties" will be used in place of "trade participants".

Time boundaries

For a DvP to successfully conclude, trade participants must perform their obligations within specified time windows. The seller specifies a time window before the settlement process is initiated where two distinct legs of the transaction will take place on the cash and securities ledgers. We have adopted asymmetric time boundaries to ensure a fair settlement that prevents unnecessary risk exposure for the participants. Our prototype also highlights the possibility of having a pricing mechanism to control the time validity of a transaction. For example, if a participant requires more time to acquire capital through financing, it could stipulate a longer settlement timeframe, subject to the agreement of the seller.

Contract locks

Contract locks render the amount of cash and securities committed by both buyer and seller untouchable on the respective ledgers. This prevents said assets from being used in another trade, hence removing the risk of payment and delivery defaults. The contract locks are in effect when counterparties commit to a transaction by sending instructions to the respective ledgers. The underlying assets will be locked and participants will be unable to use them in other transactions until the contracts are discharged when (i) the buyer and seller has fulfilled their obligations by transferring the asset to another party, or (ii) the contract has expired due to the imposed time boundaries.

Account controls

Counterparties are expected to fulfil two-of-three multi-signature conditions[29] at various points of the settlement process to advance towards settlement finality. In this setup:

- Buyer and seller will both hold individual private keys[30].
- Arbitrator will be provided with an escrow private key for safekeeping.

Participants engaged in a trade are subjected to this condition, where two of the three abovementioned authorised signatories must endorse the transaction in order for it to proceed to the next step. This also enables the arbitrator to be able to resolve disputes on the condition that either participant provides the first signature.

Self-enforcing smart contracts[31]

While autonomous self-executing smart contracts offer convenience by automating processes and transactions, they could potentially work against the blockchain they serve. The workaround is to use smart contracts that are self-enforcing instead. With the RMO also assuming the role of an arbitrator, buyers and sellers are rendered a greater degree of protection.

29 A requirement that the transaction has to be endorsed by additional users before it can be propagated in a blockchain network.

30 A private key allows a user to access their blockchain wallet and endorse (sign) a transaction to enable a transfer.

31 Smart contracts are virtual agreements encoded on the blockchain network that are executed automatically based on logic conditions when the terms of the agreement are met.

Secure secrets

Our prototype mandates the creation of a secret and its unique hash password as a means to ensure DvP finality: both buyer and seller have to use the same secret to effect asset transfer. Ideally, this secret should be generated by the RMO. The secret is sent to the seller in the form of an encrypted and password-protected PDF file at the start of post-trade settlement, and is used for the verification of instructions issued by counterparties until finality is reached.

The PDF file would also enclose the digital signatures of the signatories, which will allow participants to review the recipient of the transaction using on their public key[32] or encrypted address[33], providing a security feature to identify the recipient before initiating the transaction. This secure PDF is sent off-chain[34] and out-of-band, enhancing security for the market participants as the secret or its hash does not need to be stored on the blockchain (see Figure 22 in Appendix).

Process flow of DvP-on-DLT

In our process flow example, the following takes place: both seller and buyer of securities agree to the "asset type", "asset amount", "locking time" and hash password (HashPwd) to be exchanged. The agreement comprises two sets of asset transfers: (i) securities from seller to buyer within 48 hours, and (ii) cash from buyer to seller within 24 hours. Both seller and buyer have access to the distributed ledgers where securities and cash are settled respectively and the flow of time of these networks is predictable to both counterparties.

We examine four scenarios where DvP is carried out in a DLT-enabled environment:

- Scenario 1: Settlement success
- Scenario 2: Settlement failure with automatic recovery
- Scenario 3: Failed transaction requiring arbitration
- Scenario 4: Failed transaction with the introduction of an arbitrator

32 A large integer number that is analogous to an "account" or "address" in which the sender will transfer the underlying asset to.

33 Certain solution designs may choose to anonymise the public key through additional layers of encryption or central registry.

34 A recording and validation method that works outside the realm of blockchain technology, such as email or WhatsApp notifications.

Scenario 1: Settlement success
In this scenario, settlement is successful as both buyer and seller fulfil their trade obligations in the following steps (see Figure 6):

1. Matching engine or OTC[35] platform
Buyers and sellers submit orders to the matching engine or OTC platform. The matching engine or OTC platform matches the buyer's bidding price for a security with the seller's asking price. It then notifies these two counterparties that it will initiate post-trade settlement based on the exchange of the agreed asset type and amount, along with the payment amount.

2. Secret and hash password generation
The matching engine or OTC platform operated by the RMO generates a secret (α) and a hash password (HashPwd = H(α)) and shares them with the seller via an encrypted and password-protected file. Both will be used to verify the instructions subsequently exchanged between the two counterparties in the settlement process.

3. First Securities Instruction (seller)
Referencing the hash password, the seller creates the First Securities Instruction related to the transfer (delivery) of securities. In this instruction, the seller confirms the amount of assets to be exchanged for the agreed payment, and sets down the conditions for two possible end states.

The first end state (Tx1) sees the buyer granted the right to claim the seller's securities if (i) the buyer supplies the secret that matches the hash password (contract-lock condition), or (ii) both buyer and seller endorse this end state, or (iii) either the buyer or seller, together with the securities arbitrator, endorses this end state.

The second end state (Tx2) sees the seller granted the right to have his securities returned if (i) the buyer fails to supply the secret that matches the hash password within 48 hours (timeout condition), or (ii) both buyer and seller endorse this end state, or (iii) either the buyer or seller, along with the securities arbitrator, endorses this end state. The seller then endorses the First Securities Instruction (electronic signature) and submits it to the securities ledger.

4. Consensus (securities ledger)
The consensus mechanism of the securities ledger verifies and confirms the First Securities Instruction. It then updates the ledger with the result. At the same time, a securities contract lock – a smart contract referencing the hash password – locks up the amount of securities required by the seller for the trade. With the securities set aside on the ledger, a default on delivery is prevented.

5. First Cash Instruction (buyer)
After verifying the content of the First Securities Instruction submitted by the seller, the buyer creates the First Cash Instruction relating to the transfer (payment) of cash. In this instruction, the buyer sets down the conditions for two possible end states.

The first end state (Tx3) sees the seller granted the right to claim the buyer's cash if (i) the seller supplies the secret that matches the hash password (contract-lock condition), or (ii) both seller and buyer endorse this end state, or (iii) either the seller or buyer, along with the securities arbitrator, endorses this end state.

The second end state (Tx4) sees the buyer granted the right to have his cash returned if (i) the seller fails to supply the secret that matches the Hash Password within 24 hours (timeout condition), or (ii) both seller and buyer endorse this end state, or (iii) either the seller or buyer, along with the arbitrator, endorses this end state. The buyer then endorses the First Cash Instruction (electronic signature) and submits it to the cash ledger.

6. Consensus (cash ledger)
The consensus mechanism of the cash ledger verifies and confirms the First Cash Instruction. It then updates the ledger with the result. At the same time, a cash contract lock – a smart contract referencing the hash password – locks up the amount of cash required by the buyer for the trade. With the cash set aside on the ledger, a default on payment is prevented.

35 Over-the-counter transactions carried out between two known trading parties.

7. Second Cash Instruction
After verifying the contents of the buyer's First Cash Instruction, the seller creates the Second Cash Instruction (claiming the agreed amount of cash) that reveals the secret. The seller then endorses this instruction (electronic signature) and submits it to the cash ledger.

8. Payment complete
The consensus mechanism of the cash ledger verifies and confirms the Second Cash Instruction. It then updates the ledger with the result. At this point, the cash contract is discharged, and the seller receives the agreed amount of cash from the buyer. Payment is now complete.

9. Second Securities Instruction
Having received the secret supplied in the Second Cash Instruction of the seller, the buyer creates the Second Securities Instruction (claiming the agreed amount of securities) and inputs the secret. The buyer then endorses this instruction (electronic signature) and submits it to the securities ledger.

10. Delivery complete
The consensus mechanism of the securities ledger verifies and confirms the Second Securities Instruction and the secret. It then updates the ledger with the result. At this point, the securities contract is discharged, with the buyer receiving the agreed amount of securities from the seller. Delivery is now complete.

Scenario 2: Settlement failure with auto recovery
Regardless of how technically faultless a trading platform may be, it is still susceptible to human error: settlement failure could occur if any of the steps previously described in Scenario 1 are not followed through.

For example, settlement could fail if the seller does not send the Second Cash Instruction within the time bound of 24 hours, implying that it would be unable to obtain payment. Having received no instruction to verify and confirm, the buyer is unable to proceed with the Second Securities Instruction. Yet, both seller and buyer suffer no risk of losing their assets because the assets has not changed hands.

Through the use of smart contracts, the solution design enables automatic recovery (see Figure 7). The buyer, upon meeting the timeout condition of end state Tx4, is free to submit a cash instruction that will unlock and return his cash to the ledger after 24 hours. Similarly, the seller, upon meeting the timeout condition of end state Tx2, is free to submit a securities instruction that will unlock and return his securities to the ledger after 48 hours.

Scenario 3: Settlement failure requiring arbitration
In this scenario, settlement could fail if the buyer fails to submit the Second Securities Instruction within the time bound of 48 hours. This implies that the buyer would be unable to obtain the securities even after the payment is delivered, thereby exposing himself to principal and liquidity risk.

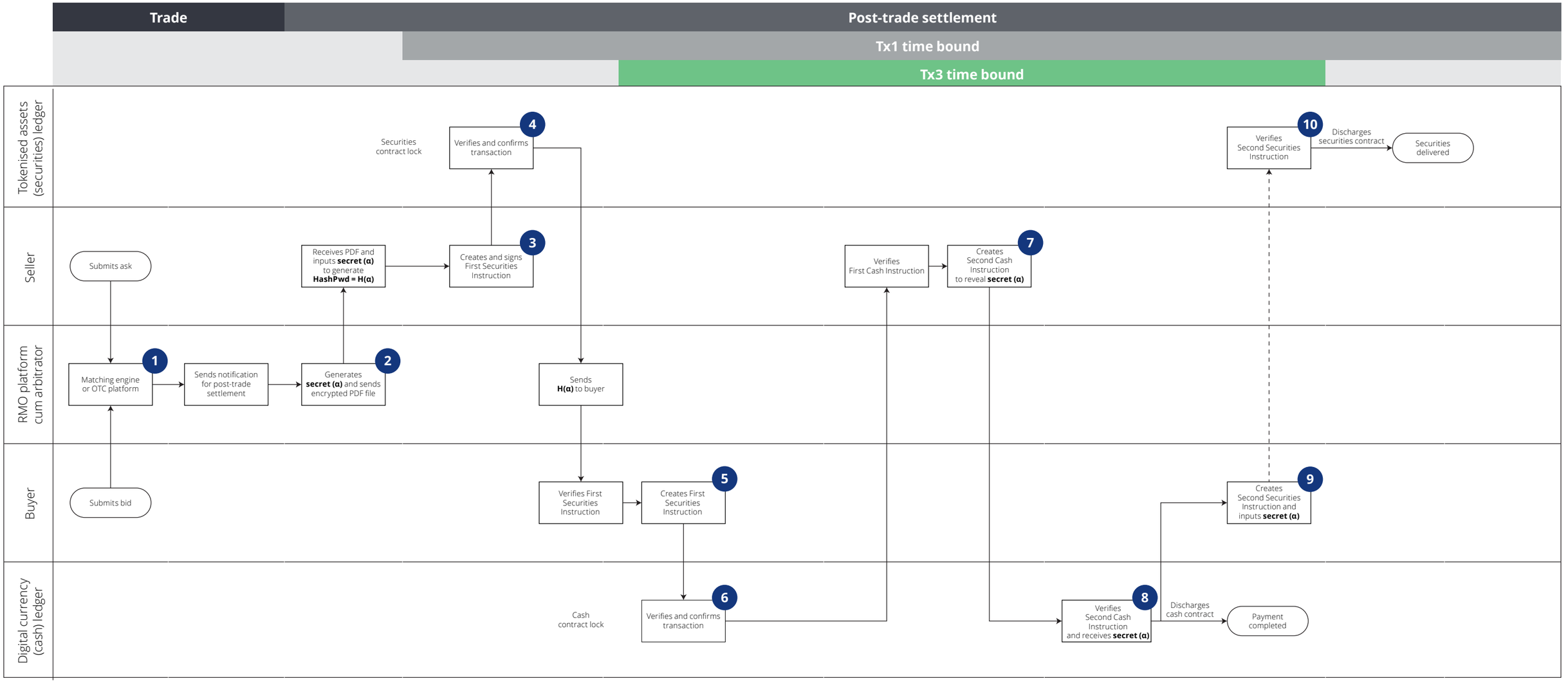
On the other hand, the seller has discharged the cash contract and claimed the payment (end state Tx3). However, the securities contract is still valid for the recovery of the committed securities (end state Tx2) – resulting in a lop-sided scenario where the seller now has received the cash payment, but continues to be in possession of the committed securities. This results in a possible dispute between the counterparties, and arbitration is now required (see Figure 8).

Scenario 4: Settlement failure with introduction of an arbitrator
In this scenario, settlement fails but an arbitrator is introduced to the settlement process (see Figure 9). Here, the buyer is able to call in an arbitrator (the trading platform) to help (i) recover the agreed amount of securities from the seller, or (ii) recover the cash that has already been paid.

To achieve (i), the arbitrator, together with the buyer or seller, must endorse end state Tx1 (First Securities Instruction), to trigger the release and transfer of securities from seller to buyer. Alternatively, if (ii) is preferred, the arbitrator, together with the buyer or seller, must endorse end state Tx4 (Second Cash Instruction) to trigger the rightful return of cash from seller to buyer.

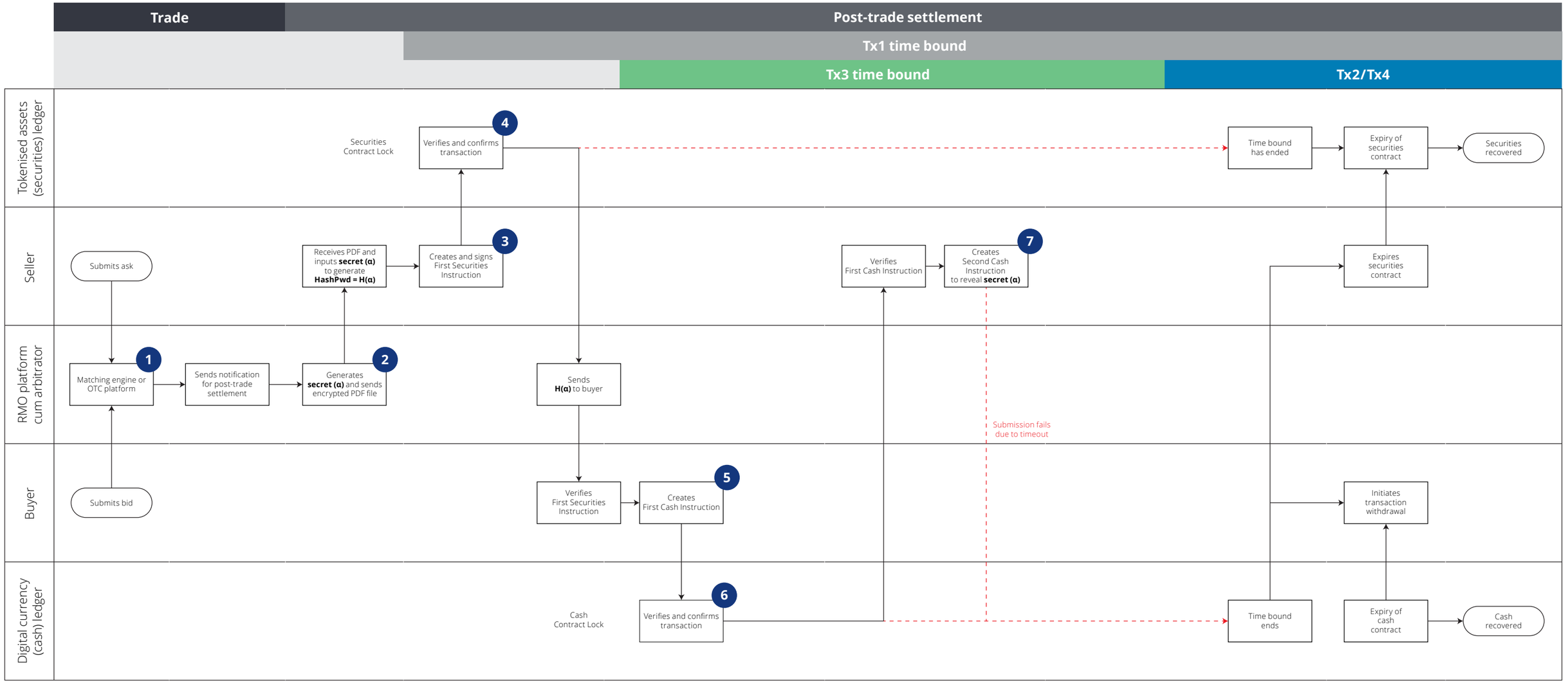
Delivery versus Payment on Distributed Ledger Technologies | Project Ubin

Figure 6: Process flow for settlement success



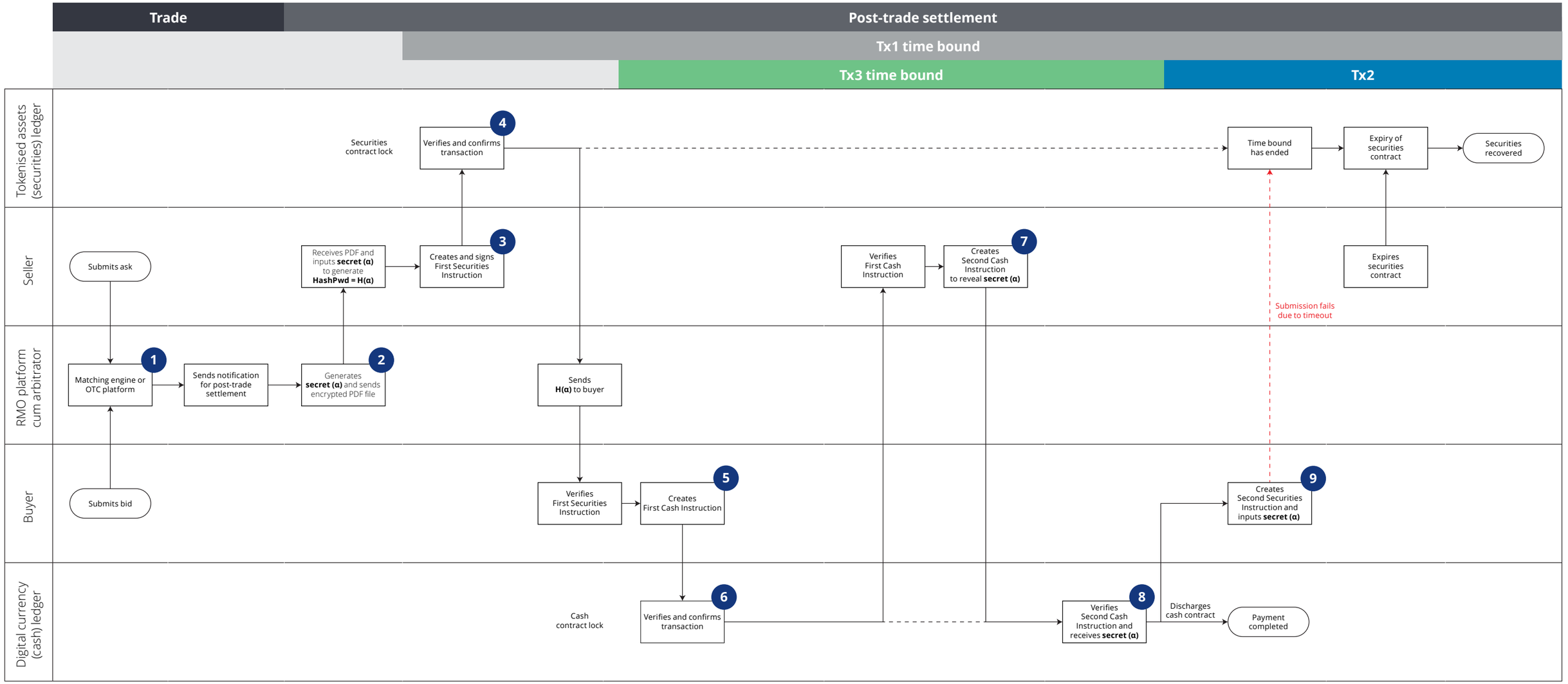
Delivery versus Payment on Distributed Ledger Technologies | Project Ubin

Figure 7: Process flow for settlement failure with auto recovery



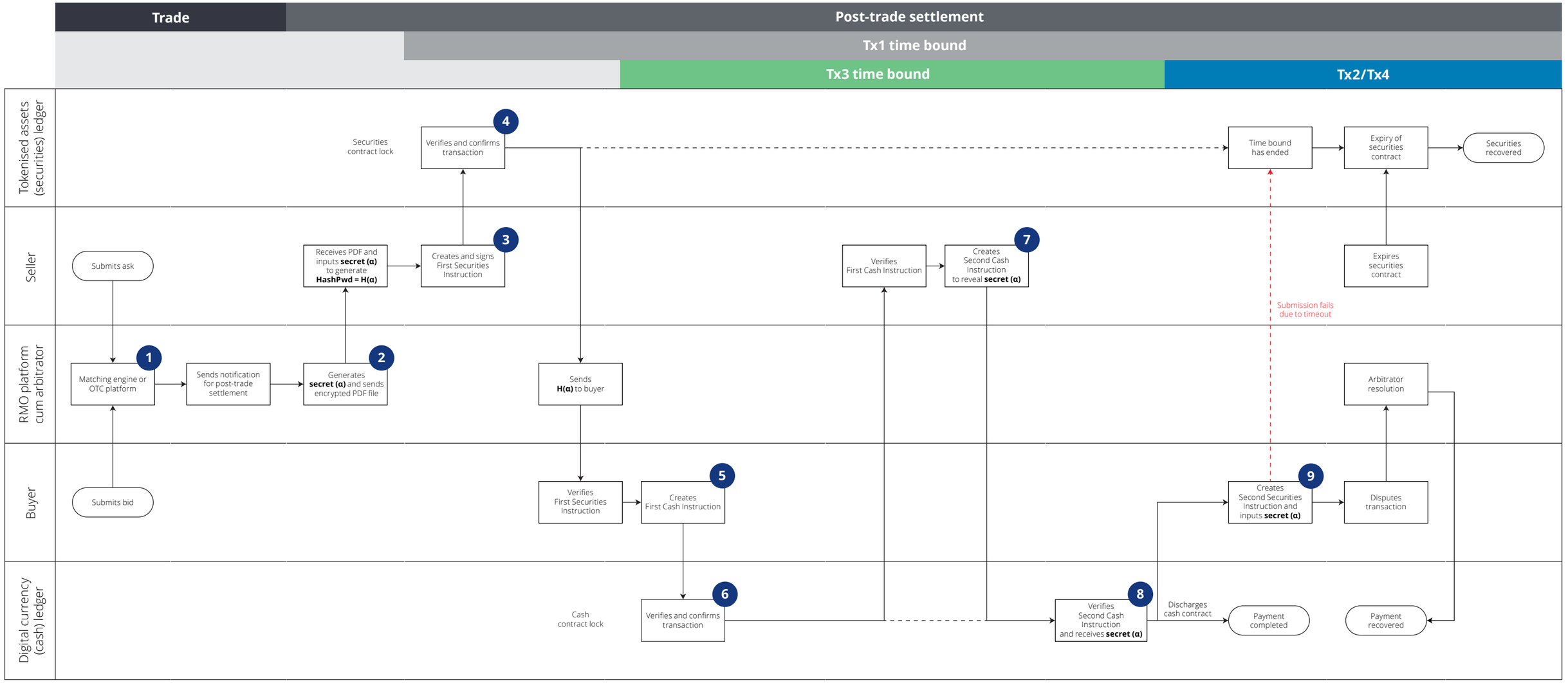
Delivery versus Payment on Distributed Ledger Technologies | Project Ubin

Figure 8: Process flow for settlement failure requiring arbitration



Delivery versus Payment on Distributed Ledger Technologies | Project Ubin

Figure 9: Process flow for settlement failure with introduction of an arbitrator



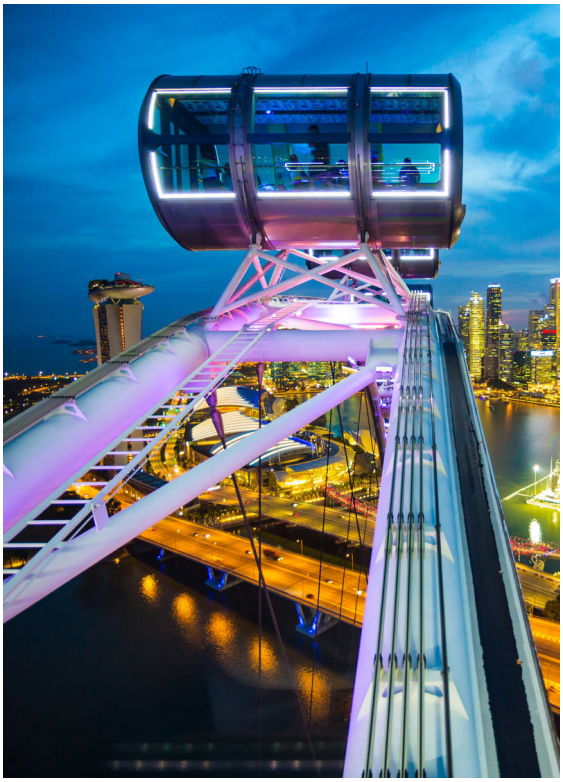
Investor protection

Assurance against account compromise

Two-of-three multi-signature conditions function as useful account controls. In a trade involving three participants (buyer, seller, and trading platform), no single participant can remove or steal the assets involved without the knowledge and endorsement of another. Hence, an arbitrator may resolve disputes by intercepting the transaction using an escrow private key[36].

For example, if the seller loses the device that is used to access the email account to which the secret is sent, the assets cannot be stolen or removed by anyone in possession of the device (and secret) without knowledge of the private keys held by the seller, buyer, and platform. Likewise, even if a non-trading member knows the individual private key of the seller, buyer, or trading platform, it cannot claim the assets involved without knowledge of the other participants' private keys and the secret.

In addition to such conditional account controls, off-chain[37] and out-of-band[38] contract locks safeguard secrets using encrypted and password-protected files as defined by ISO 32000[39]. The prototypes in the examples were designed to bear an electronic signature with document locks to protect it from tamper, thereby strengthening investor confidence and enhancing the experience.



Arbitrator presence

With the growing prominence of blockchain technology, account and transaction security issues have risen to the forefront. Convenient as it may seem to blame rogue dealers for exploiting technology for unlawful gains, such losses often stem from the lack of due diligence in conducting background checks, a healthy scepticism and, most glaringly, an avenue for recourse should things go wrong. Then there are also erroneous trades caused by mistakes such as the fat-finger error[40], which may result in extensive rollback issues for the financial intermediary (stock exchange).

The examples included in this report promote the introduction of an arbitrator presence to ensure transaction integrity and protection of market participants. Indeed, having a regulatory authority in place to oversee the follow-through of transactions, remind dealers of their obligations to facilitate the meeting of deadlines, and amicably resolve disputes should they arise – including instances of errant trading – serves to not only to assure participants, but also imbue confidence.

36 A key held by a trusted third party that works in the same way as the disconnected and isolated back-up key stored in tamper-resistant smartcard chips, or key components in sealed envelopes used by segregated key-custodians.

37 This refers to a recording and validation method that works outside the realm of blockchain technology.

38 This refers to an authentication method used to confirm a user's rightful access to information. The authentication mechanism requires the user to provide two or more pieces of evidence: (i) something the user knows, (ii) something the user has, or (iii) something the user is. In our DvP settlement scenario, the user (buyer/seller) must possess an on-chain private key (something the user has) and the secret/PDF file relayed via an off-chain communication channel (something the user knows).

39 ISO standard of the PDF format.

40 A fat-finger error is a human-keyboard input error, whereby a trading order of a far greater volume than intended, or for the wrong financial instrument, or at the wrong price, is placed.

Conventional arbitration

Although it is true that arbitration can provide respite and closure for errors, we must be clear about what the process entails, and the possible implications of DLT on current practices. Some considerations include:

Deadlines

The SGX error trade rulebook states that "the matter must be referred to SGX-ST within sixty (60) minutes from the time the error trade occurred or before 18:00 hours on that trading day, whichever is earlier"[41]. The arbitrator has the right to exercise discretion over whether to entertain reports made after the stipulated timeframe. With DLT, automated reminders encoded as smart contracts may be sent to counterparties to aid them in safeguarding their interests.

Asset classes

Different asset classes are governed by different rules. In particular, "SGX-ST will not review an error trade referred to it by a trading member, where the error trade falls at or within the upper and lower limits of a no-cancellation range, which is applied to the following instruments: (i) structured warrants, and (ii) all other securities and futures contracts, excluding bonds[42]. Here, smart contracts can again be employed to automatically determine if the conditions have been met, and smoothen the arbitration process.

Costs

SGX's rulebook states that "the requesting trading member must pay a trade review fee of $1,000 for each referral accepted for review by SGX-ST, regardless of the outcome of the review. SGX-ST may grant a waiver of the trade review fee where it deems appropriate." Administrative costs, no matter how miniscule, can add up when we consider the loss of capital and liquidity that is incurred in parallel.

Proponents of DLT may not be supportive of a regulator becoming a standard feature of trading markets, on the basis that it runs contrary to a "distributed" system. To that end, it may be worthwhile to consider the following: Does a network of distributed nodes, each adhering to a common set of rules, amount to a distributed system, or a centralised one?

Forget the physicality of entities and the answer is clear: systems built on DLT will always be centric in nature, even without the installation of an arbitrator. On this note, a 2016 paper published by the ECB on distributed ledger technologies in securities post-trading concluded that "irrespective of the technology used and the market players involved, certain processes that feature in the post-trade market for securities will still need to be performed by institutions"[43]. This further substantiates the need for governance of blockchain applications in financial markets.

Later in this report, we will also explore the implications of an arbitrator presence in a DvP-on-DLT securities settlement model – not to undermine the technology, but to enhance its operation.

41 Retrieved from Rule 8.6.3, section 8.6, Chapter 8 of SGX-ST Rules, Section C — Market Structure, SGX Rulebook. [http://rulebook.sgx.com/en/display/display_viewall.html?rbid=3271&element_id=1117]

42 Retrieved from Rule 8.6.4, section 8.6, Chapter 8 of SGX-ST Rules, Section C — Market Structure, SGX Rulebook. [http://rulebook.sgx.com/en/display/display_viewall.html?rbid=3271&element_id=1117]

43 Retrieved from "Distributed ledger technologies in securities post-trading". European Central Bank. April 2016. [https://www.ecb.europa.eu/pub/pdf/scpops/ecbop172.en.pdf]

Solution architecture

In this section, we examine the architecture of solutions proposed by the technology partners, including their key design elements, and characteristics of each DLT pair used in the respective solution.

Solution design by Anquan Capital

In Anquan's solution design, the securities ledger had been developed with Anquan's permissioned blockchain, while Quorum was selected for the cash ledger (see Figure 10).

Figure 10: Anquan's high level architecture

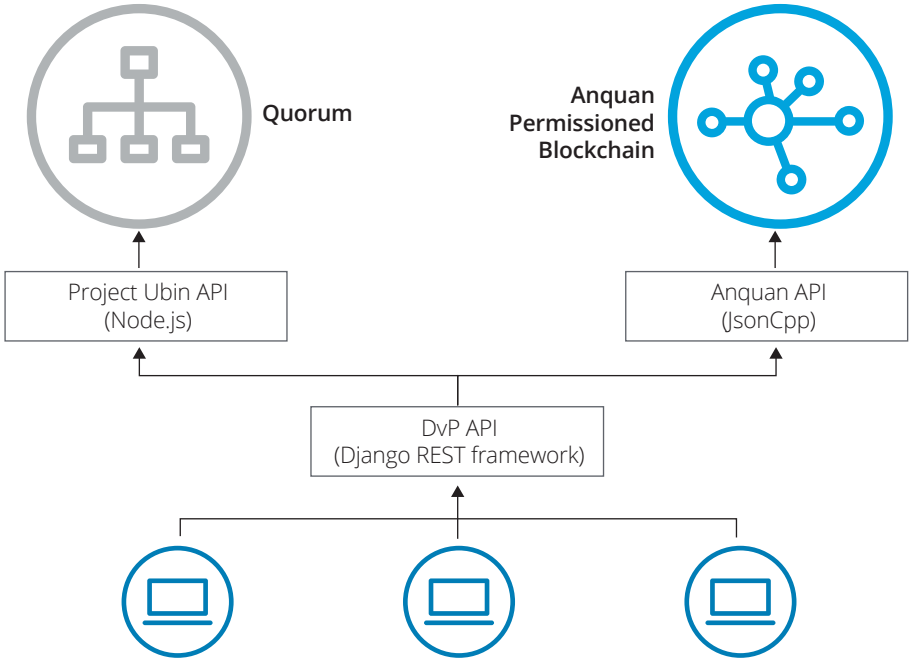
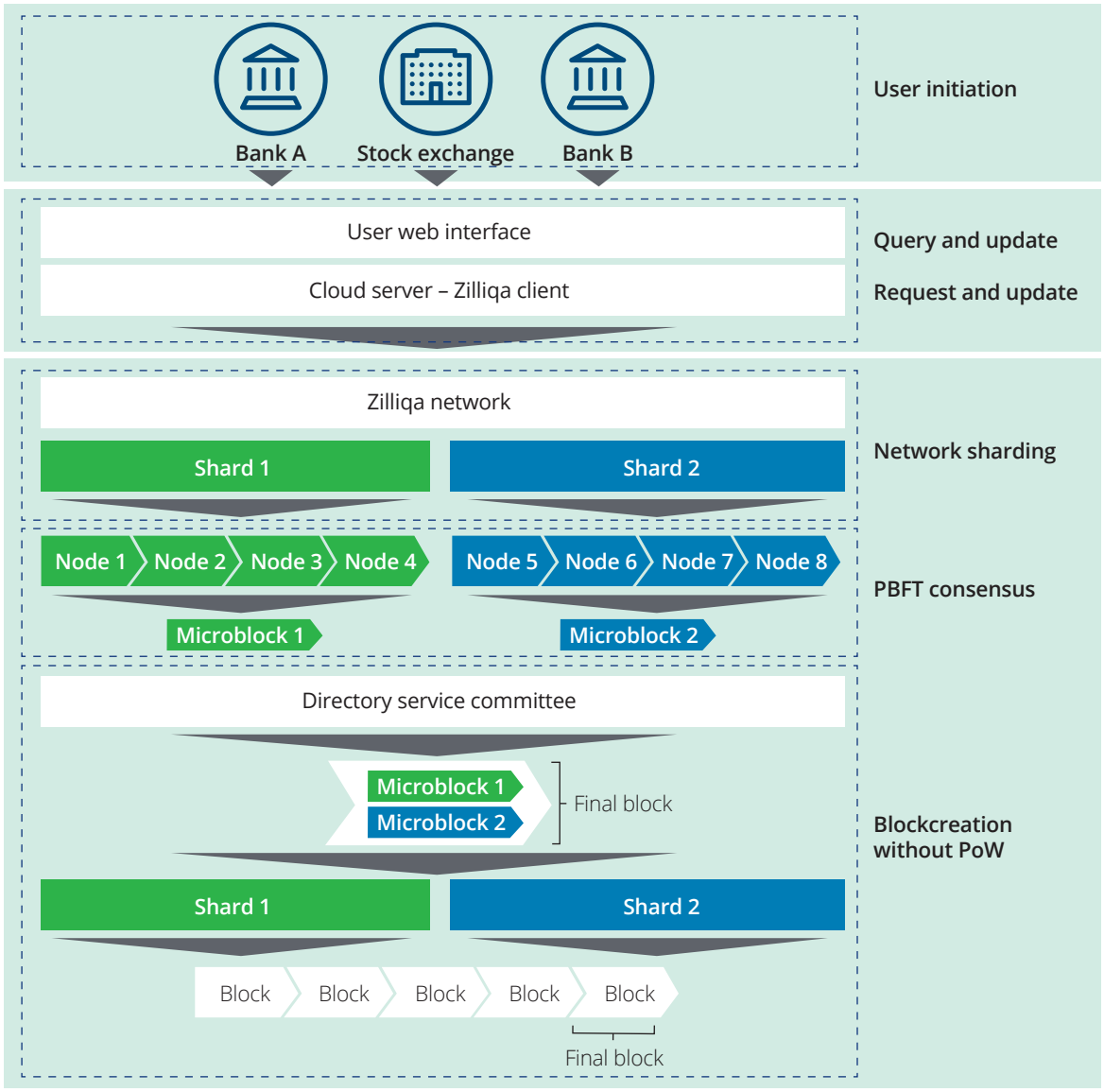


Figure 11: Anquan's permissioned blockchain



Securities ledger on Anquan's permissioned blockchain platform

Anquan's permissioned blockchain is a permissioned variant of Zilliqa, a public blockchain platform tailored to facilitate high-throughput, data-driven, and distributed applications with low transaction fees, as a solution to Ethereum's main shortcomings (see Figure 11).

Key features of Anquan's permissioned blockchain include:

- **Scalability**
  The blockchain platform makes use of a technique known as network sharding, where the entire network is divided into smaller sub-groups of nodes, and each subgroup is able to process transactions in parallel.
- **Shard creation**
  To avoid the risk of an attacker taking control of a shard, each node is randomly assigned to a shard. Shards are reshuffled at periodic intervals to mitigate the risk of collusion between participants over time.
- **Network consensus protocol**
  Practical byzantine fault tolerance protocol (PBFT) is employed for consensus within each shard. This protocol's performance scales with network size and ensures transaction finality without confirmation once the PBFT proposes a block.
- **Security protection against malicious nodes**
  PBFT requires a correct leader to begin each phase of block creation, and the view change protocol replaces a malicious node leader when the consensus protocol is stalled. This results in an independent node system that self manages according to the majority.
- **Smart contract intermediate-level language (Scilla)**
  A proprietary smart contract language was developed to impose a structure on smart contracts, making applications less vulnerable to attacks by eliminating vulnerabilities directly at the language level. It also makes applications inherently more secure and amenable to formal verification.
- **Privacy with trusted execution environment**
  All nodes run on machines with Intel Software Guard Extensions as a Trusted Execution Environment, allowing each node to verify all encrypted transactions while only revealing unencrypted data to authorised users.

Unique features of design

There are several unique features of this design, including:

- **Distributed atomicity**
  To safeguard participants, atomicity is guaranteed without a centralised arbitrator through specific design elements. Although DvP-on-DLT may possess design flaws that expose the buyer to potential risks, this can be mitigated by guaranteeing transfer instructions after both participants have committed to the ledger.
- **Integrates with existing payment systems prototype**
  Interoperability not only applies because the DvP application operates two distinct ledgers, but also because it is integrated with the payment system developed in Project Ubin Phase 2.
- **Scalability**
  Linear scalability achieved through PBFT consensus algorithm and sharding enables cross-chain atomic swap without the need to wait for confirmation from several blocks.

Key takeaways

In Anquan's implementation, specific design elements were taken into consideration to ensure transaction atomicity for DvP success without the need of an arbitrator. However, the arbitrator is still crucial in this approach as it can override the time lock mechanism in the case of a failed exchange, and address the potential liquidity risks.

As blockchains evolve rapidly, there is a need for consistent development support across multiple versions of the same blockchain, as many problems arise when different version updates are not compatible with one another.

Additionally, the privacy model for Quorum relies on binaries located on each node to generate and verify the Zero Knowledge Proofs (ZKP). However, to implement DvP capability on Quorum, a new smart contract was added to enable atomic swaps, which is not compatible with ZKP privacy features. As the payment capabilities defined in Project Ubin Phase 2 were out of scope for this project, an attempt was not made to change the binaries to account for the DvP smart contract. It is important to note, however, that projects built using ZKP should account for this added complexity.

Solution design by Deloitte

In Deloitte's solution, the securities ledger had been developed with Hyperledger Fabric technology, and the cash ledger with Ethereum technology (see Figure 12).

Figure 12: Deloitte's high level architecture

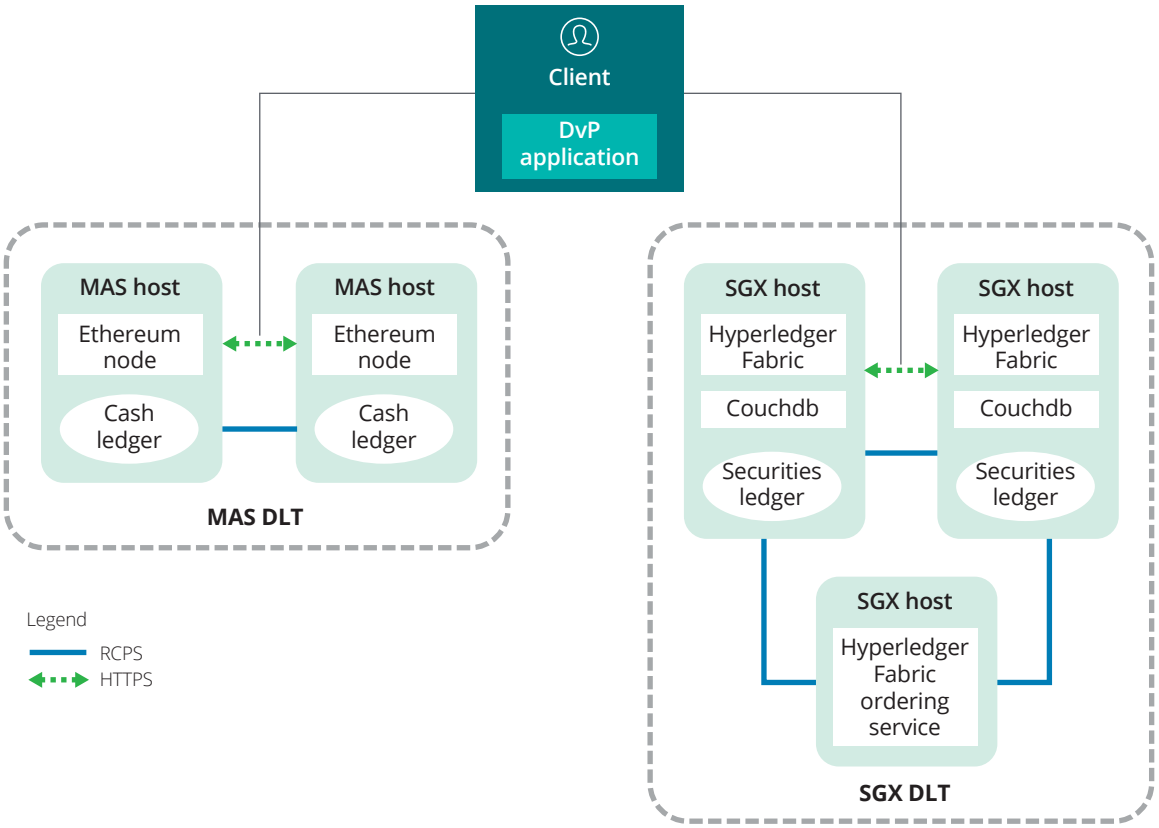
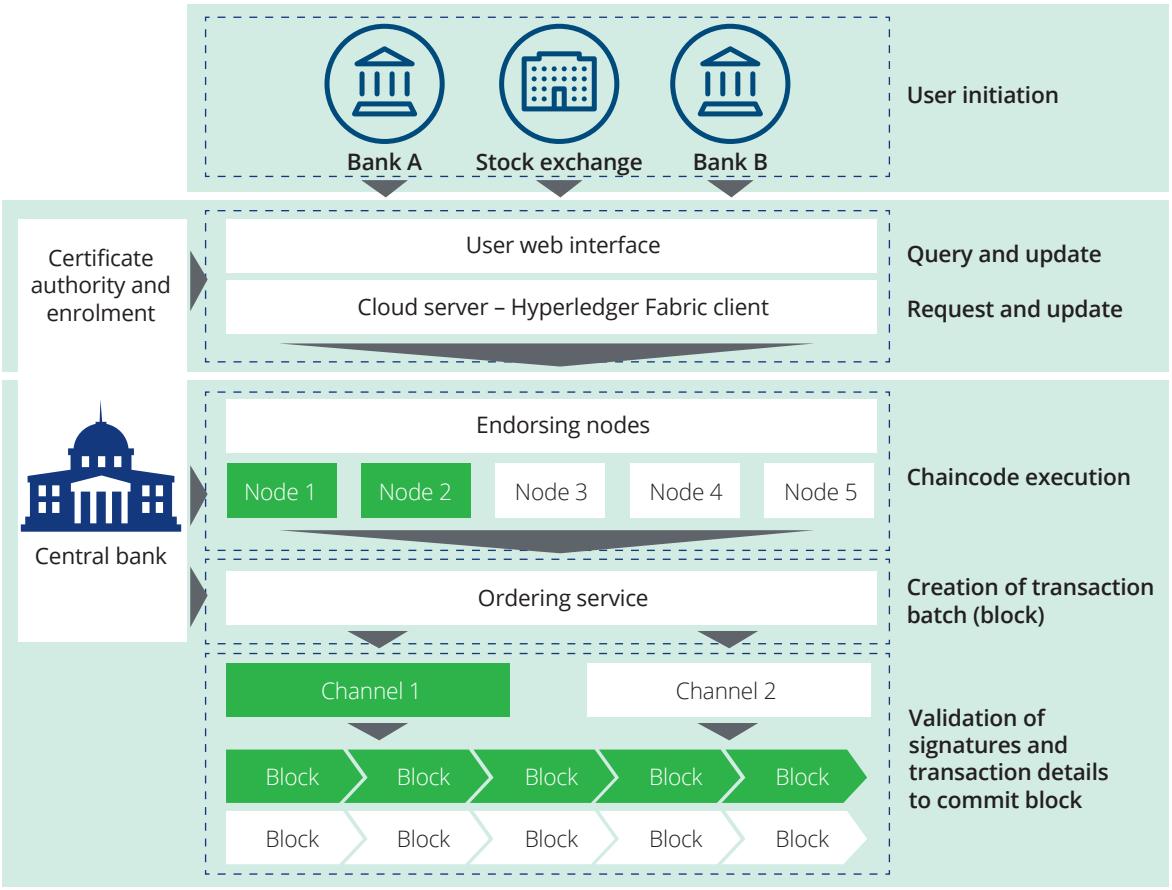


Figure 13: Hyperledger Fabric



Securities ledger on Hyperledger Fabric technology

Hyperledger Fabric technology was chosen for the securities ledger because as a permissioned DLT, it is underpinned by a modular architecture delivering high degrees of confidentiality, resiliency, flexibility and scalability (see Figure 13). In addition, it is also able to accommodate pluggable implementations of different components and the idiosyncrasies of different ecosystems.

The securities ledger possesses several key features:

- **Asset definition**
  By defining assets digitally and enabling participants to agree on both their representation and characterisation, the securities ledger is able to facilitate the exchange of both tangible and intangible asset types.
- **Security**
  Permissioned membership provides an exclusive blockchain network where participants understand that all transactions are traceable by authorised regulators and auditors to ensure compliance with standards and prevent unauthorised participation.
- **Privacy**
  Hyperledger Fabric uses channels to safeguard confidentiality of certain data elements, such as user identity, by providing data on a need-to-know basis. This is particularly relevant to the financial markets, where buy-side participants may require anonymity in their transactions to maintain competitiveness and meet regulatory requirements.

- **Immutability**
  With an immutable shared ledger that encodes the entire transaction history for each channel, auditing and dispute resolution processes can be made more efficient.
- **Scalability**
  The chaincode execution is partitioned from the different parts of the transaction ordering to allow limitations to be placed on the required levels of trust and verification across node types. As a result, network scalability and performance is enhanced.

Unique features of design

There are several unique features of this design, including:

- **Centralised user credential management**
  Typically, tokenised assets are secured with the use of the owner's private key, and it is the owner's responsibility to keep the private key secure. In this solution design, however, an authorised third party is able to provide key custody service by holding an escrow key, and endorsing transactions with its signature.
- **Semi-centralised DvP process with the arbitrator**
  Tokenised assets are commonly transacted in a disintermediated process that is more efficient and lower in cost. However, without a centralised process and an avenue for arbitration, the buyer/seller will have to bear any losses that are incurred. In this design, disintermediation is still maintained at a process level, but an arbitrator is introduced as a trusted third party with provenance over both ledgers for dispute resolution.
- **Smart contracts and public key infrastructure**
  The DvP logic is implemented in the smart contracts for the transaction to be reviewed and audited by external parties. Atomicity of the transaction is maintained through smart contracts.
- **Turing-complete blockchain solution compatibility**
  In this Ethereum/Hyperledger Fabric blockchain pair, the solution design is built on open source technology, and therefore its design enables compatibility with other Turing-complete blockchain platforms.

Key takeaways

In Deloitte's implementation of the DvP prototype, a huge emphasis was placed on protecting user privacy and enabling the control of assets. Transaction and settlement can only proceed after an authorised participant signs and endorses the transaction with the secure secret issued by service providers (such as MAS or SGX). Meanwhile, the users' private information remains confidential during the settlement process, as the process only requires a proxy address to identify a recipient and enable the transfer.

Deloitte's solution guarantees atomicity of transaction, and highlights the importance of governance, in the form of an appointed arbitrator, in protecting individual interests. A self-enforcing, but not self-executing, feature ensures that the seller and buyer can complete the settlement transaction once the smart contract's conditions are met, without over-reliance on the blockchain application. The solution also employs a user-centric design to give market participants more control over the status of their transactions.

Solution design by Nasdaq

In Nasdaq's solution, the securities ledger had been developed with Chain Core ledger technology, and the cash ledger with Hyperledger Fabric technology (see Figure 14). The solution is built to be agnostic to the underlying DLTs, separating the smart contracts from the DLT dependency.

Figure 14: Interledger DvP for Hyperledger Fabric and Chain Core technologies

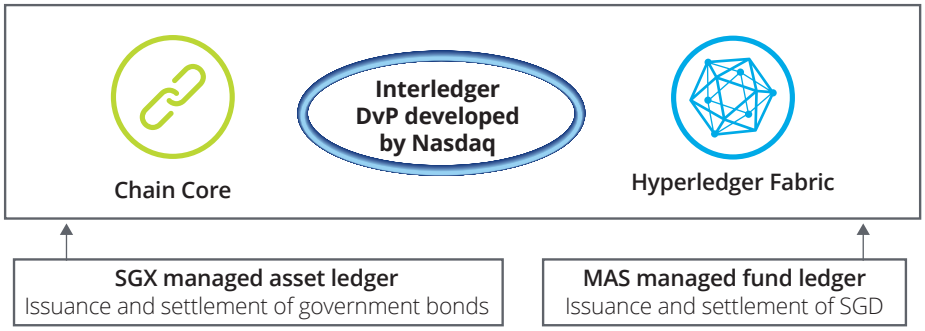
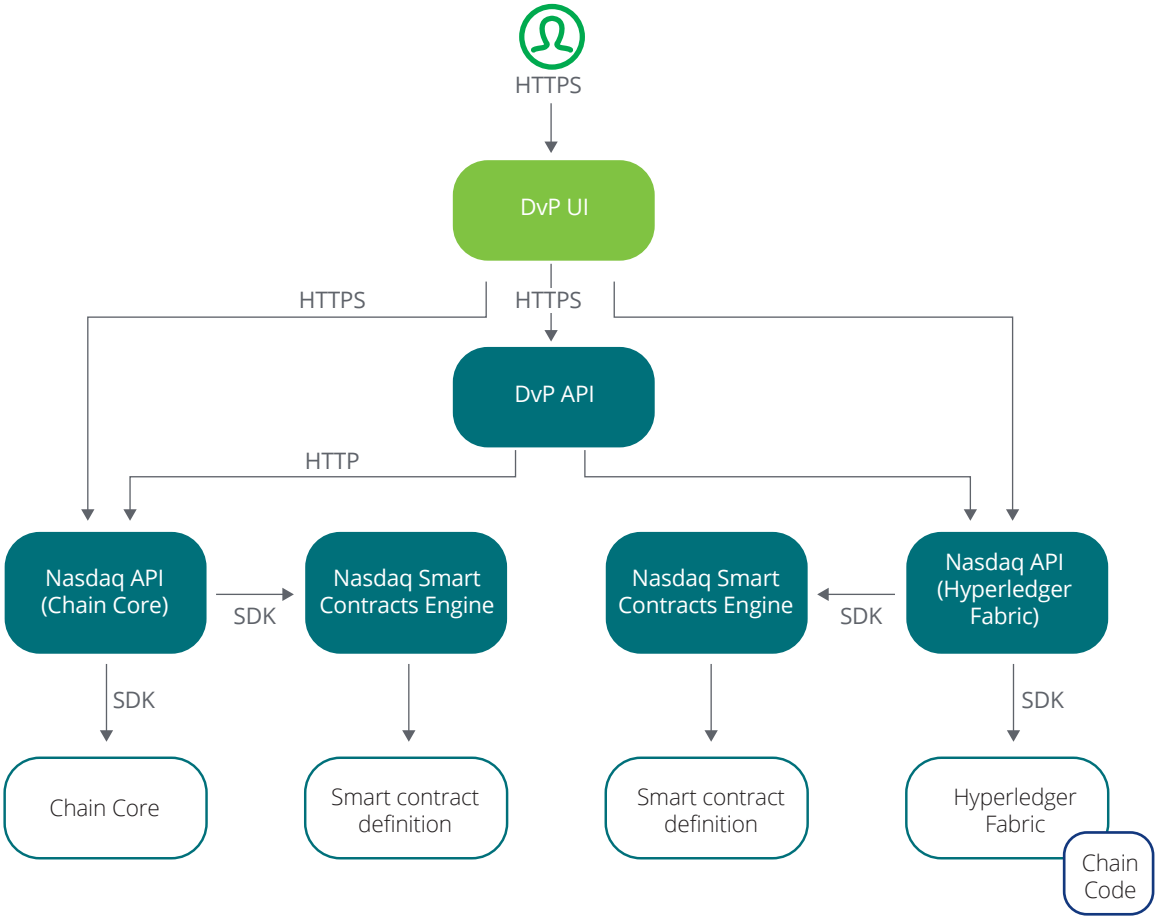


Figure 15: Nasdaq's architecture and solution design



Both ledgers and the smart contract initiation can be managed through one harmonised, role-based DvP API. Additionally, for the purpose of the proof of concept, two https connections were offered for direct access to each DLT implementation and their respective log files to validate the movement of the assets as they occurred on each ledger. The Nasdaq Smart Contracts Engine instantiates smart contracts according to the business rules and workflows that have been agreed upon.

Securities ledger on Chain Core technology

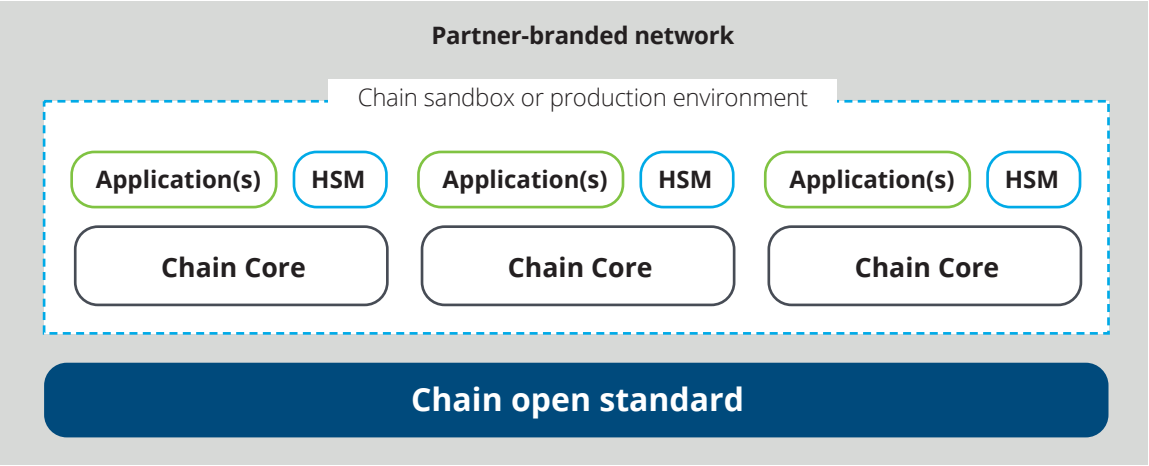
Chain Core was built specifically for large enterprises. It enables companies to build private blockchain networks that provide both the decentralisation and cryptographic security of public networks, and the performance, scalability and confidentiality needed by commercial applications. Chain Core also enables cross-network and cross-protocol transactions, and has native support for smart contracts.

The Chain Core platform

The securities ledger was built using Chain Core, and smart contracts were created to handle hash-locked, multi-signature conditions, and recovery (see Figure 16). Chain's blockchain standard, known as the Chain Open Standard, was developed through partnerships with major financial services leaders such as Nasdaq, Visa, Fidelity, Citigroup, Fiserv, First Data, and R3CEV. The Chain Core platform possesses several key features:

- **Private and secure**
  Chain supports private blockchain networks (in contrast to unpermissioned blockchain networks) and enables the network certificate authority to determine who can participate and transact on the network. Network and asset security is ensured through multi-signature key configurations, hardware security appliances, and full network validation.
- **Confidentiality and anonymity**
  Through the use of one-time-use addresses, transaction-level encryption, and data management services, the Chain Open Standard ensures confidentiality of data and transactions at a level beyond other blockchain protocols. Anonymity could also be achieved by encrypting data before transmission, or by setting up a specific channel to restrict data flow to only between the parties involved.
- **Speed and scalability**
  Chain's networks are designed to process high volumes of transactions: in production tests, it has achieved a rate of over 5,000 transactions/second, and this is limited only by the speed of the network and hardware.
- **Use of smart contracts**
  The Chain Open Standard has native support for a variety of smart contract structures to facilitate sophisticated transactions such as automated swaps in different marketplaces.
- **Interoperability**
  Chain networks, while private, can be configured to be interoperable with one another, and with other emerging blockchain protocols at a standards level.
- **Flexibility**
  The Chain Open Standard supports a variety of data, key, and deployment environments to onboard network participants with greater ease.

Figure 16: The Chain platform stack



Unique features of design

There are several unique features of this design, including:

- **DvP component with role-based APIs**
  The overarching DvP component with role-based API enables users, who are indifferent towards the underlying DLTs, to execute the necessary functions using one API. Using a role-based API, the user can also retrieve its account status for cash and securities, and perform all the necessary functions such as signing contracts with its private key, or inputting the secret on both ledgers.
- **Smart contract engine**
  A generic smart contract engine was built to facilitate the creation of smart contracts independent of the DLT. The smart contract engine allows the user to define the criteria of the smart contract in a human-readable format and execute transactions on each DLT.
- **Fully security hardened cloud solution**
  The design is fully containerised and can be deployed as a fully security hardened cloud solution for public or private operations, and to both back-end operations and user interfaces. The infrastructure also ensures configurability and elasticity by including a clear secure separation between the two blockchains and smart contracts, in addition to supporting locally installed user interfaces connected to the back-end in the cloud.

  Such an operational architecture has the advantage of being easy to scale and access, and enables the efficient use of resources. A single secure, role-based API is required to access both ledgers and the smart contracts, and also acts as an encapsulation layer for the specific DLT implementation so that a change of the underlying DLT technology will not affect the API and the resulting user experience.
- **Containerised architecture**
  The application will be operated in a cloud environment, with all application components dockerised for efficient deployment and portability. In this way, containerised deployment of applications becomes possible, regardless of the infrastructure. Three points of access were designed for the environment – one for each API component to enable proper testing and verification of the DvP solution. Additional points of access were also made available to enable verification with individual DLT APIs through which successful transactions have been completed.

Key takeaways

In Nasdaq's model, the solution is designed to be dynamic, and can be easily adapted to suit the eventual market rules and practices that will apply for DvP settlement. Additionally, although arbitration is established in this model to increase investor confidence by providing an avenue for recourse, it may be unnecessary to oversee and govern all transactions. Lower value transactions could, therefore, be automated to increase efficiency. For example, immediate DvP settlement can occur automatically for transactions with values lower than a predetermined threshold.

One design consideration was the need to ensure that the solution design can be deployed for any DLT platform. The smart contract engine that manages contract execution is not bound to specific DLT platforms, but built as a separate layer above the core DLT layer to facilitate the switching of the underlying DLT without changing the smart contract logic or the user interface encapsulating the DLT implementation.

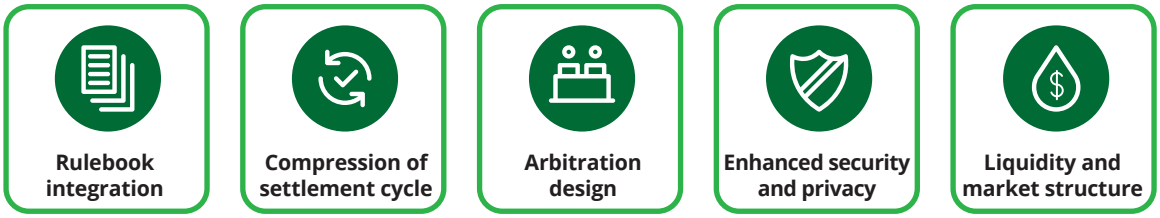
With respect to privacy, the overarching architecture design for the DvP component supports privacy handling on different levels. Anonymity can be established on the API layer or within the platform layer by generating a one-time public key for each transaction, such that an outside viewer would be unable to determine the identity of the participants. Further anonymity could also be achieved by encrypting data before transmission, or by setting up a specific channel to restrict data flow to only between the parties involved.

Conclusion

Observations about prototypes

During the project and prototype development, we have identified five key observations and future considerations that will need to be explored in further phases of Project Ubin (see Figure 17).

Figure 17: Observations about Project Ubin (DvP)



Rulebook integration

The current landscape of primary participants largely involves members[44] of an exchange, who provide a set of rules to maintain the operations of a fair, orderly, and transparent marketplace as determined by the exchange. In addition, smart contracts are use case-agnostic to accommodate many different logic conditions.

This project seeks to explore whether smart contracts can act as a replacement for compliance requirements due to the inherently integrated rulebook by, for example, having arbitration built into the smart contracts' conditions to validate transfer instructions. Furthermore, error margins that define an erroneous trade can be pre-programmed into the trade to prevent market participants from partaking in such trades.

Here, the project has provided a proof-of-concept that the functionalities of smart contracts can be used to programme conventional rulebook conditions. This could result in situations where a central bank or financial services institution may need to carry out enforcement actions on members who are located across multiple jurisdictions and therefore subjected to different degrees of regulation scrutiny and compliance standards.

One such application could be coupon payments[45] associated with the underlying fixed income security, where it can be instituted with smart contracts to enable transactions on separate DLT implementations.

Compression of settlement cycle

In Singapore, the current market practice on settlement cycles is T+3. Having a solution design that is built on DLT for interledger operability helps to illustrate the potential of compressing the post-trade settlement process to T+1 or even round-the-clock, real-time settlement.

Moving the industry forward to T+1 or real-time settlement may have many implications. For instance, with a shorter timeframe to settle, it will lower exposures to counterparty, principal and liquidity risks. Banks will have to rethink their liquidity and risk management practices to remain competitive. As the compression of the trade settlement cycle takes effect, regulators have to constantly re-evaluate and update existing rulebooks and regulations that governs the time and duration for settlement, particularly with arbitration to ensure a fair and orderly market.

44 Firms must (i) meet capital requirements, (ii) have clearing members to contribute to a clearing fund, which in turn creates a liquidity requirement held by the market participants, (iii) have all participants agree to abide by the trading rules of the exchange in the event of a dispute, and submit to the judgement of the exchange.

45 Interest payment paid by the issuer to the bondholder.

Arbitration design

The interledger transaction for cash and securities settlement have highlighted the principal risk exposure to the counterparties during specific segments of the process flow when participants do not abide by the transaction sequence, such as when the buyer does not discharge the securities contract to withdraw the securities before the time boundary expires, resulting in a situation where the seller can then expire the contract and recover the securities while having received the cash payment.

Therefore, it is crucial to appoint an arbitrator for dispute resolution, and the solution design has revealed several possible intervention opportunities. The arbitrator can assess the circumstances of the disputed trade before passing judgement on possible recourse, whether it is (i) recovery of cash payment for the buyer, or (ii) moving ahead with the transaction by transferring the ownership of the underlying asset to the buyer. This can be accomplished using smart contracts that are established at the beginning of the settlement cycle or upon the discharge of the cash contract.

Further analysis is required to provide a more robust arbitration framework. For example, during the arbitration period, the buyer may be exposed to liquidity risk if the seller possesses insufficient funds after the transaction has reached finality. Would the recovery contract provide sufficient safeguards for the buyer with a programmed condition on the cash reserve[46] requirement of the cash ledger balance? Or should there be a smart contract that is built on top of the cash payment to restrict fund movement?

Enhanced security and privacy

The prototypes that were developed are compatible with different types of trading platforms, including CLOB[47] or OTC request for quotes/auctions. This has resulted in the use of different models by our technology partners to safeguard privacy.

To maintain market competitiveness yet still abide by regulatory requirements, the identities of the participants of the trade should not be known to one another, except for OTC trades, especially in the financial services industry where anonymity is paramount. In our proposed DLT solution, an inclusion of a secure-PDF containing the secret is an important off-chain and out-of-band feature to ensure that investors' interests are protected.

Verification of recipient

An investor will be able to use the PDF that contains either a randomly encrypted address (a proxy for the public key), or the public key to verify its identity with the execution platform (user interface) before agreeing to the transfer.

Secret-sharing

The secret used for the transaction is sent through an encrypted PDF and is independent of the blockchain network. As it is not stored or propagated through the blockchain network, this ensures that the secret is not made known to other participants in the network.

The prototypes have adopted various ways to ensure that security and privacy is not compromised with an off-chain and out-of-band design. These includes remodelling the CLOB where the certificate authority keeps a record of its registered users, and using it to generate a pseudo address that is used for transactional purposes, without revealing the identity to the participants in the market. Alternatively, an OTC model can be adopted, where the buyer and seller are able to review the identity of the counterparty, in a setup that is similar to the existing market design.

46 A specified minimum threshold amount for deposits held with a central party.

47 Centralised limit order book that holds the record of all unexecuted limit orders maintained by a stock exchange.

Liquidity and market structure

SGS functions as an important financial instrument for money market liquidity. Conventionally, liquidity is affected by a multitude of factors, such as the availability of intraday credit, and the type of settlement mode. When settlement is achieved on DLT, liquidity efficiency will be lower than conventional market setups due to the underlying mechanism that locks assets to their corresponding ledgers.

Given that disputes may arise, the assets associated with these transactions may be locked for an extended duration until the contract expires, or reaches a state of resolution, before it is returned to the respective asset holders. This will have an impact on the participants and market liquidity because the underlying assets cannot be utilised for other transactions during this duration. These mechanisms are part of the solution design, and are required to serve and safeguard investors' interests. However, more research needs to be done to evaluate the effects on market structure and liquidity.

Future considerations

Project Ubin has demonstrated the functional capabilities of three different blockchain pairs to establish an interledger DvP settlement system, and highlighted the need for an arbitrator for dispute resolution to maintain a fair and orderly market structure.

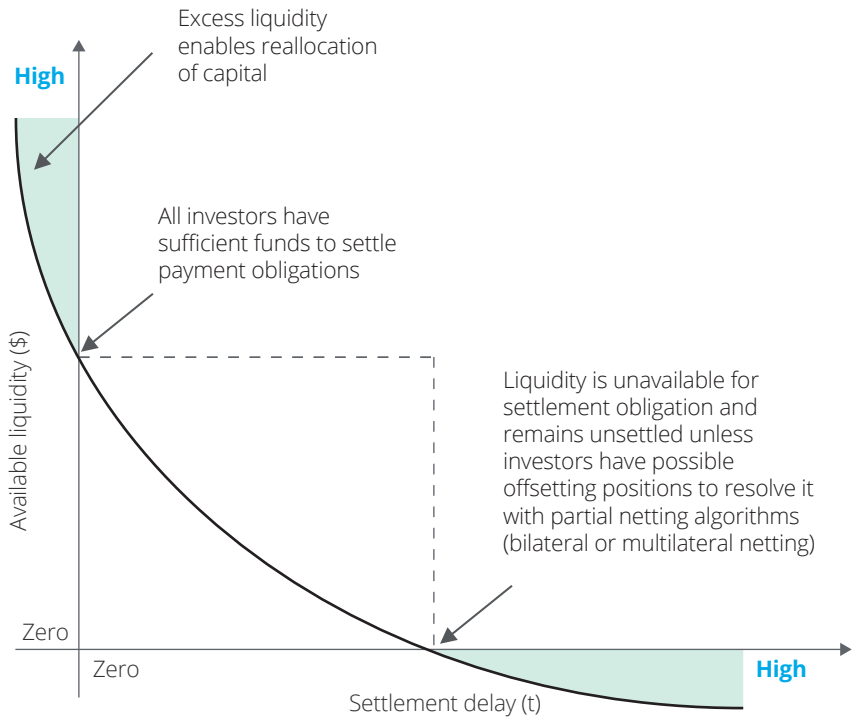
Liquidity Savings Mechanism (LSM)

Following the discussions from Phase 2 of Project Ubin, the LSM could be triggered by the RTGS system centrally using a predefined interval. The project has highlighted the importance of ensuring fairness to all participating banks with regard to their liquidity position before initiating gridlock resolution. One proposed method is to have a reserve requirement set aside for LSM processing by decoupling LSM from the fund transfer.

Project Ubin (DvP) has expanded on the possibility that an appointed arbitrator can monitor and initiate the gridlock. As the arbitrator now holds the escrow key, it can resolve any disagreements on LSM. One consideration is the need to maintain full transparency for all participants with the processes used for monitoring the liquidity positions and cut-off time. This would ensure a level playing field and a neutral stance taken by the arbitrator as a service provider. Nonetheless, more research has to be undertaken to evaluate the current regulatory infrastructure that governs the financial services industry if LSM on DvP is put into practice to understand its implications and associated risks in the marketplace.

The effects of a coupled DvP LSM system could also have potential benefits for liquidity management and help to reduce the amount of settlement delay experienced by market participants (see Figure 18). A settlement period of T+3 is given to provide a buffer for participants to secure the underlying assets for settlement. Settlement delay increases as the participants have lower liquidity, resulting in potentially unsettled trade obligations that can only be resolved with offsetting positions or additional injections of liquidity. In this scenario, LSM coupled with DvP-on-DLT can potentially alleviate this problem by ensuring that liquidity efficiency is maximised and excess liquidity can be reallocated. The compression of settlement cycles could also result in new liquidity management strategies, as banks can leverage LSM to achieve better liquidity and flexibility in trade settlement and execution.

Figure 18: DvP coupled with LSM



Round-the-clock operations

Building a solution design on DLT for interledger operability illustrates the potential of compressing the post-trade settlement process to T+1 or potentially even round-the-clock, real-time settlement. This can be further explored for cross-border transactions where time-zone differences could result in a delay in settlement times, thereby exposing participants to unnecessary foreign exchange rate fluctuations and principal risks.

Before such an endeavour can be pursued, however, there may be potential business and regulatory issues that need to be addressed in the current process:

- Foreign exchange rates for non-SGD transactions after trading hours for non-DLT participants
- Pricing for transaction and handling fees by financial intermediaries involved in transaction processing
- Varying degrees of stringency in regulatory requirements for cross-border transfers
- Operational service level agreements between domestic banks and correspondent banks
- Operating hours and cut-off times for different banks

Merging of trading and settlement processes

The conventional models of trade order execution and post-trade settlement have been distinctly separate processes, and an array of specific functionalities built for the purpose of counterparty matching or settlement have created a void of inefficiencies. By showing that smart contracts can be used as a tool for rulebook integration, Project Ubin (DvP) has highlighted the possibility to converge these processes through the application of a specific DLT solution design that utilises contract locks within multiple ledgers for cash and securities to safeguard investors' interests during and post-trade.

Specifically, smart contracts for the transaction are created during the trade execution phase to ensure that both participants possess the necessary assets required to proceed with settlement. This would ensure that participants are able to settle the obligations of the trades that are executed.

Broadening of suitable asset classes and markets

Project Ubin (DvP) identified the use case of government securities, but the underlying blockchain technology could have many other implied use cases for other asset classes, such as securities, corporate bonds, commodities, and derivative products. The current market setup has distinctly different clearing houses for specific asset classes. For example, the Singapore Exchange Derivatives Clearing (SGX-DC) is responsible for clearing derivatives, while the Central Depository acts as a clearing house for equities and fixed income. This distinction arose from the different underlying risks associated with the different asset classes.

Another area where DLT could become potentially revolutionary is derivatives, which has a broad supply chain network. DLT would enable all transaction information to be stored and traceable through the transaction history in ledgers. Essential information, such as product definition, transit location, and price, can be captured and stored, a feature that is essential not only in derivatives, but also in any maritime trade-intensive goods.

Alternatively, being able to tokenise assets and give them a digital identity would enable illiquid assets (such as real estate and art pieces) to be traded outside of conventional means. Interledger operability could potentially also open up opportunities for cross-border trade settlement on DLT. With DLT, additional asset classes can be traded unconventionally, and more markets can be connected using DLT, with the result being greater liquidity and more investment opportunities for the global investor community. Ultimately, DLT would be able to empower new business models for the financial services industry, while revamping existing primary and secondary market structures.

Appendix

Figure 19: Rights and obligations model in DvP-on-DLT for securities in Project Ubin (DvP)

Who can?	Exercise what rights?	On which obligations?
SGS Market Committee (MAS for SGS and SGX for other securities)	Arbitrate DvP securities transfer (to buyer)	Sell-side DvP Tx1 to transfer securities (from seller)
	Arbitrate DvP securities recovery (to buyer)	Sell-side DvP Tx2 to transfer securities (from seller)
Central bank (MAS for central bank-issued cash-depository receipts)	Arbitrate DvP cash transfer (to seller)	Buy-side DvP Tx3 to transfer cash (from buyer)
	Arbitrate DvP cash recovery (to seller)	Buy-side DvP Tx4 to transfer cash (from buyer)
Participant A (seller)	DvP transfer securities (to buyer)	Sell-side DvP Tx1 to transfer securities (from seller)
	DvP recover securities (to buyer)	Sell-side DvP Tx2 to transfer securities (from seller)
	DvP transfer cash (to seller)	Buy-side DvP Tx3 to transfer cash (from buyer)
Participant B (buyer)	DvP transfer securities (to buyer)	Sell-side DvP Tx1 to transfer securities (from seller)
	DvP transfer cash (to seller)	Buy-side DvP Tx3 to transfer cash (from buyer)
	DvP recover cash (to seller)	Buy-side DvP Tx4 to transfer cash (from buyer)
Participant A (seller)	Sale/when issue (to buyer)	Issue of sale/when issue (from seller)
	Cancel sale/when issue (to buyer)	
	Transfer free of payment (to transferee)	Borrow/lend/transfer of securities (from transferor)
Participant B (buyer)	Reject or confirm sale/when issue (to buyer)	Issue of sale/when issue (from seller)
	Cancel sale/when issue (to buyer)	

Note: Contracts shaded in grey are out of scope and beyond the purpose of DvP settlement. For example, the confirmation of deals can be carried out on the trading platform.

Figure 20: Rights and obligations model in Phase 1 and 2 of Project Ubin
This table summarises Project Ubin models[48] for central bank-issued cash-depository receipts with MAS. At this juncture, the scope excludes DvP for domestic securities settlement and PvP for cross-border transfers, for example, with another central bank in a different currency.

Who can?	Exercise what rights?	On which obligations?
Financial institutions (FIs), including CDP, SGX Derivatives Clearing Limited, and banks	Pledge cash	FI's own cash
	Transfer cash	(Sender) FI's own cash (Receiver) Other FI's cash
	Reprioritise queued cash transfer	(Sender) FI's queued cash transfer
	Settle queued cash transfer	(Receiver) Other FI's queued cash transfer
	Defer queued cash transfer	
	Cancel queued cash transfer	
	Propose netting plan on queued cash transfers	FI's nettable queued cash transfers Other FI's nettable queued cash transfers (Sender) FI's own cash (Receiver) Other FI's cash
	Participate in proposed netting plan on queued cash transfers	
	Settle proposed netting plan on queued cash transfers	
	Redeem cash	FI's own cash
Central bank, such as MAS	Reject/approve cash pledge	FI's cash pledge FI's own cash
	Reject/approve cash redemption	FI's cash redemption FI's own cash

48 Refer to MAS Project Ubin Phase 1 and Phase 2 reports, including Open Source, for more information. [http://www.mas.gov.sg/Singapore-Financial-Centre/Smart-Financial-Centre/Project-Ubin.aspx]

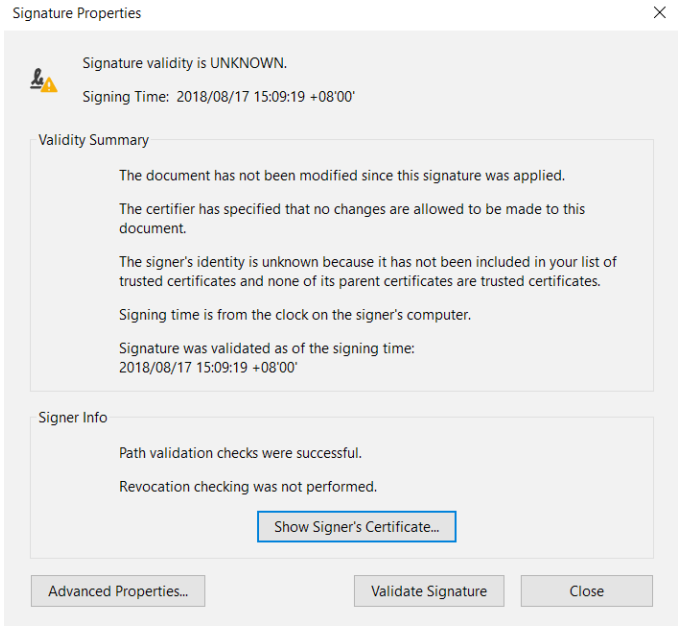
Figure 21: Template of electronic password mailer

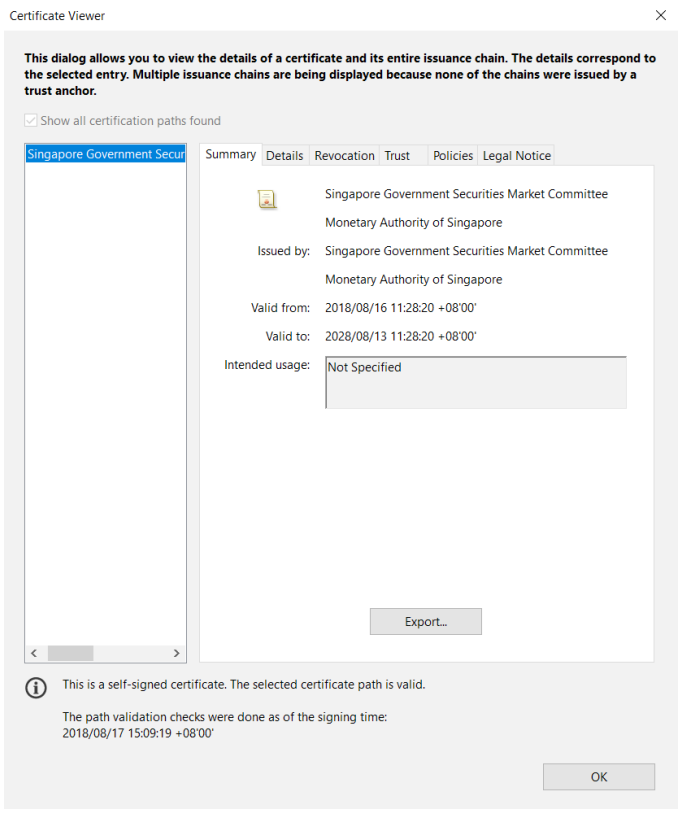
This figure illustrates a template of the electronic password mailer containing the transaction password required to hash-lock the DvP proposal on both sides: seller-side DvP to unlock buyer's cash, and buyer-side DvP to unlock seller's securities.

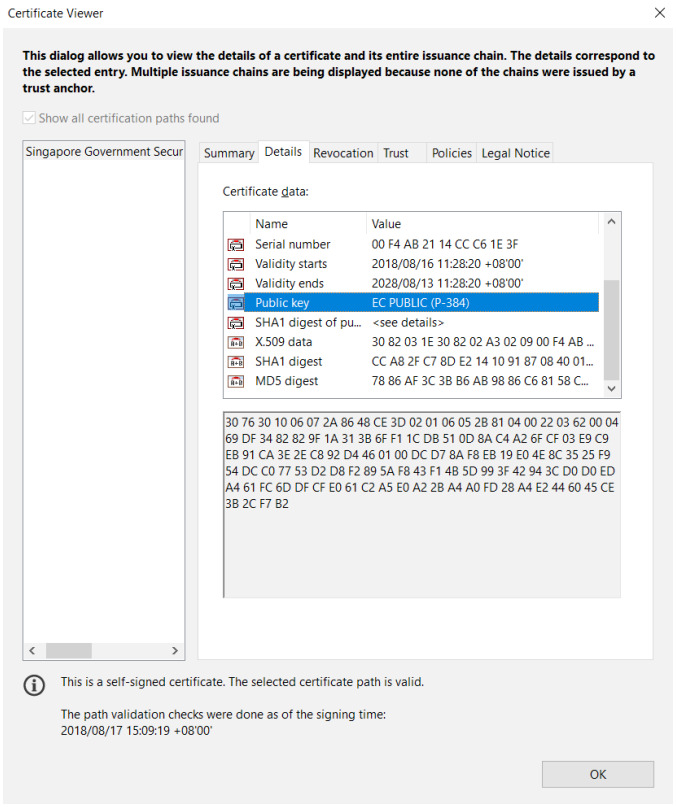
Line#	Field Name	Column	Length	Field Description
3	DateTime	15 to 36	21	Format in DD-MON-YYYY, HH24:MI:SS
5	LegalName	5 to 55	50	Investor's Legal Name
7	AddressLn1	5 to 55	50	Investor's Address Line 1
8	AddressLn2	5 to 55	50	Investor's Address Line 2
9	AddressLn3	5 to 55	50	Investor's Address Line 3
16	TransactionRef	5 to 91	86	Transaction Hash (e.g., SHA512bit) in Base64 Encoding
25	ArbitratorSig	45 to 55	10	Arbitrator's Signature (e.g., Elliptic-Curve over a 384bit prime field with SHA256bit)
25	PasswordImage	70 to 80	10	Password Image (e.g., case-sensitive, alpha-numeric)
25	PasswordQRCode	85 to 90	5	Password Quick Response Code (QRCode)

Figure 22: Secure PDF signature validation

To prevent forgery and strengthen investor protection, investors are able to validate the digital signature of the arbitrator's public key. Digital signatures are also a cornerstone of Singapore's Smart Nation vision, where it is referred to as the National Digital Identity.







DvP model by Anquan Capital

Figure 23: Settlement process flow

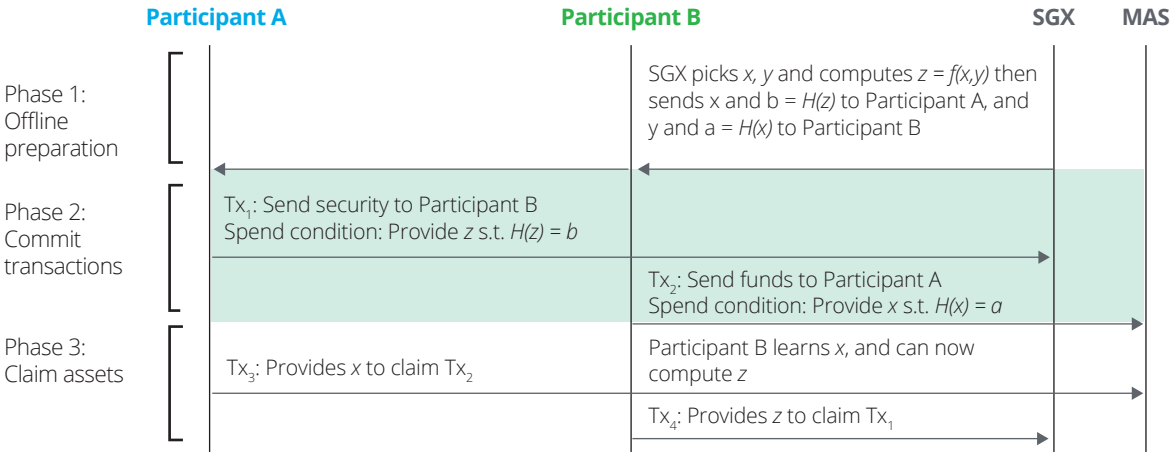
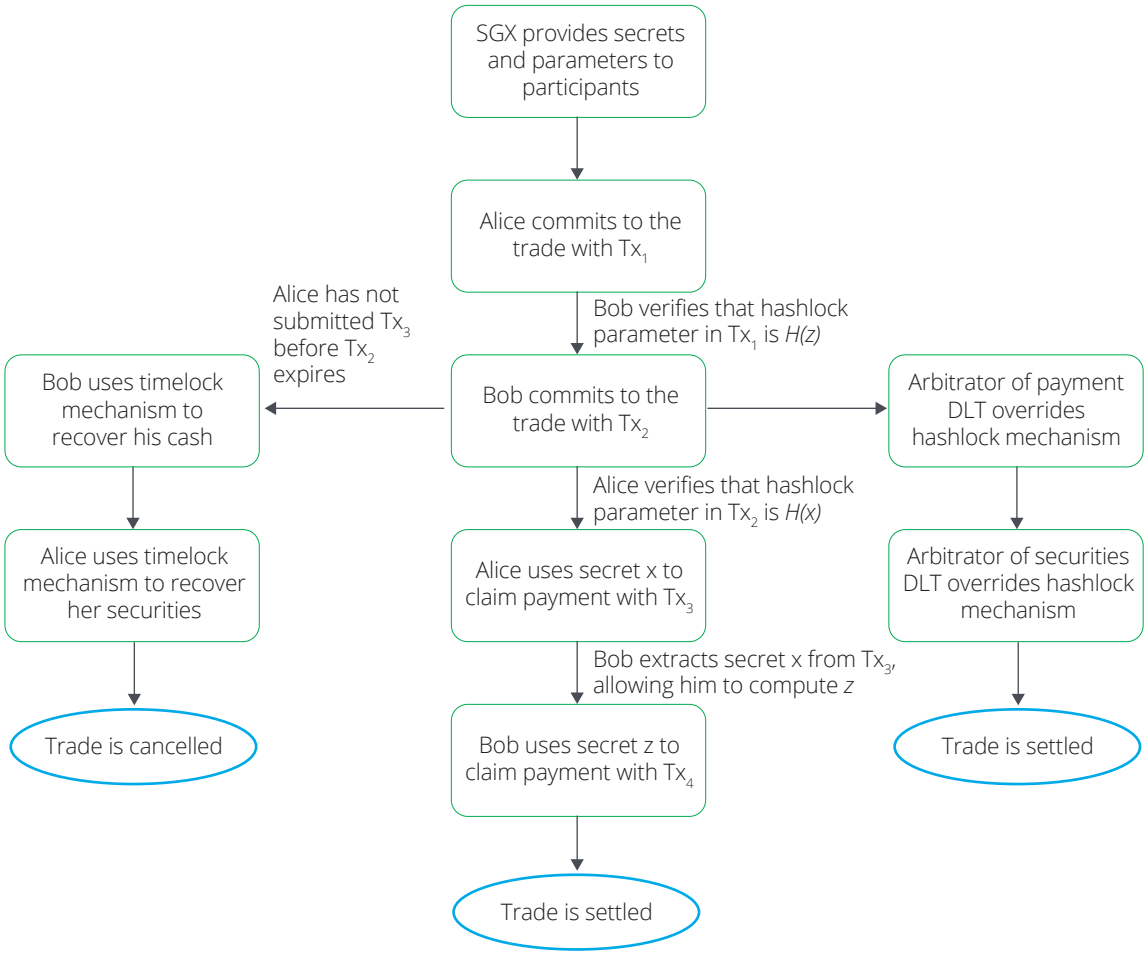


Figure 24: Detailed settlement process flow



DvP model by Nasdaq

Settlement process flow

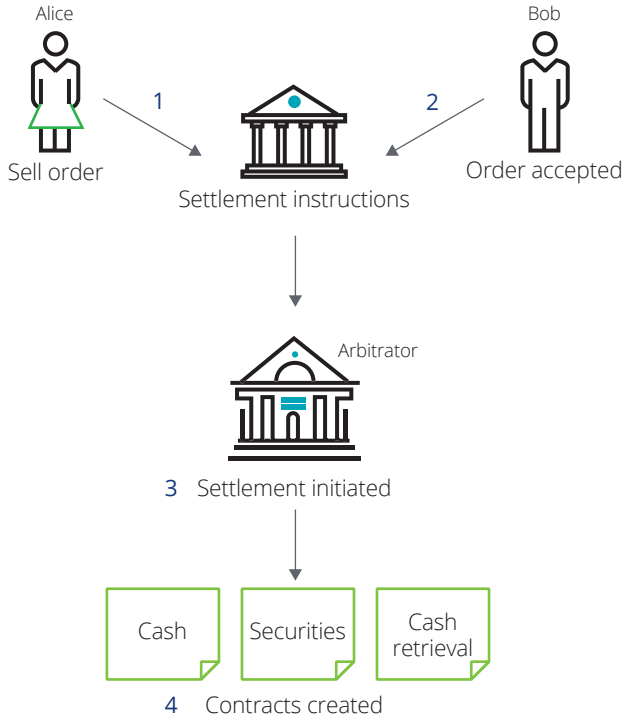
The settlement process flow was designed with the following parameters:

- Traders are anonymous.
- Short-selling of securities is allowed.
- The seller of the securities defines the time boundaries that would apply for the settlement of trade (when cash and securities shall be delivered). The buyer confirms the conditions when it is accepting the order.
- The cash contract is discharged first. That is, the cash transaction is performed first in the settlement execution process.
- Settlement failures are handled through arbitration. The arbitrator has the authority to retrieve the cash from related accounts to achieve settlement.

The following series of activities are performed:

1. Alice places sell order, and defines the time boundaries that would apply for settlement.
2. Bob accepts the order.
3. The arbitrator initiates the settlement process.
4. The contract engine creates three contracts:
   - Cash contract: First contract to secure the delivery of cash to the seller
   - Securities contract: Second contract to secure the delivery of securities to the buyer
   - Cash retrieval contract: Third contract to retrieve cash if the seller is short on securities

Figure 25: Settlement process flow



DvP model by Deloitte

Figure 26: DvP process in which buyer and seller successfully swap tokenised assets

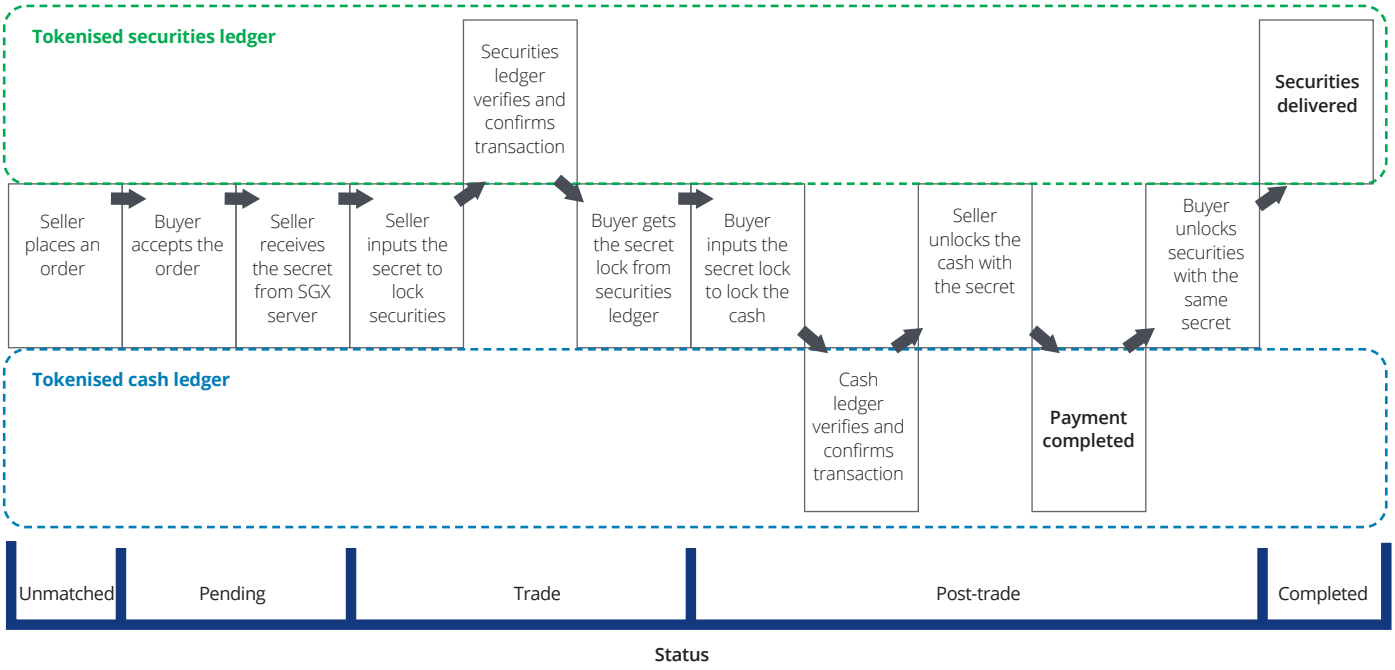
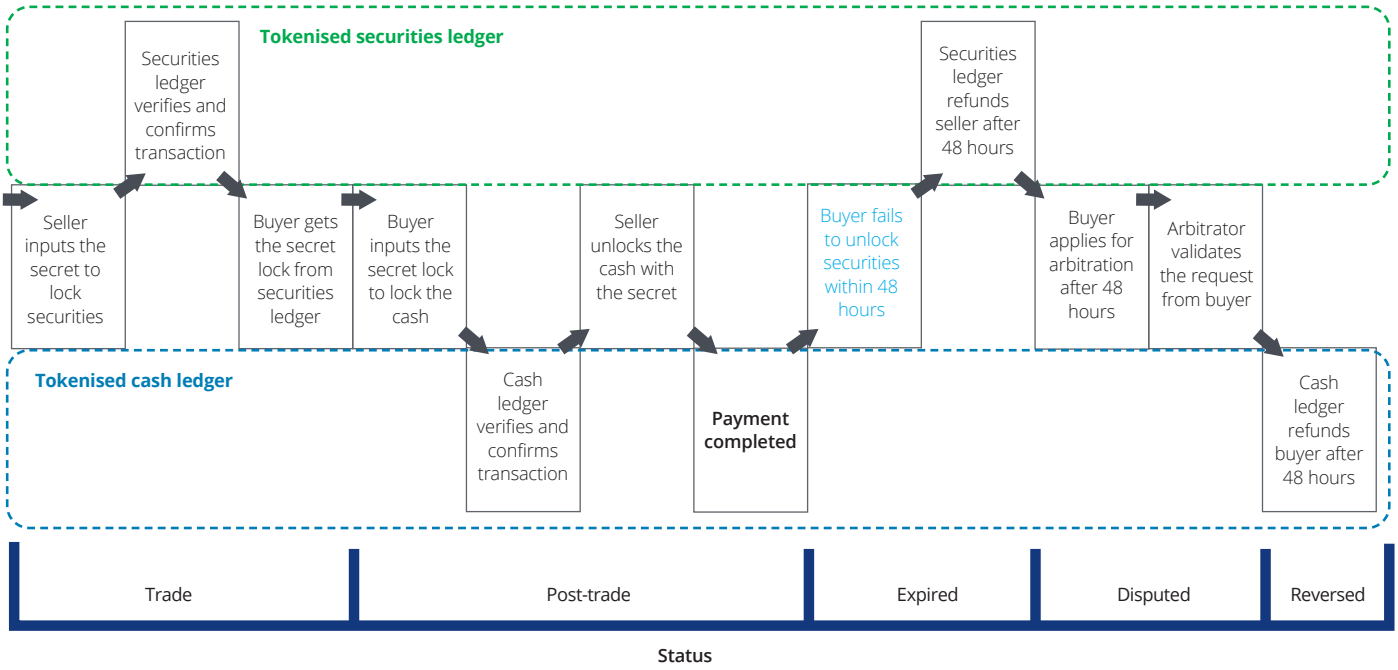


Figure 27: DvP process in which buyer and seller recover tokenised assets with arbitration



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