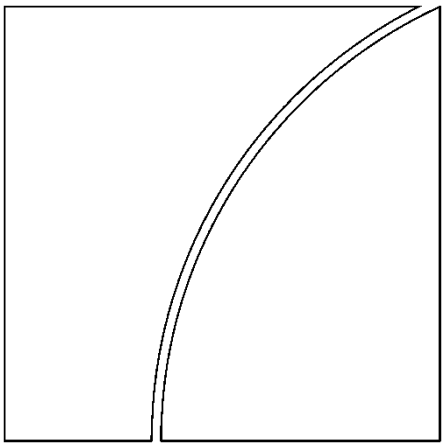
BIS Consultative Group on Innovation and the Digital Economy (CGIDE)



Report

High-level technical requirements for a functional central bank digital currency (CBDC) architecture

December 2023

BIS Representative Office for the Americas

This publication is available on the BIS website (www.bis.org).

ISBN 978-92-9259-726-9

Table of contents

Foreword

Central bank digital currencies (CBDCs) are digital payment instruments issued by central banks. They entail a new public infrastructure that offers many different technical options and functionalities. As each central bank explores the features that are most relevant for the policy goals of their own jurisdiction, it can be very helpful to share experiences with peer institutions. This may be particularly relevant in the light of future interoperability between CBDCs. In this context, this report introduces a series of high-level technical requirements for a retail CBDC proof of concept agreed by the BIS Consultative Group on Innovation and the Digital Economy (CGIDE). These requirements may serve as a basis to develop functional CBDC solutions, potentially working as a reference for member central banks in the Americas and around the world.

The CGIDE was launched in February 2020 to meet the demand for greater cooperation in technological innovation and the digital economy by BIS member central banks in the Americas. It reports to the Consultative Council for the Americas (CCA), which brings together the central bank Governors of Argentina, Brazil, Canada, Chile, Colombia, Mexico, Peru and the United States. This group provides a forum where senior central bank officials can cooperate towards the following objectives:

a. Analysing and developing public technological infrastructures geared towards tackling common shortcomings in all participating jurisdictions.

b. Promoting an environment suitable to open banking, potentially through the development of key application programming interfaces (APIs).

c. Analysing the implications of these public technological infrastructures in terms of market structure and regulatory implications.

This report was prepared by a technical task force of central bank experts who participate in the CGIDE. Its main purpose is to open a conversation around technical considerations in the designing of a CBDC. The report seeks feedback from central banks and the public on the high-level requirements for a functional proof of concept for a retail CBDC architecture, proposed by the CGIDE. It also aims to serve as a useful general reference for central banks conducting research on CBDC or seeking to develop their own CBDC initiatives. Comments are welcome and should be addressed to CGIDEreport@bis.org.

Othón Moreno	Renato Dias de Brito Gomes	Alexandre Tombini
Chair of the Technical Task Force	Chair of the CGIDE	Chief Representative for the Americas
Bank of Mexico	Central Bank of Brazil	Bank for International Settlements

Executive summary

Central bank digital currencies (CBDCs) are digital payment instruments issued by central banks with the potential to revolutionise the financial landscape. CBDCs could offer a range of benefits to both individuals and businesses and the whole economy. By leveraging advancements in technology, CBDCs can enhance payment efficiency, promote financial inclusion, increase security while preserving privacy, and enable new financial functions, for instance with asset tokenisation and trading. Central banks worldwide are actively exploring CBDCs, considering various design options and technological features. This report outlines high-level technical requirements for a retail CBDC architecture, covering modular design, core functions, operational and cyber resilience requirements and third-party services. The report aims to contribute to the research and exploration of CBDCs, and does not represent a policy position from CGIDE members and observers or their central banks on CBDC design, issuance or adoption. The technical requirements outlined here constitute the foundation for the CBDC architecture to be proposed by the CGIDE and are not intended as technical standards for CBDCs more generally.

The Consultative Group on Innovation and the Digital Economy (CGIDE) launched a technical task force (TTF) in May 2022 to create a proposal for a retail CBDC architecture, guided by high-level technical requirements endorsed by CGIDE members. The TTF aims to deliver three outputs: (i) a definition of high-level technical requirements to identify core functionality and necessary elements; (ii) a business-level flow diagram for the core functionality; and (iii) a technical-level flow diagram with infrastructure components for CBDC implementation. This report is part of deliverable (i). It is the culmination of a series of discussions among TTF members on CBDC objectives, policy considerations and technological features. The CGIDE TTF also participated in webinars and workshops to further explore the development and implementation of CBDCs.

Based on these discussions and previous work by the BIS, CGIDE members focused on three policy goals that can be supported by CBDCs. First, CBDCs can promote financial inclusion by offering alternative digital payment methods and providing access to financial instruments and payment services for people without bank accounts or those seeking alternatives to bank accounts and cash. Second, CBDCs can increase efficiency and competition in the financial system by providing a low-cost public infrastructure through which banks, non-bank financial institutions and financial technology firms can offer both payment and other financial services. This can lower entry costs for deposit-taking, credit or insurance activities. Third, CBDCs can promote interoperability, reaching a broader audience and interconnecting with existing payment services. However, policy concerns related to the potential impact on financial institutions and the need to preserve privacy in financial transactions still need further discussion.

The CGIDE explored several technological considerations for retail CBDCs. Some technological choices included whether to reuse existing payment systems or build functionality from scratch; account-based versus token-based solutions; centralised settlement versus distributed models; embedded payment-versus-payment (PvP) and delivery-versus-payment (DvP) functionalities; key modules necessary to define a complete CBDC platform; and privacy and data protection. Other key aspects for the design of a CBDC platform included scalability, technological independence and documentation distribution strategies.

The CGIDE TTF organised a series of webinars and workshops to facilitate discussions on the design and implementation of CBDCs. These sessions included presentations from various central banks and organisations, which shared their experiences and initiatives related to CBDCs. The presentations covered a wide range of topics, including projects and prototypes by the BIS Innovation Hub, R3's Corda platform for multi-party workflows, Uruguay's e-peso pilot and Project Hamilton, by the Federal Reserve Bank of Boston and MIT, which all explored the technical feasibility of retail CBDCs. During the CGIDE in-person meeting held in March 2023, members also discussed the experience of the Central Bank of The Bahamas in the adoption of the Sand Dollar. In addition, taskforce members discussed complementary options to enhance payment systems, such as Brazil's fast retail payment system Pix, Mexico's Cobro Digital (CoDi) for instant payments, India's open banking strategy and the United Kingdom's open banking

implementation. The discussions provided valuable insights into different approaches, challenges and opportunities in CBDC implementation and highlighted considerations related to technology, governance, privacy and performance.

The high-level technical requirements for a functional retail CBDC proof of concept, to be developed by the TTF, are grouped into five categories: (i) modular design; (ii) core functions; (iii) operational requirements; (iv) cyber resilience requirements; and (v) requirements related to third-party services. Based on these high-level requirements, the CGIDE TTF will present a proposal for a CBDC architecture. The initial stage of this proposal will focus on technological features concerning clearing and settlement. Regarding the modular design, the TTF prioritises a balance-keeping layer that allows for the creation, custody and destruction of CBDCs, with a fungible approach. Additionally, the design will include the possibility to issue non-fungible tokens (NFTs) for specific use cases. The proposed CBDC architecture will also facilitate seamless integration with existing payment systems and leverage APIs for data exchange and payment initiation. Core functions to be considered include centralised issuance and destruction of CBDCs, as well as payment initiation features facilitated by an API. The operational module emphasises scalability, user experience and the definition of the attribute function matrix. Cyber security is also a top priority, with requirements such as encryption, data confidentiality, technological independence and auditability to protect the integrity and confidentiality of the CBDC architecture. All other requirements, including interoperability, cross-border payment functionalities, risk management and business continuity issues are deemed crucial for a comprehensive CBDC architecture. These requirements will be addressed in the second stage of the project, scheduled for the second quarter of 2024.

Together, these requirements present a challenge for central banks in the design of CBDCs. However, through collaborative efforts, central banks can design architectures that meet these needs and establish a robust foundation for future innovation. The CGIDE will continue to collaborate closely, working towards the design of a CBDC architecture that effectively addresses the technological priorities of CCA central banks.

Introduction

Central bank digital currencies (CBDCs) are digital payment instruments which are denominated in the national unit of account and are a direct liability of the central bank (Group of Central Banks (2020)). They represent a new form of currency that can be used for electronic transactions by financial institutions and/or households and businesses and can be stored and exchanged digitally. Most central banks around the world are exploring CBDCs, and more than half of them are conducting concrete experiments or working on a pilot (Kosse and Mattei (2023)). The motivations behind this lie in CBDCs' potential to support different policy goals. For instance, CBDCs can improve the efficiency of payments, reducing the cost and time of transactions. CBDCs can also increase financial inclusion, making it easier for unbanked and underbanked populations to participate in the financial system. Additionally, CBDCs can offer greater transparency and security, as central banks can determine the degree of anonymity or traceability of transactions. They may also promote interoperability with existing payment instruments and enable new functionalities.

Depending on an economy's specific needs and objectives, central banks have different design options and technological features available in their CBDC exploration. These considerations include the underlying technology used for CBDC implementation, the different layers comprising the core CBDC infrastructure, the degree of anonymity or traceability of transactions, the degree of involvement of the private sector in the CBDC infrastructure and the interoperability of CBDCs with existing payment systems.

In this report, the CGIDE TTF presents a series of high-level technical requirements for a retail CBDC architecture that it will develop in the next stage. These high-level requirements are classified into five categories: (i) modular design with a layered infrastructure; (ii) core functions; (iii) operational requirements; (iv) cyber resilience requirements; and (v) other requirements related to services provided by third parties. The report also provides background on the work undertaken by CGIDE TTF to date and the steps forward.

As in previous reports of the CGIDE, the work of the CGIDE TTF on CBDCs aims to serve as a general reference for individual countries conducting research on CBDCs or planning to implement a CBDC solution. The output of the CGIDE TTF would not imply a policy position from any CGIDE member or observer or their respective central banks.

This report presents two sections. Section 1 describes the background work conducted by the CGIDE TTF to identify the technical requirements that the CBDC proof of concept will include. This section contains a summary of the CGIDE discussions on CBDC policy objectives and implications and technological considerations, as well as some experiences with CBDC issuance and adoption. Finally, Section 2 presents the proposed high-level technical requirements for a CBDC architecture.

1 Background

The CGIDE TTF was created in May 2022 to design a proof of concept for a retail CBDC architecture, based on the high-level requirements validated by CGIDE members. The objective of this exercise is to contribute to the discussion and the CBDC research initiatives at each CCA central bank. The proposed architecture aims to serve as a reference and does not constitute an official position from CGIDE members or observers or their central banks with respect to the design, launch or adoption of CBDCs. The TTF will produce three outputs: (i) a prioritisation of the requirements to identify core functionality and the necessary auxiliary elements to support it; (ii) a business-level flow diagram for the core functionality; and (iii) a technical-level flow diagram of the core functionality with pieces of infrastructure required for the implementation of the CBDC (eg hardware, software modules). The prioritisation of the requirements was presented by the TTF to the CGIDE during the meetings held in September and October 2022. This report presents the high-

level requirements for the definition of a retail CBDC architecture. Based on these requirements, the CGIDE TTF will work on deliverables (ii) and (iii).

Prior to defining the high-level requirements, CGIDE members exchanged views on the objectives and policy considerations of CBDCs, and technological features of CBDC design in their jurisdiction. The CGIDE TTF also participated in several webinars and workshops to deepen discussion on the development and implementation of CBDCs. These discussions served to share knowledge and contributed to a common understanding of many key concepts that will be discussed in greater depth.

1.1 CBDC policy objectives and considerations

CGIDE members agreed on three main policy goals that can be supported by CBDCs and on which the TTF focused.[1] First, CBDCs could **foster financial inclusion**, by providing an alternative means of digital payments. CBDCs have the potential to bridge the unbanked and underbanked population and the financial system. They could broaden access to financial instruments and payment services for people without bank accounts or who are seeking alternatives to bank accounts and cash. By extending the functionalities of CBDCs, they could also be used to support financial services (beyond payments) that are tailored to the needs of the population.

Second, CBDCs could **increase efficiency and competition** in the financial system. They could provide a low-cost public infrastructure through which banks, non-bank financial institutions and financial technology firms could offer both payment and other financial services. For example, entry costs related to deposit-taking, credit or insurance activities could be lowered, as new financial service providers compete on a level playing field with incumbent institutions.

Third, CBDCs could **promote interoperability.** Depending on their technological features, CBDCs could reach a broader audience and interoperate with existing payment services. Interoperability would be necessary to ensure that people with and without CBDC holdings could interact with each other.

As a new payment infrastructure, CBDCs offer many options to support these policy goals. Countries are at different starting points. Some are more advanced in retail fast payment systems or the adoption of digital payments, while others are at an earlier stage. Still, the consensus in the CGIDE is that a CBDC would be a complement to existing payment rails.

The success of CBDCs in supporting these policy goals will depend on their wide adoption. One measure of success could be the degree of adoption by the population, and how much it changes the financial and payments ecosystem. Other indicators of success could be the impact on access to transaction accounts or to financial services beyond payments, payment costs in the economy, the degree of competition and whether a CBDC enables more interoperable financial services and responsible innovation.

Among the policy concerns related to the introduction of a CBDC are how it would interact with financial institutions and how it would affect privacy in financial transactions. First, a CBDC could potentially affect financial institutions by displacing deposits (disintermediation). If CBDCs were intermediated by financial firms, and if they did not pay interest, this could be less disruptive. Financial firms would still be the main providers of credit and savings services and could lead in the distribution of the CBDC. Second, user privacy is a crucial consideration for all payment instruments, including CBDCs. In this light, a CBDC should preserve or enhance the current level of privacy in financial transactions. A CBDC should be designed with firm technological and institutional safeguards on data privacy.[2]

[1] These policy goals are broadly applicable in countries around the world, but they apply particularly in the Americas. See Auer et al (2020), Auer et al (2021) and Kosse and Mattei (2022) for a discussion of the motivations, approaches and economic implications behind CBDCs.

[2] This can be promoted through both technological design and institutional frameworks. See Uhlig et al (2023).

1.2 Considerations for the technological design of CBDCs

The CGIDE discussed the technological features of CBDCs based on the previous policy objectives and considerations. The insights from these discussions contributed to defining the high-level requirements. Some of the technological considerations included:

– *Reusing functionality from existing payment systems vs building functionality from scratch*. On one hand, reusing existing technologies could speed up the time required to develop a complete CBDC solution. For instance, real-time gross settlement (RTGS) systems run by the central bank could be part of a CBDC's settlement layer, or credit notifications previously implemented on an RTGS could be the initial implementation for a token or account-based layer. Some of the drawbacks of this option include the generation of a single point of failure, the limitations of some systems in terms of availability, and scalability. Additionally, there are concerns related to the operation of payment systems by the private sector. On the other hand, a CBDC system could be developed with full functionality from scratch in such a way that it can interconnect with the existing system. The advantages of this option include resilience of the ecosystem, flexibility in terms of technological capabilities and no legacy infrastructure. However, producing a new system takes longer to implement and requires additional investment. These two views could be accommodated by designing a **modular architecture** that considers the functions of a payment system as exogenous. This would mean that it can support a pre-existing settlement mechanism or a newly developed one. This consideration also applies to the end user layer where central banks will have to make design choices related to the development of new devices or apps for CBDC, or the use of existing apps and payment devices with CBDC capabilities embedded in them.

– *Account-based vs token-based solution*. This concerns whether validation is based on the identity of an individual (account-based) or on the veracity of the instrument (token-based). While the former has clear advantages in some cases,[3] the CGIDE considers that a **token-based approach** could be desirable for peer-to-peer transactions. While programmability features can be achieved with both approaches, a token-based solution could offer a more extensive and flexible programmable infrastructure and facilitate the use of smart contracts. There may be solutions that allow for the benefits of digital tokens (and tokenisation) while preserving sound identification.[4]

– *Centralised settlement vs distributed permisionless model*. The CGIDE members agree on the difficulties associated with decentralised permissionless models. For example, these models require a consensus mechanism to validate transactions. However, due to their distributed nature, there is the risk that participants involved in the network could collude to manipulate the system. In the absence of sufficient oversight, governance mechanisms or regulatory control, this could result in negative outcomes. For this reason, distributed permissionless models also require the definition of the incentive structure (technological, monetary or regulatory) to discourage collusion among participants, and a notary layer able to ban participants.

  In turn, centralised or permissioned ledger models require the definition of redundancies, resilience and business continuity requirements that would reduce the risks from a single point of failure. These models have the potential to host an open finance layer built on top of the transaction layer, allowing financial service providers to offer last-mile payment services to final users.

[3] See BIS (2021a) for a discussion of the advantages of account-based CBDC variants, which include combating illicit activity and the possibility of establishing interest rate tiering and caps on holdings in the CBDC design.

[4] Digital tokens are units of value that exist in digital form on a blockchain or distributed ledger. They are the representation of an asset and can be created, issued and transferred electronically. Tokenisation refers to the process of recording claims on financial assets that exist on a traditional ledger onto a programmable platform. See Aldasoro et al (2023).

Relative to distributed permissionless models, centralised or permissioned ledger models offer some advantages. Firstly, they allow for a higher level of control that can be maintained by the central bank. They also enable the enforcement of strict anti-money laundering (AML) and know your customer (KYC) requirements. As financial institutions should adopt and comply with AML and KYC regulations, the design of a CBDC needs to facilitate adherence to these rules. Considering these trade-offs, the CGIDE agreed on a **flexible approach that envisages solutions alternative to a fully centralised model**, with the possibility to design permissioned ledgers that exhibit some decentralisation. This approach aims to strike a balance between centralised control and broader access to specific institutions.

– *Embedded payment-versus-payment (PvP) and delivery-versus-payment (DvP) functionalities*. The integration of PvP and DvP functionalities offers a seamless settlement process that ensures both counterparties fulfil their obligations simultaneously. This can be achieved through a choice between a distributed approach or a centralised platform. In a centralised model, a platform overseen by the central bank could employ an algorithm to match bid with ask positions to form prices. Such an algorithm could be designed to optimise the central bank's objectives, such as maximising matched positions to enhance liquidity. Alternatively, the distributed approach enables individual positions to search the network for the "best" opposite position. In this setup, each participant's algorithm seeks the "best" match, allowing for efficient contracts to facilitate transaction settlement. This programmable environment enables various search mechanisms to drive price discovery.

  In this context, authorities may pursue several policy objectives to ensure financial stability, market integrity and efficiency. PvP and DvP functionalities could benefit from centralised consensus mechanisms, owing to more control and oversight from the central bank. However, incorporating PvP and DvP functionalities in a decentralised CBDC structure could allow varous participants, including fintech and financial institutions, to contribute to the ecosystem. In addition, APIs could facilitate the creation of new financial products and services built on top of the core CBDC architecture. The choice between centralised and decentralised PvP and DvP functionalities would depend on the central bank's objectives and the desired level of private sector participation. The preferred approach is to design **a core platform for contract settlement and funds transfers, with the potential to enable both the private sector and the central bank to build modular functionalities on top of it**. The design can also take into account asset programmability and straight through processing principles.

– *Issuance of fungible vs non-fungible tokens:* CBDCs could be designed and distributed as fungible or non-fungible tokens (NFTs). Fungible tokens are used to represent identical assets such as a unity of currency, which can be exchanged at par value, due to its interchangeable nature. NFTs can be used to represent and track assets that are individually unique (Lee et al (2020)). Unlike fungible tokens, NFTs are whole and indivisible units with unique characteristics, which cannot be exchanged on a one-to-one basis. While fungible tokens simplify transaction processing and clearing, NFTs involve more complex technical and operational considerations for central banks. However, NFTs hold a distinct advantage for some central banks due to their capability to individually identify and track each unit, providing ownership information and origin traceability. In this context, the CGIDE embraced a **fungible approach that leaves open the possibility to incorporate NFTs for specific use cases.**

– *Key modules necessary to define a complete CBDC platform.* A CBDC design involves several modules that work together to ensure the functionality, security and efficiency of the whole infrastructure (Group of Central Banks (2021)). The modules depend on the specific attributes and characteristics of the platform. A CBDC design could include several modules: (i) issuance and distribution, which involves determining the allocation mechanisms (ie account-based or token-based distribution) and the rules for issuing CBDCs; (ii) identity verification and authentication mechanisms (which may be the remit of private sector payment service providers); (iii) transaction

processing, clearing and settlement mechanisms; (iv) interoperability and integration; (v) privacy and security; and (vi) governance aspects related to oversight, business continuity and risk management capabilities to detect issues such as doublespending or counterfeiting.. The specific design choices may vary depending on the objectives, priorities and policy considerations of the issuing central bank.

– *Key technological aspects for the appropriate evolution of a CBDC platform*. The proposed key technological aspects were **scalability, technological independence, new releases and documentation distribution (semi- or even fully automatically generated) strategies**. For technological independence, the key aspect would be to clearly set each of the modules' inputs and outputs in order to integrate new technologies or functionalities into specific modules. This would prevent requiring a complete overhaul of the entire system to reduce cohesion between layers (eg by using APIs). In that way, the module's technology could take any shape and could be adjusted or modified. The setup would also align with the requirements of the distributed platform.

– *Privacy and data protection*. Privacy is a crucial consideration for all payment instruments, including CBDCs. In this light, the proposed CBDC design will guarantee adherence to privacy and data protection principles. This is essential to ensure user trust in the CBDC system. Central banks may wish to minimise the data to which they have access, including information on individuals' identity, so as to avoid being the target of cyber attacks or political pressures. The design could consider different technological options to safeguard privacy and minimise personal data exposure, such as aggregate data analysis, encrypted data processing and data minimisation.[5] Institutional and technological safeguards to prevent access to personal data would avoid both the risks and the perception by the public that their data could be misused.

1.3 Experiences with CBDC design and adoption

The CGIDE TTF organised different webinars and workshops to foster discussions among TTF members on CBDC design and implementation, based on other central banks' experiences. In addition, during the March 2023 CGIDE in-person meeting members also had the opportunity to learn from experiences with the adoption of CBDCs, eg in the Bahamas.

– **Innovation Hub Heads:** The Heads of the BIS Innovation Hub Centres in Hong Kong SAR, Switzerland and Singapore presented different initiatives to contribute to the CBDC discussion. These initiatives include applied technology research, proofs of concept and prototypes with central banks around the world.

  The Hong Kong Centre is leading Project Aurum jointly with the Hong Kong Monetary Authority. The project delivered a retail CBDC prototype and technology stack comprising a wholesale interbank system and a retail e-wallet system. Project mBridge is a joint initiative between the Hong Kong Monetary Authority, the Bank of Thailand, the Digital Currency Institute of the People's Bank of China and the Central Bank of the United Arab Emirates to enable cross-border PvP using a common multi-CBDC platform.

  The Switzerland Centre presented the scope of Projects Jura and Helvetia. Project Jura involved settlement of cross-border and cross-currency transactions in wholesale CBDC (wCBDC) on a single multilateral platform. Project Helvetia involved the integration of wCBDC in core banking systems. It also explored the settlement of interbank, cross-border and monetary policy transactions (eg open market operations and standing facilities) on a tokenised asset platform. In the last case, the experiment involved the central bank issuing (redeeming) wCBDC linked with a

[5] See Bank of England (2023) for a discussion of privacy-enhancing technologies.

DvP settlement of a tokenised asset purchase (sale). As a result, the central bank balance sheet expanded (shrank).

The Singapore Centre presented the roadmap and milestones of Project Dunbar. This project explores multi-CBDCs as a common platform for international settlements. Its goal is to design interoperable CBDCs and m-CBDC platforms that would enable faster, cheaper, safer cross-border payments and enable new commercial use cases.

– **e-peso pilot:** The Central Bank of Uruguay (CBU) shared its experience with the e-Peso pilot and the lessons learned after the launch. The CBU representative highlighted seven lessons from the pilot: (i) reputational risk is key in the discussion on central banks' corporate governance around CBDCs; (ii) motivations behind the adoption of CBDCs determine authorities' strategy to promote their adoption; (iii) the technological solution must stay as simple as possible to keep operational and cyber risks controlled; (iv) security aspects and traceable transfers are central for operational risks problems; (v) a token solution is a good option for CBDC implementation; (vi) digital money was used mostly for small payments and transfers; and (vii) CBDCs complement the existing means of payment.

– **Project Hamilton:** The Federal Reserve Bank of Boston presented the architecture design and main features of Project Hamilton. This research project explores the CBDC design space to understand CBDC's technical challenges and opportunities. The project uses a collaborative open source design to help explore the technical feasibility of CBDCs. The project's first phase focused primarily on designing a modular and extensible transaction processing system, implemented in two different architectures (the first used an ordering server and the second used parallel processing across multiple computers).

  The system was designed to be flexible, scalable and resilient, with the ability to accommodate intermediaries and various data storage models. Both architectures demonstrated robust and efficient performance. The second architecture could potentially process 1.7 million transactions per second with 99% of transactions completing in under a second. The main learnings from the first phase of Project Hamilton are: (i) selected ideas from cryptography, distributed systems and blockchain technology can provide unique and robust performance; (ii) CBDC design choices are more granular than commonly assumed, with complex choices in terms of access, intermediation, institutional roles and data retention; and (iii) CBDC designers and policymakers need to address trade-offs related to performance, auditability, functionality and privacy.[6]

– **Corda:** R3 presented its Corda platform, a distributed application network that allows multi-party workflows without relying on blockchain. Corda uses industry standard, corporate-friendly libraries and technology. R3's CBDC work involves running the largest collaborative CBDC working group, which includes several central banks and BIS projects (Helvetia, Jura and Dunbar). There is also a growing number of CBDC projects utilising Corda, such as the e-krona.

– **Sand Dollar:** The Sand Dollar is the digital representation of the Bahamian dollar, issued by the Central Bank of The Bahamas. It was launched in October 2020 and became the world's first live CBDC. The main motivations for issuing the Sand Dollar were promoting inclusive acccess to regulated payments and other financial services for unbanked and underbanked communities. Additionally, through the introduction of the CBDC the central bank expects to reduce service delivery costs and increase transactional efficiency for financial services. Some of the key features of the Sand Dollar include: (i) interoperability among existing channels for the provision of payment services; (ii) near-instantaneous validation of transactions; (iii) a fully auditable transaction trail, with strong privacy safeguards; and (iv) multi-factor authentication for wallet users. In the Bahamas, users can access Sand Dollars with a digital wallet provided by financial

[6] See Federal Reserve Bank of Boston and MIT Digital Currency Initiative (2022) for further details on the core design and results of Project Hamilton.

institutions, with a mobile app or a card. To reduce the risk of disintermediation, use of the Sand Dollar is restricted to domestic transactions. There are transaction and balance limits for different types of wallets (tiers), and the Sand Dollar does not pay interest. The central bank is currently working on enabling offline functionality and conducting educational campaigns to increase adoption.

Retail CBDCs and fast payment systems (FPS) are two potentially complementary options to achieve various policy goals, such as fostering financial inclusion and digital payment use and enhancing competition in financial and payment systems. Depending on their design, CBDCs can integrate seamlessly with an FPS, leading to faster, more efficient and secure payment transactions. Similarily, the integration of CBDCs and open banking initiatives could serve as a source of synergies for innovation. For these reasons, CGIDE members also dicussed some innitiatives on the adoption of FPS and open banking.

- **Pix:** The Central Bank of Brazil presented the background and structure of Pix, Brazil's fast retail payment system. Pix enables payments in a few seconds with immediate availability of funds to the final beneficiary. Payments and transfers are available for people, businesses and government entities. It is an open environment where a broad range of payment service providers can offer Pix. It operates 24/7 at no cost for people and low cost for businesses. The central bank determines the Pix rulebook and operates the settlement platform.
- **CoDi:** The Bank of Mexico launched CoDi as a request-to-pay functionalitya real-time payment solution over the Mexican Interbank Electronic Payment System (SPEI) rail. CoDi facilitates funds collection by using QR codes and direct messages to mobile devices as a simple way to initiate instant payments. Additionally, CoDi includes a functionality for credit notifications. CoDi is free of charge and has a safe and robust infrastructure. Currently there are more than 12 million validated CoDi accounts.
- **Open banking in India:** The National Payments Corporation of India presented the open banking strategy in India. This strategy comprises two principal aspects. First is the sharing of financial data with non-bank third parties (account information services), through the account aggregator framework. Second is to initiate payments from users' users' bank accounts via third parties of their choosing (payment initiation services), through the real-time payment platform – the Unified Payments Interface (UPI).
- **Open banking in the UK:** Open banking in the UK was initiated by the Competition and Markets Authority in 2017 to increase competition in the provision of retail banking services. The nine largest banks in the UK were obliged to create and pay for an Open Banking Implementation Entity (OBIE) that acts as the governance, system and data architect and standard setter. The OBIE publicises and maintains the open banking standard and follows a process that involves evaluation, consultation and implementation, with the OBIE developing content, running consultations and organising working groups. The standard goes beyond API specifications to include customer experience guidelines and operational guidelines. It is designed to enable a well functioning, successful ecosystem, where there are no barriers to the provision of products and services by third-party providers. The standard covers all online payment accounts and includes the core components such as API specifications, security profiles, customer experience guidelines, operational guidelines and a reference library.

2 High-level technical requirements for a CBDC architecture

As the purpose of the CGIDE TTF was to propose a functional proof of concept for a retail CBDC architecture, Table 1 presents the list of high-level requirements the TTF identified, grouped into five categories: (i) modular design with a layered infrastructure; (ii) core functions; (iii) operational

requirements; (iv) cyber resilience requirements; and (v) other requirements related to services provided by third parties. These categories ensure the CBDC design will have a user-centric approach, primarily focused on meeting the needs, preferences and usability requirements of the end users. The table also identifies those requirements in each category which CGIDE members considered as high-priority in order to start working on the first stage of the design of the CBDC architecture. All other requirements, including interoperability, cross-border payment functionalities, risk management and business continuity issues are deemed crucial for a comprehensive CBDC architecture. These requirements will be addressed in the second stage of the project, scheduled for the second quarter of 2024.

These categories were defined by CGIDE members based on the reviewed experiences and discussions held in the group. A flexible modular framework would accommodate the evolving needs from different jurisdictions in terms of policy, legal, regulatory and governance considerations.[7] In addition, core functions of CBDC designs typically include issuance and redemption, transaction settlement, payment initiation and programmability. The definition of these functions provides a solid foundation for the CBDC system and ensures its clarity, functionality and integrity. On the other hand, common operational aspects are scalability to handle a high volume of transactions efficiently, user-friendly experience, a function matrix that outlines the system's specific features and capabilities and interoperability with existing payment system and financial infrastructures.[8] Cyber resilience features were placed in a separate category given the higher importance of implementing robust security measures to protect the CBDC system's integrity. Finally, an additional category was added for features related to an open architecture that facilitates clear interaction pathways between third parties and the CBDC system.

As a first stage, the work of the CGIDE TTF will primarily focus on programmability features related to clearing and settlement. The selection of technical requirements within each category specifically related to these features was based on a survey conducted among TTF members. Each central bank member chose the technical requirements they deemed as priorities based on their respective policy objectives. On the modular design category, CGIDE members consider as a priority that the balance-keeping layer allow the creation, possession and destruction of CBDCs and that it have a fungible approach with the possibility of issuing NFT for specific use cases. The modular design will also permit building on top of or in parallel to existing payment systems and using APIs for consent and payment initiation, in line with previous CGIDE work on enabling open finance through APIs.[9]

The core functions of the architecture that will be considered for the first stage are related to the centralised issuance and destruction of CBDCs and payment initiation features. In the first case, the central bank would maintain an account within the RTGS system to facilitate the transfer of CBDC units to participant banks and financial institutions. A token-based CBDC design would allow the creation/destruction of a token, whereas an account-based one would increase/reduce the overall balance of the ledger. In the second case, the API would enable authorised parties to send payment instructions, operate and provide services to end users. The API would also enable different systems to communicate, simplifying transition to other providers and enabling access to other financial services. In addition, the process of enrolling users should be seamless, enabling them to access the CBDC system without frictions or barriers.

On the operational module, the features related with scalability, user experience and the attribute function matrix are considered a priority. A scalable architecture allows the system to expand and meet the volume and throughput requirements at low cost (Group of Central Banks (2020)). User experience considerations such as simplicity, accessibility and seamless integration also play a crucial role. The

[7] See BIS Innovation Hub et al (2022).

[8] See Group of Central Banks (2020).

[9] See BIS (2021b) for details regarding the technical issues related with payment initiation using APIs.

function matrix or framework should be controlled by the central bank and should allow distributed consensus on the validity of transactions in a decentralised way.

Cyber security issues are also foundational requirements. Ensuring cyber resilience is essential to protect the integrity, availability and confidentiality of the CBDC architecture. Priority cyber security requirements include encryption, data confidentiality, technological independence within the modules of the architecture and mechanisms to be able to audit specific transactions in the CBDC system if needed (eg due to strong evidence of financial integrity concerns).

As an additional feature of the CBDC architecture, the CGIDE TTF will still consider the technical requirements to enable private tokenised money to complement the CBDC system. Within this context, tokenised deposits could be designed to resemble the functionality of traditional bank deposits within the existing payment system. Including tokenised deposits as a complementary feature of the CBDC system would preserve the integrity of money with automated settlement, foster potential innovation and efficiency improvements in the settlement process, guarantee finality of payments and enhance banks' flexibility to provide credit and liquidity.[10]

CGIDE high-level technical requirements for a CBDC architecture — Table 1

Category	High-level technical requirements	High-priority
Modular design	**Balance-keeping layer**	
	Allows for the creation, possession and destruction of CBDC	**X**
	Allows for flexible approach, issuing fungible tokens (type 1) and non-fungible tokens (type 2) for specific use cases	**X**
	Scalable databases (ledger-keeping infrastructure) to hold resources and on which settlements can be reflected	
	Connectivity between basic type 1 ledger and type 2 tokenisation infrastructure	
	Settlement layer	
	Central banks can use parts of existing payment systems or can create a new platform that works in parallel to the existing system	**X**
	API infrastructure allows for consent and payment initiation	**X**
	Design of API infrastructure considers previous CGIDE work	**X**
	Settlement function is highly scalable in terms of the number of transactions, issuers and recipients	
	API infrastructure allows for information-sharing (balance and transactions)	
	Public wallet through an app that consumes the API architecture described above to serve as a backstop in case other solutions are unavailable	
Core functions	**Issuance/destruction is centralised (only by the central bank)**	
	Issuance could be considered by transferring resources through the RTGS to an account held by the central bank for this purpose	**X**
	The previous step would allow for the creation of a token in the type 2 case or to increase the balance of the ledger for a type 1 solution	**X**
	For adequate destruction, tokens in the possession of the central bank are deleted (type 2) or the overall balance is reduced (type 1) solution	**X**
	The second step would imply the settlement of a transaction from the issuance account to the general account of the central bank	
	Both issuance and destruction could work for type 1 and type 2 solutions	
	Transaction settlement	
	Centralised in first stage (only the central bank's signature can validate transactions after checking ownership and no double spending)	
	Adaptable to allow for more signatures to the ecosystem (validate transactions through distributed consensus of approved signatures)	

[10] See BIS (2023) for further discussion on the potential of tokenisation in the context of a "unified ledger" that captures its full benefits by combining central bank money, tokenised deposits and tokenised assets on a programmable platform.

	Payment initiation / account information services	
	API calls to send requests (both information and payment initiation), provided a secure consent mechanism is used	**X**
	Financial service providers broadly defined should be able to operate and provide services to final users	**X**
	Uses API architecture to simplify value transfer to other providers and enable access to other financial services	**X**
	Payment service providers can access CBDC balances in any wallet (not only the one provided by the central bank), upon compliance with regulatory frameworks and security and data privacy principles.	**X**
	Information-sharing protocols and clear message structures to share transactional, aggregated and general information	
	Secure transactional information treatment	**X**
	Open architecture to exploit information	
	Programmability	
	Straight through processing of clearing and settlement instructions	**X**
	Implementation on a centralised structure	
	Can explore the possibility of a decentralised programmability functionality	
	Programs/systems that take temporary ownership of assets to allow DvP and PvP settlements, with the option of allowing financial intermediaries and qualified entities to potentially hold assets for settlement purposes	
	Conditions or rules to support offline payments are defined	
	Secure enclaves on phones or other secure hardware to develop an offline functionality with the type 2/tokenised layer of the solution	
	Design focused on simplicity for the final user	
	Seamless onboarding of new users or entities onto the CBDC platform that allows for a smooth and efficient registering process	**X**
	System is consistent with projects on cross-border functionality by the BIS Innovation Hub	
Operational	**Scalability (universal access)**	
	Scalable ledger at the different levels of the system keeping infrastructure that can handle many simultaneous transactions	**X**
	Highly scalable settlement infrastructure to fulfil settlement needs within the CBDC record-keeping infrastructure	**X**
	User experience (universal access)	
	Simple onboarding	**X**
	Adaptable to allow for private intermediaries to distribute the CBDC to end users or to enable direct participation of end users with the system (public direct-to-customer access)	**X**
	Ability to enable P2P transactions and operate with private intermediaries	**X**
	Attribute function matrix on certified permissioned institutions	
	Matrix is completely controlled by the central bank	**X**
	Possibility for distributed consensus in the decentralised transaction settlement for the type 2 case	**X**
	Dynamic, so that the central bank can modify functions or add new ones	**X**
	Interoperability with traditional settlement system and other CBDCs	
	Architecture allows platform to have modules to interact with different CBDC implementation protocols	
	Architecture allows platform to have modules to interact with different payment messages (eg domestic, ISO 20022)	
	Seamless transfers between commercial bank money and CBDC, and vice versa	
	CBDC participants in existing payment systems could help in this area	
Cyber resilience	**Embedded from the beginning of the design**	
	100% available, granting flexibility to adapt to variations in the availability of the supporting infrastructure (eg allowing transactions to be processed once the infrastructure is back online)	**X**

	Highest compliance with cyber security standards (eg those of the National Institute of Standards and Technology)	**X**
	Modular protocol for settlement instructions to allow for partial or total encryption with separate keys	**X**
	Allows for separate message fields to keep relevant information encrypted only for those who need to see it	**X**
	Crypto-agile	**X**
	Encryption of databases	**X**
	Separates personal information from transactional information in databases	**X**
	Distinct levels of data confidentiality. Space for additional data uses, subject to users' authorisation or sufficient application of privacy preserving techniques.	**X**
	Geo-redundancy to mitigate the impact of unexpected events	
	Technological independence	
	Technology within the modules is easy to modify, replace or update if the information input and the expected output are not modified	**X**
	Inputs and outputs of each module are defined to ensure that changes in the module's technology would not affect the system (APIs). API endpoints are versioned, with new methods being added as new or overloaded functions	**X**
	Integration	
	Some modules can be outsourced to the private sector, under two conditions: (i) the central bank must have access to the source code and associated artifacts needed to build the executable module; and (ii) there needs to be an alternative solution in the market to the private entity provider	
	Central banks have a perfect view of what is happening within their walls and can intervene and change providers	**X**
Other	**Clear path to provide services by third parties**	
	Clear rules of engagement	
	Open architecture for payment initiation	**X**
	Open architecture for information-sharing	
	Open API architecture	**X**
	Open API architecture allows financial third parties to provide services based on CBDC	

Annex A: Members of the Technical Task Force of the Consultative Group on Innovation and the Digital Economy

Members

Central Bank of Argentina	Mara Misto Macias
	Fabian Pereyra
	Mariano Vázquez
	Silvina Ojeda
Central Bank of Brazil	Fabio Araujo
	Angelo Duarte
Bank of Canada	Scott Hendry
	Alin Dan
Central Bank of Chile	Claudia Sotelo
	Enrique González
	Diego Ballivián
	Francisco Hidalgo
	Álvaro Merino
Central Bank of Colombia	Carlos Arango
	Mauricio Pinzón
	Samuel Gutiérrez
Bank of Mexico	Othón Martino Moreno González
	Ángel Salazar Sotelo
	Daniel Garrido Delgadillo
	Aurelio Martín Reyes Montoya
Central Reserve Bank of Peru	Milton Vega
	Jushua Baldoceda
Central Bank of Uruguay	Adolfo Sarmiento
Board of Governors of the Federal Reserve System	Francesca Carapella
	Peter Lone
	Franklin Ervin
BIS Innovation Hub	Miguel Díaz
Eastern Caribbean Central Bank	Sharmyn Powell

Observers

Bank for International Settlements	Alexandre Tombini
	Jaime Cortina
	Christian Upper
	Fabrizio Zampolli
	Jon Frost
	Tara Rice
	Anneke Kosse
	Carlos Cantú
	Carolina Velásquez (secretary)

References

Aldasoro, I, S Doerr, L Gambacorta, R Garratt and P Koo Wilkens (2023): "The tokenisation continuum", *BIS Bulletin,* no 72, April.

Auer, R, G Cornelli and J Frost (2020): "Rise of the central bank digital currencies: drivers, approaches and technologies", *BIS Working Papers*, no 880, August.

Auer, R, J Frost, L Gambacorta, C Monnet, T Rice and H S Shin (2021): "Central bank digital currencies: motives, economic implications and the research frontier", *BIS Working Papers*, no 976, November.

Bank of England (2023): "The digital pound: technology working paper", February.

BIS (2021a): "CBDCs: an opportunity for the monetary system", *Annual Economic Report 2021,* Chapter III, June.

——— (2021b): *Enabling open finance through APIs: report on payment initiation*, September.

——— (2023): "Blueprint for the future monetary system: improving the old, enabling the new", *Annual Economic Report 2023,* Chapter III, June.

BIS Innovation Hub, Bank of Thailand, Central Bank of the United Arab Emirates, Digital Currency Institute of the People's Bank of China and Hong Kong Monetary Authority (2022): *Project mBridge: Connecting economies through CBDC*, October.

Federal Reserve Bank of Boston and Massachusetts Institute of Technology Digital Currency Initiative (2022): *Project Hamilton phase 1: a high-performance payment processing system designed for central bank digital currencies*, February.

Group of Central Banks (2020): *Central bank digital currencies: foundational principles and core features*, October.

——— (2021): *Central bank digital currencies: system design and interoperability*, September.

Kosse, A and I Mattei (2023): "Making headway – results of the 2022 BIS survey on central bank digital currencies", *BIS Papers*, no 136, July.

Lee, A, B Malone and P Wong (2020): "Tokens and accounts in the context of digital currencies", *FEDS Notes*, December.

Uhlig, H, M Alonso and J Frost (2023): "Digital payments and privacy – escaping the panopticon", *Georgetown Journal of International Affairs*, forthcoming.