Interoperability Analysis for CBWebWeb3

CBWeb3

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Content

Introduction

CBWEB3 is an IDB Lab project that seeks to enable a regional test-network (Test Net) for Latin America and the Caribbean that will allow for the issuance of CBDCs and the tokenization of financial assets, with a focus on cross-regional interoperability between central banks and financial institutions. The Test Net will build upon the technological capabilities and infrastructure of IDB Lab's initiative LACChain[1] and LACNet[2] the Alliance for the Development of the Blockchain Ecosystem in Latin America and the Caribbean, and capitalize on the Korean experience on the topic including Korean entities from the public, private and academic sectors such as the Bank of Korea (BOK), Korea Exchange (KRX), KAIST Network Security and Privacy Lab and Sungkyunkwan University (SKKU).

A core goal of CBWeb3 is to ensure **cross-border interoperability** between central banks and financial institutions in the region. This report provides a technical deep dive into CBDC interoperability, focusing on wholesale use cases (interbank/high-value payments) while acknowledging a future path toward retail. We examine global state-of-the-art interoperability efforts and design patterns, from multi-CBDC platforms to hub-and-spoke models, and assess how these insights inform a **Digital Public Good (DPG[3])** architecture based on Hyperledger Besu[4] for the LAC[5] region.[6]mBridge[7], Dunbar[8], MAS[9]'s Project Ubin[10], Project Icebreaker), regional experiments like Brazil's [11], and an evaluation of Besu's capabilities and limitations for interoperability. We also discuss how emerging frameworks (Hyperledger Cacti, [12] CCIP[13])

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[1] LACChain is a global alliance for the development of the blockchain ecosystem in LAC by IDB Lab.
[2] LACNet is the executing agency that will sign the agreement with the Bank for this project. This executing agency is a non-profit foundation based in Uruguay. LACChain Networks are blockchain networks developed by the LACChain Alliance and orchestrated by LACNet. Under the framework of LACChain, LACNet plays a pivotal role in not only facilitating the institutional consolidation and sustainability of the LACChain operations, but also in harnessing the collective strength of the LACChain Alliance community.
[3] **DPG** – Digital Public Good: open-source technology with broad social benefit, endorsed by the Digital Public Goods Alliance.
[4] **Hyperledger Besu** – An Ethereum-based open-source blockchain client suitable for permissioned (enterprise) networks.
[5] **LAC** – Latin America and the Caribbean.
[6] **Project mBridge** – BIS-led pilot with multiple central banks testing cross-border payments on a unified multi-CBDC ledger.
[7] **Project Dunbar** – BIS Innovation Hub initiative enabling direct CBDC transactions between multiple central banks.
[8] **MAS** – Monetary Authority of Singapore.
[9] **Project Ubin** – MAS project on blockchain for financial infrastructure, culminating in cross-chain payment experimentation.
[10] **Project Icebreaker** – BIS-led project for cross-border retail CBDC payments using a hub-and-spoke model.
[11] **Hyperledger Cacti** – A modular interoperability framework from the Hyperledger Foundation that connects diverse blockchain platforms.

[13] **Chainlink CCIP** – Cross-Chain Interoperability Protocol by Chainlink, enabling decentralized message and token transfers across chains.

can extend Besu, and outline what can be achieved natively versus what requires external components or governance arrangements to scale interoperability across countries.

Case Studies and Examples

To ground the analysis, we first survey prominent CBDC interoperability initiatives worldwide (Benchmark CBDC Table). These case studies illustrate different models and technologies for cross-platform or cross-border CBDC payments, offering insights applicable to the LAC region:

DREX (Brazil)

DREX (the digital real) is Brazil's CBDC pilot, built on Hyperledger Besu in alignment with LACChain's. Launched in 2023, its first phase demonstrated interbank transactions with tokenized assets (e.g., government bonds) on a permissioned blockchain[14]. In 2024 the pilot entered a second phase expanding to use cases like trade finance and real estate transactions via third-party smart contracts. Uniquely, DREX is **exploring cross-border interoperability by integrating with Chainlink's Cross-Chain Interoperability Protocol (CCIP)**. This suggests that the platform could exchange value or messages with other networks using decentralized oracles[15]. The **ultimate vision** is for DREX to replace Brazil's RTGS system (STR) with a "STR 2.0" that supports tokenized deposits and potentially cross-border payments. The Central Bank of Brazil has explicitly highlighted interoperability goals: the DREX platform is being designed for *"interoperability with legacy domestic systems"* and *"integration with systems from other jurisdictions, aiming to enable cross-border payments."*[16] This regional emphasis on connectivity – coupled with the use of Besu – makes DREX a critical reference for LAC CBDC design.

Project mBridge

Project mBridge (Multiple CBDC Bridge) is a collaboration between the BIS Innovation Hub and several Asian and Middle Eastern central banks (Hong Kong, China's PBoC, UAE, Thailand). It developed a prototype **multi-CBDC platform** to directly settle cross-border payments using central bank digital currencies on a shared ledger. In the current pilot, each participating central bank can issue its CBDC on the common platform, and licensed commercial banks hold and transact in multiple CBDCs on this network. Four currencies (HK dollar, RMB, Thai baht, UAE dirham) are issued and settled on a *"single logical ledger"* with a custom consensus protocol (inspired by HotStuff) to ensure finality. The primary use case is cross-border trade settlement, with advanced features in scope such as atomic Payment-

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[14] A moeda digital oficial brasileira (Drex) – Referências básicas
[15] **Oracle** – A service that connects blockchain smart contracts with off-chain data (e.g., exchange rates or event triggers).
[16] Drex Real Digital

versus-Payment (PvP[17]) for FX, liquidity management, and privacy controls. Notably, mBridge is considering how to connect with external systems: *"providing connectivity with other DLT-based CBDC systems, RTGS, and traditional payment systems"* is a stated requirement. This highlights that even a single-platform approach eventually needs interoperability with domestic rails[18]. **Key insight:** mBridge demonstrates the efficacy of a unified ledger for multi-currency wholesale CBDC transactions, delivering faster, cheaper, and more transparent cross-border payments, while also revealing the need to interlink with existing infrastructures.

Project Dunbar

Project Dunbar was a BIS Innovation Hub experiment (in partnership with central banks of Australia, Malaysia, Singapore, and South Africa) that built prototypes of a shared multi-CBDC platform for international settlements. The goal was to enable direct cross-border transactions between financial institutions using different CBDCs on a common network. Dunbar successfully showed that banks from different jurisdictions could use a single system to transact across currencies, potentially reducing reliance on intermediaries and lowering costs and delays. It tackled challenges like implementing a common rulebook and governance for multiple central banks on one platform. The project's findings contributed to the G20 roadmap on enhancing cross-border payments[19]. **Key insight:** A *shared platform* can technically facilitate multi-CBDC PvP settlement, but clear governance and access policies are required (e.g., which institutions can access which CBDCs, how jurisdictional oversight is applied). Dunbar's approach, similar to mBridge, emphasizes that a tightly integrated network of central banks can achieve near-instant cross-currency settlement if legal and operational agreements are in place.

MAS Project Ubin (Singapore)

Singapore's **Project Ubin** was a multi-phase initiative by the Monetary Authority of Singapore exploring DLT for payments. In its later phases, Ubin shifted focus to cross-border interoperability. In 2019 (Phase 5), MAS partnered with industry (J.P. Morgan and Temasek) to test a **multi-currency network** that could enable different blockchain platforms to interoperate. The prototype allowed payments in different currencies and demonstrated the ability to perform *"conditional payments and escrow"* as well as **interoperability between multiple blockchain networks**. In fact, one aim was *"to enable multiple blockchain networks to interoperate"* and facilitate cross-platform DvP[20] and PvP scenarios. This experiment used

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[17] **PvP** – Payment versus Payment: a settlement mechanism ensuring that a currency is only delivered if the counterparty delivers the other currency.
[18] Options for Access to and interoperability of CBDCs for cross-border payments.
[19] International settlements using multi-CBDCs.
[20] **DvP** – Delivery versus Payment: a settlement mechanism ensuring that securities and cash are exchanged simultaneously.

a Quorum[21] (Ethereum-based) network, and its success led to the creation of **Partior[22]**, a production-grade cross-border payment network co-founded by Temasek, JPM, and DBS Bank[23]. **Key insight:** Ubin showed that Ethereum-derived platforms (Quorum/Besu) can be used to build cross-border payment networks, and that **common standards plus connectors** can link heterogeneous ledgers. Including over forty institutions in Phase 5 also highlighted the importance of scale and industry collaboration for viability.

Another point to highlight is the articulation initiative between the Ubin project (Singapore) and the Jasper project (Canada), which, based on Quorum and Corda respectively, used the **HTLC[24]** protocol to test the proof of concept with a limited number of participants in each network. The report highlights that the design achieves **technical feasibility** for DLT-based PvP across jurisdictions and proposes a future roadmap for integrating with **wholesale CBDCs (wCBDCs)** and broader interbank networks[25].

Project Icebreaker

Project Icebreaker (2023) was a joint project of BIS Innovation Hub Nordic Center with the central banks of Israel, Norway, and Sweden, examining retail CBDCs for cross-border payments. Icebreaker pioneered a **hub-and-spoke** model: rather than a single unified network, each country runs its own retail CBDC system, and a central **"Icebreaker Hub"** facilitates cross-border transactions by linking them. A cross-currency payment is split into two domestic transactions, one in each local CBDC system, coordinated via the hub. An important element is the involvement of competitive foreign exchange providers in the hub that converts between the two currencies. This design lets multiple FX providers bid to execute the conversion, which can lower costs and avoid reliance on a single intermediary[26]. **Key insight:** Icebreaker demonstrates an *interlinked system model* where interoperability is achieved through a messaging hub and FX marketplace, without requiring countries to share a ledger. It emphasizes that even retail CBDCs of different technologies can interoperate through a common protocol, and that **simplified integration and scalability** (each country only connects to the hub) can make connecting many jurisdictions feasible. For LAC, where countries may prefer to run independent CBDC platforms, a hub model is instructive, it offers cross-border functionality while each central bank retains autonomy over its system.

These examples illustrate a spectrum of interoperability approaches, from unified multi-CBDC infrastructures (mBridge, Dunbar) to network-of-networks linkages (Icebreaker), including hybrid public-private solutions (Ubin/Partior). They underscore several design considerations:

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[21] **Quorum** – An Ethereum-based permissioned ledger technology used in previous CBDC pilots like Ubin and Partior.
[22] **Partior** – A cross-border payment platform developed by Temasek, JPMorgan, and DBS using blockchain.
[23] Singapore, JP Morgan, Temasek run blockchain trial of multi-currency payments.
[24] **HTLC** – Hash Time-Locked Contracts: smart contracts that enable atomic cross-chain swaps.
[25] Enabling Cross-Border High Value Transfer Using Distributed Ledger Technologies.
[26] Project Icebreaker: Breaking new paths in cross border retail CBDC payments.

the trade-off between a **single system** (with streamlined settlement but complex governance) and **interlinked systems** (with local control but added integration layers), the need for common technical standards, and the importance of governance, access, and FX arrangements in any cross-border CBDC setup.

CBDC Interoperability Mechanisms and Design Patterns

BIS and other standard-setters have identified several high-level models for CBDC interoperability[27]. These are not mutually exclusive, but they frame how CBDC systems can be connected or combined:

1. **Compatible Standards (Loose Coupling):** CBDC systems are designed using **common standards and protocols** but remain separate. For example, two countries might both adopt ISO 20022[28] messaging and similar API formats for their CBDCs. This *compatibility model* means any PSP (Payment Service Provider) or bank operating in both systems faces lower integration costs. However, the CBDCs are not directly linked FX conversions and transfers happen via existing correspondent banking or an intermediary, just with improved efficiency. Compatibility alone can improve interoperability by ensuring semantic and technical consistency (a "least common denominator"), but it does not inherently provide new cross-border transaction channels.

2. **Interlinked Systems (Bilateral or Hub Links):** In this model, distinct CBDC platforms are **connected via linking infrastructure** or agreements. There are sub-approaches here:

    - *Bilateral Links:* Two CBDC systems establish a direct connection (or a gateway) to enable transfers between them. For instance, Country A's CBDC ledger might have a gateway node that is also a participant in Country B's ledger, allowing transfers in and out. This is analogous to a single access point bridging two systems.

    - *Hub-and-Spoke:* Multiple CBDCs connect to a **common hub** or network that coordinates inter-CBDC transfers. Each jurisdiction integrates with the hub, which handles routing and FX conversions (as in Project Icebreaker). The hub itself does not hold retail balances but facilitates message exchange and **synchronized payments** (e.g., using Hash Time-Locked Contracts or real-time API calls to ensure Payment vs Payment).

    - *Correspondent/Intermediary Model:* A private or public intermediary entity could act as a settlement agent connecting multiple systems (like the traditional

[27] Options for access to and interoperability of CBDCs for cross-border payments.
[28] **ISO 20022** – A universal financial messaging standard for exchanging information across payment networks.

correspondent banking model but potentially using DLT gateways). For example, a **“single gateway” PSP** could operate accounts in multiple CBDC systems and provide conversion/transfer services.

In all interlinked cases, **FX can occur either at the intermediaries or via the link/hub**. These models let each central bank maintain its own ledger and policies, but require robust interfaces and agreement on protocols. They introduce points of dependency (the gateway or hub) whose governance and resilience are critical. BIS notes that governance of a link or hub is a key challenge especially if multiple countries have competing demands for control or regulatory oversight over the intermediary infrastructure. Despite complexity, interlinking allows incremental adoption (two countries can start bilaterally, hubs can grow as more join) and can leverage existing systems.

3. **Single System (Integrated Multi-CBDC Platform):** Multiple jurisdictions agree to **share one common technical infrastructure** hosting multiple CBDCs. In this *multi-CBDC platform* model, all participating central banks either run nodes on a joint network or rely on a third-party operator of the network. Each CBDC is issued and transacted on this shared ledger, typically under a single rulebook or governance framework for the platform. This approach, used by projects like mBridge and Dunbar, offers *seamless PvP settlement* and a unified view of liquidity. It can eliminate the need for intermediate messaging or timing coordination, a cross-border payment becomes just a ledger transfer of two CBDC tokens with an atomic swap. **Benefits:** short transaction chains (no hops through separate systems), no reconciliation between different ledgers, and potentially easier enforcement of uniform compliance checks. **Drawbacks:** The governance is complex, participating central banks must agree on who operates the infrastructure, how decisions are made, and how jurisdictional legal issues are managed. There is also a **resilience consideration**: a single system can be a single point of failure if not properly decentralized. Furthermore, onboarding new members or changes requires multilateral coordination. Despite these challenges, BIS observes that *“most cross-border wholesale CBDC projects [to date] use a single system model,”* likely perceiving it as having high potential value or being simpler to prototype initially. Over time, such a platform could act as a hub itself, linking non-member jurisdictions through defined APIs.

It is worth noting that these models can **coexist** or form hybrids. For example, a group of countries might share a multi-CBDC platform (single system) which then connects via a hub to other platforms combining models. Or one might start with bilateral links that evolve into a multilateral hub. The choice of model affects not only technical design but also policy: e.g., a single system may require a treaty-like governance structure, whereas a compatibility approach leans more on standardized regulations and oversight in each country[29]. All models

[29] Interoperability between central bank digital currency systems and fast payments systems.

demand that certain common elements be addressed, such as **message semantics, identity and access management, and synchronized settlement** to achieve true interoperability.

In addition to CBDC-to-CBDC interop, central banks must also consider interoperability **with non-CBDC systems,** for instance linking a CBDC to existing payment systems like RTGS or instant payment networks. This is crucial for practical cross-border use where one country might use CBDC while the counterparty uses traditional accounts. Approaches here include using the CBDC as a settlement asset for other systems (as studied by the World Bank in experiments to settle instant payment obligations with wholesale CBDC) or vice versa and leveraging APIs/bridges to trigger actions across CBDC and non-CBDC ledgers[30]. The bottom line is any CBDC design should be *"born interoperable*," not only domestically (with legacy systems) but internationally. As the BIS, IMF and World Bank cautioned, *"if CBDCs are not designed with the international dimension in mind, fragmentation of CBDC systems… is possible,"* whereas CBDC offers a *"clean slate"* chance to avoid existing payment silos. Interoperable CBDCs can address the pain points of today's cross-border payments high cost, slow speed, and limited access – by enabling direct, digital exchange of value across borders[31].

Emerging Interoperability Frameworks and Tools

Achieving cross-platform CBDC interoperability often requires components beyond the core ledger software. A range of emerging frameworks and protocols can **complement Hyperledger Besu** (or any DLT) by providing interoperability as a service or toolkit. Two notable examples are **Hyperledger Cacti** and **Chainlink's Cross-Chain Interoperability Protocol (CCIP)**:

- **Hyperledger Cacti:** Cacti (formerly known as Hyperledger Cactus, merged with Weaver Lab) is an open-source, pluggable interoperability **framework for distributed ledgers**[32]. It is a set of libraries, SDKs, and modules that allow different blockchain networks (which could be heterogeneous, like Besu/Ethereum, Hyperledger Fabric, Corda, Stellar, etc.) to orchestrate transactions across one another. Crucially, Cacti is designed so that one network can transact with another **"without a central or common settlement chain**," preserving each network's autonomy. Instead of forcing all participants onto one blockchain, Cacti enables *connector modules* on each network that can coordinate atomic operations (asset transfers, information exchange) across boundaries. For example, a token could be locked on a Besu network and a corresponding token minted on Fabric, with cryptographic proofs exchanged via a Cacti connector to ensure consistency. This approach leverages techniques like **hashed time-lock contracts (HTLCs), notary schemes, or relay nodes** depending on the plugin used. The benefit for a CBDC context is that Cacti can integrate a Besu-based CBDC network with other networks (another country's different DLT or even a

[30] Interoperability between central bank digital currency systems and fast payments systems.
[31] BIS, World Bank, IMF urge CBDC interoperability for cross border payments.
[32] Hyperledger CACTI.

traditional system via API), enabling **cross-platform interoperability** through a DPG approach. Cacti's design emphasizes security, privacy, and modularity, e.g., connectors can implement custom trust agreements or use intermediate validators as needed. As a Hyperledger project, Cacti aligns with the DPG ethos of open collaboration and could be tailored for a LAC regional hub connecting multiple national ledgers. Early prototypes (e.g., bridging **Stellar and Besu** networks using Cacti connectors) have demonstrated the practicality of this approach[33].

- **Chainlink CCIP:** The Cross-Chain Interoperability Protocol by Chainlink takes a slightly different track, offering a **decentralized oracle network** to transfer messages and tokens between blockchains. CCIP acts as a "cross-chain highway" where a network of independent oracles observes events on one blockchain and, via consensus, trigger actions on another. For instance, if a smart contract on Network A (Besu) requests to send one hundred tokens to Network B, the CCIP oracles[34] will lock/burn the one hundred tokens on A and mint/unlock one hundred tokens on B in a target contract, all governed by CCIP's security mechanisms. Chainlink has integrated CCIP with **Hyperledger Besu** to provide *"secure, seamless cross-chain interoperability"* for Besu-based networks[35]. This means a Besu CBDC network could use CCIP to connect with another Besu network or even public chains, without each central bank building custom bridges. The advantages of CCIP include a **unified interface** (smart contract calls for cross-chain operations) and the security of Chainlink's proven oracle infrastructure (which secures tens of billions in DeFi). It abstracts the complexity of managing HTLCs or direct integrations, at the cost of relying on an external decentralized service. In a CBDC scenario, CCIP could enable, for example, a **programmable PvP**: a smart contract could atomically swap a tokenized dollar on one network for a tokenized peso on another by instructing CCIP, which guarantees either both transfers happen or neither. Chainlink's approach has already attracted institutional attention, for instance, **SWIFT's recent experiments** used CCIP to trigger transactions on multiple blockchains with a single message, aiming to interlink CBDCs and traditional systems. For LAC central banks, CCIP offers an out-of-the-box interoperability layer that could connect Besu networks across countries or even link a regional CBDC network with external ones, *without each pair of ledgers having to coordinate one-off integrations*. The trade-off is that the governance of interoperability shifts partly to the oracle network; central banks would need assurance of CCIP's reliability and compliance features (Chainlink is evolving CCIP to meet institutional requirements, potentially even allowing permissioned oracles).

In summary, **Cacti provides a flexible, self-hosted toolkit** for building bespoke bridges and **CCIP provides an interoperability service** ready to use. They are complementary: Cacti could be used to implement region-specific gateways or a LAC-wide interoperability

[33] Building Bridges: Developing the Stellar Connector for Hyperledger Cacti
[34] **CCIP Oracles** – Independent nodes observing blockchain events and initiating cross-chain actions in Chainlink's CCIP.
[35] Institutional-grade interoperability for Hyperledger Besu.

hub (open source, fully under the control of participating central banks), whereas CCIP could serve as a fast-track solution for certain cross-chain use cases or connecting to external ecosystems (with the benefit of an established network). Both approaches underscore that Hyperledger Besu's native capabilities can be **extended** significantly what Besu lacks in native cross-chain features can be supplied by these interoperability layers. Notably, Brazil's DREX is already integrating with Chainlink's CCIP for cross-border interoperability, validating CCIP's relevance. Likewise, the Hyperledger community's investment in Cacti signals a maturing landscape of open standards for blockchain interoperability that a DPG in LAC can leverage rather than reinvent.

Beyond Cacti and CCIP, other interoperability initiatives include the World Wide Web Consortium's **Interledger Protocol (ILP)** (focused on payment routing across ledgers), enterprise solutions like Quant's Overledger, and international data standards (ISO 20022 for payments messaging, BIAN APIs, etc.), all of which can play a role in an overarching interoperability strategy. The BIS has also outlined **API-based architectures** (e.g., Project Rosalind for retail CBDC API standards) that ensure different systems can interface in a uniform way. A combination of **open standards**, **gateway technologies**, and **cross-chain protocols** will likely form the interoperability stack for CBDCs.

Considerations for Implementation

Implementing CBDC interoperability in a multi-country context presents several technical and operational considerations:

- **Performance and Scalability.**
- **Security and Privacy.**
- **Synchronization and Settlement Finality.**
- **Integration with Existing Systems.**
- **Compliance and Monitoring.**
- **Operational and Cost Considerations.**

By addressing these considerations early, in the architecture and pilot phases, the project can avoid painful gaps later. A **gradual testing approach** is advisable: start with a contained corridor (say two countries linking their test CBDCs) to refine the technology and rules, then scale up to more participants or a more complex network. This iterative strategy echoes the BIS's advice that interoperability options should be assessed against criteria like *"do no harm,"* efficiency, resilience, *"financial inclusion,"* and **security** before broad rollout.

Features and Limitations of Besu for CBDC Interoperability

As the chosen backbone for CBWeb3, Hyperledger Besu (deployed in the LACNet environment) offers a solid foundation for CBDC development. This section evaluates how Besu's features map to interoperability requirements, and what its limitations are in this context.

Use Case Context: In a wholesale cross-border scenario, we anticipate two primary interoperability use cases:

- **Domestic (DvP)**: Transfer and settlement of digital assets (e.g., tokenized bonds) and CBDCs, where financial privacy is critical.
- **International (PvP)**: Cross-border payments for FX settlement between interoperable networks, such as CBWeb3 and DREX, requiring privacy and regulatory compliance.

Capabilities for Interoperability

- **EVM Smart Contracts and Tokenization:** Besu's full EVM support means we can natively represent **multiple CBDCs as tokens or accounts** on a single network if desired. For instance, one could deploy ERC-20-like tokens for each national CBDC on a shared LACChain network. Each central bank could control the mint/burn of its token while the network validates transactions. This provides an *out-of-the-box way to host multiple currencies* together, achieving a form of interoperability (the single system model) using just Besu's native capabilities. It also allows building **smart contracts** for conditional payments, multi-party transactions, and escrow. For example, one could code a Solidity smart contract for atomic PvP: two central banks deposit their respective CBDC tokens into the contract, which swaps them if both deposits arrive by a deadline (or refunds if not). Such logic leverages Ethereum's well-known patterns and does not require additional software – Besu can execute it as part of its consensus.
- **Permissioning and Network Management:** LACNet's implementation of Besu includes advanced permissioning controlling which nodes can join, which accounts can deploy contracts, etc. This is critical for a multi-country environment: it means the network can be restricted to authorized participants (central banks, invited commercial banks) and governed by a consortium. Fine-grained account permissioning could allow, say, only a central bank's account to call the "mint" function of its CBDC contract. Besu's native permissioning thus supports a *federated governance* structure, which is beneficial if multiple central banks run validators. Furthermore, consensus protocols

like **IBFT[36] 2.0 (Istanbul BFT)** give immediate finality and tolerate up to f faulty nodes out of 3f+1. Immediate finality is essential for cross-border payments to avoid uncertainty of rollback. This means once a transaction is in a block, it is final and can be acted upon by another network without waiting. In practice, a network of central bank nodes running IBFT could finalize blocks in a few seconds or less, enabling near real-time cross-LEDGER settlement when combined with interoperability tools.

- **Interoperability via Event Emission and Oracles**: Besu can emit events from smart contracts which off-chain or cross-chain components can catch. This is useful for interoperability: for instance, a smart contract on Besu could emit an event "PaymentMade(txID, amount, currency)" when a payment is done. A Chainlink CCIP or a Cacti connector listening for that event can then trigger the corresponding action on another network. Because Ethereum has a rich ecosystem of developer tools, integrating Besu with oracle networks or connectors is straightforward. In fact, Besu's Ethereum compatibility makes it *easier to use existing cross-chain solutions* (like CCIP) since they often already support Ethereum interfaces. This means Besu networks can serve as one "spoke" in a hub like Chainlink with minimal custom development essentially **plug-and-play interoperability**. By contrast, a custom ledger would need custom integration. This compatibility is a strong point for Besu as a DPG: many interoperability solutions **natively speak Ethereum protocols** (e.g., they can read Ethereum logs, verify Ethereum cryptographic proofs, etc.).
- **Flexible Deployment (On-premises or Cloud):** The Besu/LACNet stack can be deployed in various environments – central banks can run their nodes on-prem for control or in the cloud for scalability, and LACNet provides a supporting layer. This flexibility aids interoperability because each participant can choose its comfort level and still interconnect. For example, a smaller country's central bank could ask LACNet to host its node if it lacks capacity, ensuring it still participates in the network. The *alliance model* of LACNet, where multiple stakeholders share infrastructure, can reduce costs, and ensure consistent operations, which is important when coordinating cross-country IT systems. Moreover, Besu's support for standard protocols (JSON-RPC, GraphQL[37]) means integration with other services (like analytics dashboards, compliance monitoring systems, or gateways to RTGS) is feasible with existing tools.
- **Proven Use in Similar Contexts:** Besu (and its Ethereum relatives) have been used in several relevant pilots. For example, as noted, **Brazil's DREX uses Hyperledger Besu**, indicating that Besu can meet central bank requirements for security and performance. Besu was also utilized in Project Jura for cross-border CBDC DvP (between France and Switzerland) via a third-party platform, and in some phases of Project Ubin (Quorum, an Ethereum variant). The fact that these experiments succeeded lends confidence that Besu's technology can underpin complex interoperability scenarios. Additionally, private implementations like Partior use Quorum (close to Besu) to handle multi-currency ledgers among banks, showing that *Ethereum-based permissioned networks are battle-tested* for high-value transactions.

[36] **IBFT** – Istanbul Byzantine Fault Tolerance: a consensus mechanism offering immediate finality in permissioned networks.

[37] **JSON-RPC / GraphQL** – Web APIs commonly used to interface with Ethereum nodes, including Besu.

This existing knowledge base (including code libraries for token standards, identity management, etc.) is a valuable asset, developers in LAC can draw on global expertise when building on Besu.

Challenges and Limitations

- **No Native Cross-Chain Module:** Out-of-the-box, Besu is a single-network blockchain platform and does **not natively provide cross-chain communication**. Unlike some interbank systems (e.g., RTGS Global or certain vendor solutions) that might incorporate built-in links, Besu by itself is confined to its ledger. Any cross-chain transaction thus requires external coordination (via oracles, notary nodes, or custom scripts). This means that by default, two Besu networks cannot "see" each other's transactions or transfer assets between each other. While one could deploy the same contract on two networks and manually coordinate (e.g., user locks funds on Network A and then calls a function on Network B to mint funds, relying on off-chain coordination), doing this safely requires additional layers. Essentially, Besu provides the platforms on each side, but **developers must fill the gap in between**. This is precisely why frameworks like Cacti or CCIP are needed, they handle what Besu alone does not. The limitation here is not unique to Besu (most DLTs lack native interoperability with others), but it highlights that an interoperable system will always be more complex than a standalone Besu deployment. Careful design is needed to ensure that the bridging logic or third-party service is as secure and reliable as the ledgers themselves.
- **Potential Performance Overheads for Security:** If we implement cross-chain safety using techniques like HTLCs on Besu, there could be performance costs. For instance, HTLC contracts might require multiple transactions (initiate, redeem, refund) and waiting periods to ensure both sides have time to act. These timeouts, often in the order of minutes or hours, conflict with the goal of instant cross-border settlement. Tuning them too low can risk failure if one network lags. This is a limitation that needs to be balanced, it might mean that truly instantaneous PvP might not always be achievable in a two-ledger scenario without some trust assumptions. Besu's consensus can finalize a single transaction quickly, but an atomic swap across chains needs to finalize two transactions in sequence. Solutions like **bridged consensus** (where one set of nodes validates both ledgers) could mitigate this, but that veers towards a single system model. In short, the *interoperability layer can become a bottleneck*, not Besu itself, but end-to-end performance is what matters to users.
- **Interoperability vs. Privacy Trade-off:** Besu networks can be made private at the transaction level using add-ons (like Tessera[38] for private Tx, or custom encryption of payloads). However, when bridging two networks, information often must be revealed to facilitate the transfer (e.g., a hash pre-image or an event indicating a payment). Ensuring that this does not leak sensitive data is a challenge. If, for example, Country A does not want Country B to know details of a transaction beyond the necessary, it must trust that the interoperability protocol only shares what is required. **Privacy on a**

[38] **Tessera** – A former privacy manager used with Besu to manage private transactions; now deprecated.

shared ledger (if multiple CBDCs on one chain) is also tricky: nodes from one country might see transactions in another's CBDC unless privacy measures are in place. Besu with permissioning can restrict who participates in which transactions, but currently Besu's privacy features (Pantheon/Tessera) are more oriented to bilateral private Tx than scalable confidential groups. This is a limitation if a single network is used: additional privacy layers (like zero-knowledge proofs[39] or encrypted enclaves) would be needed to ensure, for example, that banks in Country X cannot surveil transactions of banks in Country Y on the same chain. While not a showstopper, it adds complexity, and indeed privacy was cited as a challenge in DREX and other Besu-based CBDCs.

- **Governance and Software Updates:** Running Besu nodes across many jurisdictions means any update or configuration change (block size, gas limits, etc.) requires coordination. Besu releases updates periodically; if one central bank upgrades their node and others do not, it could cause a consensus divergence or downtime. This means a *governance process for technological changes* is needed. Compared to a proprietary system managed by a single vendor, the decentralized nature can slow down upgrades. However, since LACNet can coordinate on behalf of members, this risk can be managed. Another aspect is troubleshooting and support if something goes wrong in production, multiple parties will need to come together to diagnose an issue in the Besu network, which could be harder than a single-team environment. Again, not unique to Besu but inherent in collaborative infrastructure.
- **Interfacing with Non-EVM Systems:** If some LAC countries choose different tech (**e.g.,** one uses Hyperledger Fabric or R3 Corda for their CBDC), Besu's interoperability challenge extends to non-EVM integration. While Cacti provides some solutions, without it, bridging Besu to a fundamentally different ledger (different transaction model, no smart contracts perhaps) can be complex. It might involve an intermediate system or simply adopting a message-based approach (where transactions are coordinated by a centralized system rather than on-chain contracts). Besu does not provide tools for that out-of-the-box, so we would lean on external middleware. The limitation here is simply that Besu is not a *universal translator*; it excels when both sides speak Ethereum-like language. If that is not the case, we either encourage convergence on similar tech or invest more in the middleware to handle divergent systems.
- **Existing Limitations of Ethereum Tech:** Issues such as gas costs, transaction ordering (MEV Miner/Maximal Extractable Value[40]), and contract vulnerabilities exist on Ethereum and thus on Besu. While a permissioned network with known validators is less susceptible to some public network problems, one must still code contracts carefully to avoid bugs that could be exploited. If using cross-chain smart contracts, errors could have amplified impact (e.g., a flaw could be exploited to steal across borders). Auditing and testing are crucial. Also, Besu currently does not support *sharding* or advanced scalability features of future Ethereum versions, if the

[39] **Zero-Knowledge Proofs (ZKP)** – Cryptographic proofs that enable data validation without revealing the data itself.
[40] **MEV (Maximal Extractable Value)** – Profits that validators can make by reordering or including specific transactions in blocks.

transaction volume in a regional network grows significantly (say retail level), scaling up might require either moving to an Ethereum 2.0-based client in future or layering L2 solutions. As wholesale volume is typically lower than retail, this is fine for now, but it is a forward-looking limitation to be aware of.

Conclusions

Interoperability is a linchpin in unlocking the full potential of CBDCs for cross-border use. For Latin America and the Caribbean, where economic integration and remittance flows are significant, designing CBDCs with interoperability from day one is essential to avoid digital islands. This report's analysis leads to several clear conclusions regarding a **DPG-based CBDC solution on Hyperledger Besu**:

1. Native Capabilities of Besu (What Can be Done on-Chain): Hyperledger Besu (and Ethereum-based technology generally) can represent multiple assets/currencies on a single network, executing complex settlement logic via smart contracts, and enforcing fine-grained permissions – all of which are powerful tools for interoperability. A **single multi-CBDC ledger** for LAC could be implemented directly on Besu, allowing cross-border transactions to occur natively on one platform. Besu's immediate finality and smart contract programmability mean features like PvP, DvP, and conditional payments can be achieved **within the ledger's environment**. Additionally, by adhering to common standards (ERC token standards, ISO 20022 messaging integrated into contract events, etc.), a Besu-based system can be made naturally interoperable with participants' existing systems and even with public blockchain infrastructure. In short, Besu provides a *reliable transaction engine* and *shared development language (Solidity)* that multiple countries can use collaboratively. Many interoperability **design patterns can be prototyped natively** on Besu (e.g., escrow contracts for HTLCs, multi-currency wallets, etc.), which can then either be deployed in a unified network or used as part of a connector strategy.

2. Necessity of External Components and Standards (What Requires Off-Chain or Add-Ons): Despite Besu's strengths, certain interoperability goals **cannot be met by Besu alone**. Chief among these is linking distinct networks, whether for connecting to a different DLT or to a traditional system. Here, external components like **Cacti** (for custom cross-ledger protocols) or **CCIP** (for oracle-mediated transfers) are indispensable. They act as the **bridges** where Besu has no built-in bridge. Likewise, standardized messaging frameworks (e.g., ISO 20022, ISO 20022-based APIs, or even JSON/REST APIs agreed upon by central banks) must complement the on-chain activity to handle communications, error handling, and integration with banking processes. **Identity and authentication infrastructure** is another external necessity: to trust actions from another country's system, digital signatures, and a PKI (Public Key Infrastructure)[41] that spans countries will be needed. Besu provides the hooks (it can verify signatures, etc.) but the identity management (issuing certificates to institutions, etc.) is an off-chain governance matter. Another area requiring external consideration is **compliance**

[41] **Public Key Infrastructure (PKI)** – A system for managing digital certificates and public-key encryption for authentication.

screening and analytics, while transactions occur on Besu, tools to monitor patterns (for AML) across the network or to enforce travel rule data are external (or bolt-on smart contract modules) that need to be standardized. Furthermore, to connect with non-blockchain systems like a RTGS, *API gateways or middleware* must be developed. These could take the form of a microservice that listens to Besu events and generates ISO messages to an RTGS and vice versa. In sum, a full production-grade interoperable CBDC system will be an **ecosystem**: Besu as the core ledger(s), augmented by oracle/connector networks, messaging standards, identity systems (possibly a regional digital ID for institutions), and monitoring dashboards, all orchestrated together.

3. Governance and Architectural Considerations for Scaling Across Countries: Technology will fail without the right governance enabling it. A few key recommendations emerge:

- *Start with Wholesale, Plan for Retail:* Focusing on wholesale CBDC (interbank transfers, cross-border settlements among known parties) is prudent as an initial step. It limits complexity (fewer parties to manage, clearer legal context) and allows testing interoperability in a controlled environment. This aligns with the conclusion in the privacy analysis that **"wholesale transactions [serve] as an immediate focus"** to gain learnings. However, the architecture should be designed with an eye toward future retail expansion or at least interoperability with retail systems. This means modularity: the ability to add on a retail payment hub or to incorporate APIs for retail payment providers later. The Icebreaker model can be instructive for scaling down to retail without overhauling the wholesale core.

- *Regional Governance Body:* Establish a formal **interoperability working group or steering committee** among participating central banks under an existing regional forum (or a new one). This body would govern the rulebook for cross-CBDC operations, oversee the shared components (like a regional hub or network), and handle disputes or upgrades. It would also coordinate with global bodies to ensure adherence to best practices. A clear governance structure will make it easier to invite new countries to join the network, since roles and responsibilities are predefined. Over time, this could evolve into a LAC-wide "digital currency agreement" analogous to how SEPA was governed for EU payments.

- *Common Technical Standards and Testing:* All countries in the network should agree on technical standards (data formats, protocols) as part of the design, effectively a *technical constitution*. This should include using ISO 20022 for any messages, common APIs for any open interfaces, and a baseline cybersecurity framework (e.g., mandatory support for certain encryption standards). Regular **conformance testing** should be scheduled: before a new participant comes online or a new version of software is deployed, a battery of cross-border payment tests (including failure cases) must be run in a sandbox involving multiple countries. This ensures problems are caught in testing, not in production between tokenized central bank money.

- *Layered Architecture:* Architecturally, think in layers: **Ledger Layer** (Besu networks in each jurisdiction or a shared Besu network), **Interoperability Layer** (Cacti connectors, CCIP oracle network, or hub with routing logic), and **Application Layer** (the business applications like FX marketplace, liquidity management, or user-facing interfaces). By decoupling these, each layer can evolve without breaking the others. For instance, if tomorrow a better cross-chain tech than CCIP appears, it could replace CCIP in the interop layer without requiring the ledger layer to change, if it adheres to the same interface. This is akin to how the Internet's TCP/IP can swap out link layers. Using a DPG approach, all these layers can be built with open components, avoiding vendor lock-in and enabling collective ownership.

- *Scalability and Inclusion:* Once the core is proven with a few major players (say, connecting the largest economies in LAC), plan to scale out to smaller nations and even beyond the region. This might involve a **hub-of-hubs model** eventually, where the LAC hub connects with an African or Asian CBDC hub for truly global reach. Preparing for that means ensuring the solutions chosen are *interoperable at the global level too*. Embracing international standards, as repeated, is the best way to future-proof the regional solution. Additionally, consider the on-boarding process for additional countries: documentation, reference sandbox, and a "plug-and-play kit" for any LAC central bank to connect (especially if they adopt the same Besu-based DPG stack domestically).

4. Strategic Outlook: The technology and experiments discussed show that **interoperability is achievable**, the question is more about coordination and will. With Hyperledger Besu as a starting point, the LAC region has the advantage of building on open, widely used technology, making it easier to attract developers and align with external systems. Projects like mBridge and Icebreaker provide blueprints for different approaches, and DREX demonstrates regional leadership that others can follow. A pragmatic strategy for LAC could be **establish a common test network (CBWeb3) where can be two scenarios: cross-border payment within the same TestNet (seamless interoperability) and between CBWeb3 TestNet and Drex or another advanced pilot in the LAC region and** iterate on legal rules alongside technical tests. This TestNet can incubate the standards and governance needed for production.

When moving to production, LAC central banks must decide on the operational model: a single shared network (managed by all) vs. a network-of-networks. Given the political complexities, a **network-of-networks with a neutral bridging hub** may gain more traction initially. Besu networks in each country could be bridged via Cacti connectors run by a neutral party (like a regional development bank or BIS Innovation Hub). Over time, as trust and experience grow, deeper integration or a shared ledger could be pursued for efficiency.

Finally, as a **Digital Public Good**, the knowledge and software artifacts produced (smart contract templates for PvP, connector code, APIs) should be open-sourced and shared. This not only helps other regions and promotes global standards but also ensures transparency and security through community scrutiny. It would position LAC as a contributor to global financial infrastructure innovation.

In conclusion, **Hyperledger Besu provides a robust platform for LAC CBDC interoperability, but it must be paired with smart interoperability protocols and strong multilateral governance** to achieve the cross-border fluidity envisioned. Many pieces of the puzzle are already in place or in progress, from BIS-tested models to region-specific projects like DREX, and LAC is poised to integrate these into a cohesive solution. By addressing what can be done on-chain versus off-chain and establishing clear cooperative frameworks, the region can create an interoperable CBDC network that enhances financial inclusion, efficiency, and innovation, without compromising on national monetary autonomy or security. This balance of technical excellence and policy foresight will determine the success of CBDCs in weaving a more connected financial fabric across Latin America and the Caribbean.