Level of conceptual interoperability model for blockchain based systems

Babu Pillai
School of ICT
Griffith University
Gold Coast, Australia
babu.pillai@griffithuni.edu.au

Kamanashis Biswas
Faculty of Law and Business
Australian Catholic University
Brisbane, Australia
kamanashis.biswas@acu.edu.au

Zhé Hóu
School of ICT
Griffith University
Brisbane, Australia
z.hou@griffith.edu.au

Vallipuram Muthukkumarasamy
School of ICT
Griffith University
Gold Coast, Australia
v.muthu@griffith.edu.au

***Abstract*—The Level of Conceptual Interoperability Model (LCIM) is a widely used framework that represents inter-relationship among interoperability and composability of different information systems. Although this model has been successfully applied to various domains such as cybernetics and informatics, there are many challenges in directly adopting the model for blockchain-based systems. This paper identifies those challenges and proposes a new Level of Conceptual Interoperability Model for blockchain systems based on the original LCIM. We define five different levels of interoperability for blockchain-based systems and theoretically evaluate the level of interoperability (LOI) achieved by different blockchain networks. The evaluation outcomes show that there exists technical interoperability (Level 1) between Bitcoin and Ethereum networks, whereas Solana and Binance achieve pragmatic interoperability (Level 4) by conveying state changes with Ethereum network and Polkadot achieve dynamic interoperability (level 5) by suitably conveying state changes within the ecosystem of its networks. We present case studies that demonstrates how the proposed LCIM for blockchain systems map various real-world applications to their respective levels.**

***Index Terms*—blockchain, interoperability, level of interoperability model, blockchain interoperability model, cross-chain technology, cross-blockchain technology**

I. Motivation

Interoperability is understood as the ability of two or more systems to communicate with each other and utilise the information that has been exchanged [17]. While this concept of interoperability has been extensively explored for information systems, it remains a great challenge for blockchain-based networks because it requires integration of different inter-linked information sources that are not inherently supported by design [38]. A first step in developing interoperability involves defining metrics to measure the LOI between systems. One of the ways of addressing the challenge is through the design of a *level of interoperability model* that clearly describes the stages through which systems should evolve to reach the best performance in the realization of a given objective. This paper proposes such a model for evaluating interoperability for blockchain-based systems by analysing different aspects of blockchain networks and determining their relevance. A variety of methods are proposed to achieve cross-chain interoperability for blockchain-based systems [5], [16], [19], [21], but almost all of them currently rely on using some form of an integration system. *True interoperability is not simply the ability to share data — the real value comes with the exchange of data with its conceptual and contextual meanings*.

Various studies suggest that interoperability across different blockchains will become a core requirement for public and private blockchains in the future [19], [20], [34]. While there are projects aimed to address interoperability, understanding this capability within a system framework necessarily requires a model to be developed with interoperability. This paper aims to investigate and categorise the issues associated with interoperability at various levels and provide a framework to measure interoperability capability. The model-driven approach is critically important since it helps understand what processes are involved at various stages. This not only exhibits a view on the system process but also provides a basis for presenting how these different processes will interact with each other. With such a model, the identification of information exchange processes between systems becomes relatively easy and systematic. We also focus on the specific requirements that are necessary to support different degree of interoperability for blockchain-based systems.

II. Blockchain Interoperability

Blockchain technology has gained a significant interest in the last decade. One of the benefits come in the form of security offered by censorship resistance of the distributed networks [49]. However, these systems' functions are restricted to a single blockchain network by design, making interoperability an open challenge [19], [25], [44]. In future, there will be many networks of blockchains across different enterprises, each of which will be application-specific networks. These networks will need to communicate and transfer data to agree on a global state. Therefore, it will require an integration system to share the data in a secure manner such that other blockchains be able to verify the integrity of the data. Existing research works on interoperability of blockchain networks try to address the challenges in interpreting and exchanging data through various integration systems such as bridges and connectors. These keep track of transactions in each connected chain to manage the transfers between different networks [15], [27], [45].

Several projects are experimenting with cross-blockchain integration mechanisms and proposing interoperability through different integration architectures: i) Solutions to interconnect homogeneous networks such as SubChains and InterChain [15], and alliance chain and private chain [48]; ii) Heterogeneous networks connecting to each other through the use of customised bridges; iii) Polkadot [46] and Cosmos [24] platforms bringing a new level of interoperable blockchain ecosystem.

The Polkadot [29], [46] network consists of a central Relay Chain and an subsystem of parachains that run in parallel. Cross-chain transaction data can be sent between parachains because of Polkadot's cross-chain composability. This opens up the possibility of interoperable networks within its ecosystem. Parachains can be connected to external networks such as Bitcoin, Ethereum, etc through cross-network bridges. The Cosmos [24] project aims at creating an Internet of Blockchain that connects different chains through the Inter-Blockchain Communication (IBC) protocol. Cosmos network runs on its own token and consists of shared hub and zones. The zones are independent networks and the hub connects different zones. Interoperability is achieved through the shared Cosmos Hub, powered by the Tendermint consensus protocol, which keeps track of the number of tokens in each connected chain and manages transfers between them. Apart from these, another type of blockchain network communicates and interacts using a hub and spoke model within its ecosystem or uses bridges to communicate with each other.

Although many blockchain projects are being built and new projects are constantly emerging, most application-specific blockchain networks are not interoperable by default [25]. It is important to describe and formalize how well different blockchains can work together and interact with each other to achieve a common goal. Such formalization must be performed using principles of interoperability processes. The ability to effectively interact is one of the key factors used to measure the overall performance of collaborative processes. This factor is related to the concept of the interoperability process. Blockchains involved in collaborative processes must meet certain interoperability goals. To accomplish this goal, they need to detect and anticipate their interoperability challenges. To identify the nature of interoperability problems, we may use a model-based approach where interoperability elements can be viewed from different perspectives in a linear scale of varying degree of abstraction. For this reason, an interoperability development process is often classified as 'levels of interoperability' in the literature [1]. All that means composability is defined in a layered format that describes a structure of interoperability requirements related to the collaborative process. It is, therefore, essential to achieve a common understanding of the interoperability process through a conceptual model.

III. Conceptual Model

Conceptual models are state of the art method used in information system development and management process. A conceptual model aims to capture the main concepts of a system. It represents various elements within the system and aims to resolve any issues [32]. It also provides a common ground for understanding the components within a system. Such a model is used to evaluate and compare the system processes. Technically, a system model should facilitate predicting its behaviour within an environment, even before the system is developed. Thereby, it allows reasoning about consequences of various potential scenarios and understanding of the system's complexity.

The fundamental requirement of a conceptual model is to capture the concepts and provide a common ground to understand the components, essential behaviour, and features of a system. Several initiatives on interoperability have proposed interoperability frameworks to lay out the issues. Existing research on interoperability in information systems and enterprises proposes structuring the issues into *barriers* and *concerns* related to interoperability [11], [26]. Generally, to capture the elements associated with interoperability structure, two fundamental aspects are considered: the *interoperability barriers* and *interoperability concerns*. The goal is to overcome the interoperability barriers related to interoperability concerns.

- *Interoperability barriers* identify various obstacles to interoperability in three categories: conceptual, technical and contextual.
- *Interoperability concerns* define the content of interoperability that may take place at various levels: application, service, process, and business.

A recent *preprint* paper [4] proposes a layered structure of interoperability based on the European Interoperability Framework model [12] identifying different layers of interoperability its concerns and barriers. Since our work is based on a different model [41] we leave a possible comparison for future work.

IV. Interoperability Barriers

Generally barriers are interoperability problems. Thus, the objective is to identify and categorise common barriers in the interoperability process for different scenarios. An interoperability process includes *exchanging, interpreting and integrating data*, which happens at various levels. Given that the existing interoperability barriers are expressed based on their application domains [13], [43], we define three interoperability barriers for blockchain-based system as: *technical, conceptual, and contextual*. For information systems, the technical and conceptual barriers [2], [11] are already defined. The contextual barrier discussed here is more specific to blockchain systems.

- *Technical Barriers* are related to incompatibility of hardware and software components.
- *Conceptual Barriers* are related to the incompatibility of data in terms of syntax and semantics.
- *Contextual Barriers* are related to the contextual meaning of the message.

Compared to the layers proposed in [4], here we examine from the information system point of view. We, therefore, do not address organizational and legal interoperability aspects. The following subsections discuss the barriers we defined in detail.

A. Technical barriers

Technical barriers are related to information technology systems' incompatibility with hardware and software components [8], [10], [23]. Technical interoperability deals with moving data from one system to another [6] and it is not concerned about the meaning of what is being exchanged. The barriers are at the *bit* level caused by interfaces, interconnection services, hardware components, or platforms. For example, hardware-related barriers include different hardware requirements and data frame sizes or types.

B. Conceptual barriers

Conceptual Barriers are related to incompatible *syntax* and *semantics* of the data [8], [10], [13]. Within this, the *syntax* is associated with the format of data and *semantics* deal with agreements on the interpretation of the data [22]. In computer systems, *syntax refers to the grammar and formal rules*, that means syntax specifies the binding structure of the data - for example protocols such as HTTP and XML. A semantic barrier is associated with the agreement on the interpretation of the data. Without semantics, the data gets its structure but does not get the meaning for interpretation. Interoperable systems need to interpret and use data in the same way [6].

C. Contextual barriers

Contextual barriers are related to the contextual meaning of the representing data, for example, a trading currency of $10.11. The contextual information includes: it is a currency, its source (Australian or US), precision, accuracy, scale factor and status [35]. This is an important property for things that have a conceptual value attached to them, for example, cryptocurrencies (BTC, ETH) and non fungible tokens (NFT).

Let us assume that interoperability aims for exchanging and transferring data between networks. However, interpreting and interacting with the exchanged data depends on the interoperability level. Interoperable interactions take place at the technical level. Compared to applications such as simple routing of data between systems, as opposed to interpreting its meaning we face conceptual and contextual challenges. In the context of blockchain, the key challenge is the contextual barrier.

V. Interoperability concerns

The interoperability process takes place at various levels [9]. This section defines the interoperability concerns that are derived from various activities taking place at different levels.

- *Application-level* concerns relate to the ability to establish a connection with the network.
- *Service level* concerns relate to the comparability services related to resolving compatibility issues.
- *Process level* concerns relate to the process designed for a system.
- *Business level* concerns relate to business purpose and rules each system is designed for.

These given concerns are defined from the perspectives of blockchain-based systems. The objective is to capture interoperability concerns at different levels. The concerns are linked, such that one might contribute to or detract from another.

A. Application-level

Application-level concerns are firstly related to the user's privilege and permission to operate on the network (such as the permission to perform operations, authenticate the transaction); secondly related to having necessary administrative requirements (such as accounts in the corresponding blockchain network); and thirdly related to dApp applications (such as service connectivity with the network, generally dApps are not integrated part of the node, therefore, the dApps must be able to communicate with nodes of different networks).

B. Service level

Service level concerns are related to services that identify and compose various processes that are designed to resolve comparability aspects of the system (examples of such components are connectors, bridges, and oracles).

C. Process level

Process level concerns are related to functional aspects of the system process. A process is defined as a sequence of functions designed according to specific requirements of the system [8], [10]. For example, a system using proof-of-work consensus interacting with a system using proof-of-stake consensus.

D. Business level

Business level concerns are related to contextual value, purpose and business rules for which each system is designed for. For example, a value implementing the business logic in a platform which is custom made and coupled with the system.

Having described the framework with barriers and concerns for interoperability, we now explore further guidance on what elements are needed to be captured. Although these frameworks can be used to create a better classification and structure of interoperability aspects, they cannot simply be used to evaluate interoperability. The evaluation of interoperability is mostly performed with interoperability models such as *Levels of Information Systems Interoperability* (LISI) [18] or *Level of Conceptual Interoperability Model* (LCIM) [41].

VI. Proposed Interoperability Model

The level of interoperability (LOI) may vary from not-interoperable to full interoperability. There are many different situations in which a LOI is desirable. From a high-level application standpoint, it outlines the usage of interoperability. However, on a conceptual level, we can create a much simpler classification of interoperability types. Incorporation of such an assumption into a formal model is required. Tolk and Muguira [41] introduce the *Level of Conceptual Interoperability Model* (LCIM) which helps to establish the degree to which systems interoperate. To the best of our knowledge, a conceptual model has never been used to understand and interpret interoperability in blockchain technology. Therefore, in this paper we use LCIM as the foundation to systematically understand and analyse interoperability among blockchain systems.

A. LCIM for information systems

A significant amount of research has been done in defining levels of interoperability for information systems [14], [33]. To achieve a meaningful LOI, an understanding of the underlying conceptual model is necessarily required [41]. Such a model helps to understand interoperability by providing an essential knowledge of the required format of information, the way data is generated, transmitted, and responded. The LCIM provides a layered approach to define the LOI requirements and a framework that features a reference model to evaluate the levels of interoperability [39], [41], [42]. Each such level builds upon the layers to achieve increased level of interoperable capability as illustrated in Fig. 1.

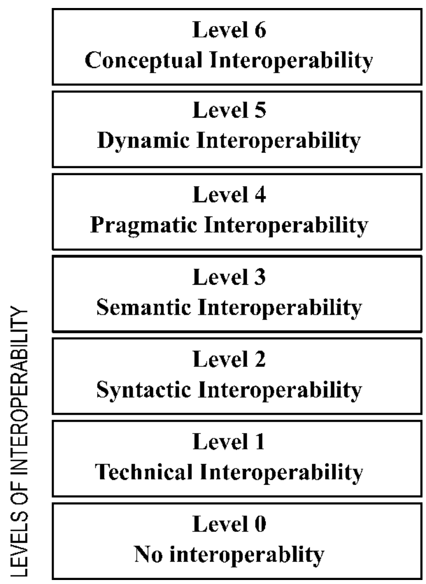

Fig. 1. The level of conceptual interoperability model (LCIM) for information systems.

The LCIM has been used in several software domains to explain and understand interoperability [36]. We briefly explain the levels as follows:

- Level 0: totally stand-alone systems having no interoperability.
- Level 1: the level of interoperability is limited to exchange of bits on a shared network.
- Level 2: at this level devices share an understanding of the format/structure of the data exchanged.
- Level 3: at this level devices share an understanding of the meaning of the data exchanged.
- Level 4: at this level both the devices are aware of the methods and procedures that each other are employing.
- Level 5: at this level devices can exchange changed information due to the interaction of another system.
- Level 6: at this level both the systems are entirely aware of each other's information, processes, contexts and modelling assumptions.

Even though the current LCIM framework has been used in several software domains, it is not explicitly designed to explore the requirements of specific applications such as blockchain systems. For example, in LCIM: i) Dynamic interoperability defined as "devices can exchange information changed due to the interaction of another system". Fundamentally a blockchain system is designed in a way that it will not be operated by an external system; ii) Conceptual interoperability implies that both the systems are entirely aware of each other's information, processes and functionality. Considering the decentralised nature of the architecture, where multiple nodes participate in the process to reach finality, nodes must retain the same result. Therefore, nodes must have or be given information to process the transaction. If the nodes are set to fetch data from other blockchain systems, there is a chance that if the data fetched from the other blockchain are dynamic in nature, they might interfere with the consensus process and end up with a different result. Thus, the concept of one blockchain system to dynamically interact with another blockchain system is not achievable.

For these reasons, by defining the specific application requirements, and the characteristics of different blockchains, flexible interoperability operation model can be developed. Since the core principles described in LCIM are developed through many iterations over the years, applied in various domains successfully and well understood [40], we modify the definition to fit for blockchain-based technologies in the following subsection.

B. Blockchain level of interoperability model

We conduct a theoretical analysis on the LOI requirements for the blockchain systems. Since such a formal interoperability requirement has never been defined for blockchain-based systems, we have established a set of requirements for each of the core principles in LCIM, using assumed goals of blockchain systems. The re-designed levels for blockchain-based system is shown in Fig. 2.

Level 1 – At the technical level, both blockchain systems share a standard network level communication protocols.

Level 2 – At the syntactic level, data structure of the blockchain systems such as format of the block and transaction are same. However, the value that each system carry is unique to that ecosystem. For example, the value of *BTC* token in Bitcoin blockchain will not recognise *BXC* token from bitcoin classic blockchain and vice versa.

The current state of value exchange for level 1 and 2 are through external entities so called *third-party* rather than internal. The downside is the corresponding blockchain system cannot validate or verify any such process carried out by a third-party provider or system. Internally the protocol requires proof to verify the transaction. Therefore, the integration

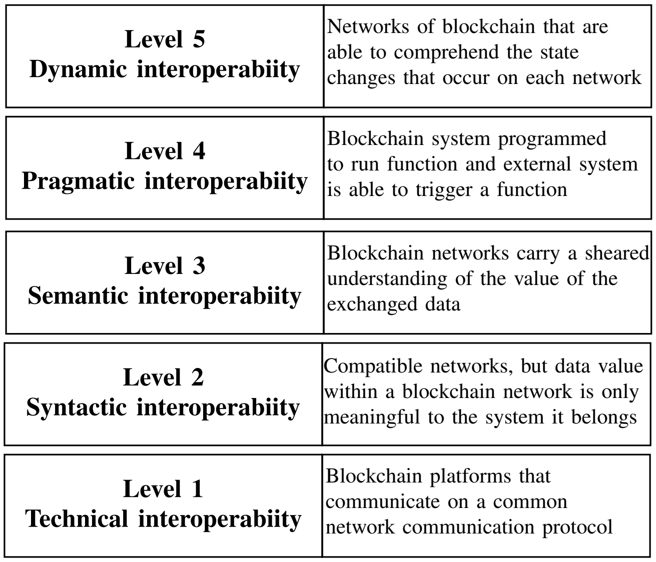

Fig. 2. The proposed LCIM for blockchain systems.

process must satisfy the protocol requirements. The form of proof may vary based on the application. However, the pattern must be consistent and agreed upon by the parties of the underlying obligation. For levels 3, 4 and 5 there exist some form of integration services that are recognised by the network protocol to carry out value transfer and facilitate interoperability between networks.

Level 3 - At the semantic level, the corresponding blockchain systems' carry a shared understanding of value. One system should be able to interpret the data/message from the other system [30]. This may be a human interpretation of the content or machine interpretation. Therefore, a shared understanding about the definition of the data/message is expected to exist.

Level 4 - Blockchain system achieve pragmatic interoperability [3] when a system execute a function(s) that involves multiple blockchain systems. At this level, a user triggers a transaction on a blockchain system to execute some functions that may update its own state based on that of another blockchain system. For an example, smart contracts calling other smart contracts [31] or solutions that allow different blockchain networks to interact through a gateway.

Level 5 - At the dynamic interoperability level, blockchain systems are able to comprehend the state changes happened on other networks. Cross-chain transactions get updated on the connected networks dynamically. The current state of dynamic interoperability is enabled through hub and scope model which creates a network of networks.

Levels 4 and 5 enable cross-chain composability between systems. For example, defined nodes within network N_1 make smart contract calls deployed in network N_2 and make sense of that data by unpacking the events and making use of data for specific use cases. The main difference between Level 4 and 5 is that Level 4 is a unidirectional, whereas Level 5 is a bidirectional relationship.

The LOI reference model has been successfully used in various domains. This model-driven approach is useful to reach an agreement between varied decision-makers involved in the cross-communication process. The idea is to understand the business processes, then choose the appropriate LOI requirement, and capture them in a standard model, e.g., to understand the cross-communication process and act as a basis for designing and deploying suitable systems.

VII. Case Study

This section aims to understand blockchain based system's barriers related to the defined concerns and determine the interoperability level they are intended to support in real-life examples. As an instruction to use the framework, we present a relationship in Table I showing concerns, barriers and the LOI. Many of the barriers are derived from the concerns, and the dependencies are presented as follows. The corresponding metamodel is simple, by addressing the defined barriers and concern, the framework illustrates its level of conceptual interoperability.

The interoperability issue is likely to be addressed through some form of cross-blockchain integration system. It is important to describe and formalise how different blockchain networks exactly interact to achieve interoperability; however, they are out of the scope of this paper. The LOI is one of the key factors used to measure the overall performance of the interoperability collaborative process. This section analyses various interoperability scenarios to determine their LOI.

For the given case study scenarios in Table I, interoperability is assessed between two blockchain networks. Let us define two networks N_1 and N_2, where a token from N_1 to be transferred to N_2 is indicated as $N_1 \rightarrow N_2$ for a one-way transfer and $N_1 \leftrightarrow N_2$ for a two-way transfer. Interoperability leads to integration of networks, in our context the integration system needs to address technical, conceptual and contextual barriers. Let us assume that the integration system is equipped to address cross-blockchain integration's security and trust issues.

The networks involved are listed in the first column with the arrow indicating the direction of token travel. The second column describes the state of interoperability, and the third and fourth columns state the barriers and concerns respectively to be addressed at that level.

Let us assume that blockchain systems carry values (digital asset) [28], and interoperability allows the possibility of exchanging or sharing messages or values in the form of data across different blockchain networks. In this case study, we are focusing at transferring values between blockchain networks.

For crypto-coin value transfer, platform level interoperability between Bitcoin and Ethereum are identified to be at Level 1. Even though these platforms communicate on a standard network protocol (TCP/ IP), they are natively not interoperable by design. Users within these networks rely on external third-party services to facilitate interoperability. In the case of networks with the same platform structure that are

TABLE I
INTEROPERABILITY SCENARIOS

Networks	Level and state of interoperability description	Barriers	Concerns
Polkadot Parachain-1 ↔ Parachain-2 Cosmos Hub-1 ↔ Hub-2	Level 5 - These are platform specific network of networks that works like a hub and spoke model. Such a platform has a predefined programming interface to write cross-chain functions with its own interoperability protocols and mechanisms to handle cross-chain transactions. For example, Polkadot [29] interconnects its parachains through the *Polkadot relay chain*, Cosmos [24] interconnects its hub chains through the *Cosmos hub*.	Contextual(IV-C), Conceptual(IV-B) Technical(IV-A)	Business(V-D), Process(V-C), Service(V-B), Application(V-A)
Solana → Ethereum Binance → Ethereum Polkadot → Ethereum	Level 4 - They are heterogeneous networks of blockchain. In this case, Solana interoperates with the Ethereum network through its built-in cross-chain bridge Wormhole [47] protocol. Similarly, the Binance network interoperates with the Ethereum network through the Binance Smart Chain [37] bridge. Polkadot's ChainBridge [7] connects its Moonbeam parachain and Ethereum. However, Ethereum is not interoperable with Solana, Binance or Polkadot network.	Contextual(IV-C), Conceptual(IV-B) Technical(IV-A)	Business(V-D), Process(V-C), Service(V-B), Application(V-A)
Mainchain ↔ Sidechain	Level 3 - They are application-specific homogeneous networks that carry a shared understanding of its value. Interoperability is supported through some form of predefined protocols/ mechanisms such as Pegging.	Contextual(IV-C), Conceptual(IV-B) Technical(IV-A)	Business(V-D), Process(V-C), Service(V-B), Application(V-A)
Ethereum → Ethereum classic Rinkeby ↔ Ropsten	Level 2 - Technically they are homogeneous networks, therefore, syntax of data remain the same. Users within the network rely on external services to exchange value.	Technical(IV-A), Conceptual(IV-B)	Application(V-A), Service(V-B)
Ethereum ↔ Bitcoin	Level 1 - Both are application-specific networks with distinct value type. Users within the network rely on external services to exchange value.	Technical(IV-A)	Application(V-A)

able to address the technical and conceptual barriers, they are identified at Level 2. For example, with current Ethereum and Ethereum classic, network features such as block generation verification logic and data structure are relatively consistent to be considered as homogeneous networks. The distinction of LOI between Levels 1 and 2 are based on platform and value type. At Level 1, interacting blockchains have different value types and platforms; whereas at Level 2, blockchains use identical platform and value types that have similar properties[1].

The blockchain systems designed to seamless interoperability through a predefined integration system are identified to be at Level 3 or above. This integration can be *network to network*, *application to network* or *application to application*. From Level 3, the semantics of transaction values are agreed upon, therefore networks are able to recognise the values. At Level 3, homogeneous networks interoperate through shared states. For example, a side-chain is interoperable with the main chain through a peg system. Level 4 enables one way integration of heterogeneous networks though the integration system such as bridges. Finally, Level 5 is where two way integration of heterogeneous networks is enabled through integrated systems such as connectors. The connector will act as the intermediary that passes messages between networks.

By knowing the strengths and weaknesses on each level and demonstrating the current status of interoperability, an LOI model can be used for improving or enhancing interoperability. That means the proposed LOI model can be used to identify which aspect of interoperability is weak and requires improvement. Regardless of the layered approach it will not address how interoperability can be achieved, instead it assists on establishing processes how to achieve interoperability [14].

a) limitation: Cross-chain technology is still in its early stage of development. Therefore, several uncertainties remain to be addressed for cross-chain technology. For example, reasoning about network integration with different performance (transaction speed), security assumptions, and cost (gas usage) of cross-chain transactions in multi-network situation (who pays, how, what token) are not evaluated.

VIII. CONCLUSION

There are varying LOI, and different models already exist that are used to determine the degree of interoperability between information systems. However, to the best of our knowledge, such a model has not yet been established in the domain of blockchain. In an attempt to capture the evolving interoperability aspects of blockchain, this paper introduced a framework with a level of conceptual interoperability. Many challenges still remain, including formalising and demonstrating the applicability of this approach. The case study shows that the proposed framework is promising and suitable for comparing relevant elements. It enables us to determine the level of interoperability via complementary dimensions such as interoperability barriers and concerns. Future work will include other dimensions and refining the framework.

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