Towards a Standard Framework for Blockchain Interoperability: A Position Paper

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April 02, 2024

Abstract

Decentralized ledger technology (DLT) is becoming ubiquitous in today's society. However, organizations need to connect their existing systems and processes to blockchains (centralized, decentralized) securely and reliably, sometimes also implying that they need to connect blockchains (decentralized, decentralized). This challenge is known as blockchain interoperability.

We put the case forward that academia and industry must propose evaluation frameworks for blockchain interoperability solutions that address the three interoperability modes. Those are data transfers, asset transfers, and asset exchanges. In this position paper, we illustrate the remaining challenges of interoperability, focusing on the systematic evaluation of interoperability mechanisms based on the state of the art and our own experience. Our evaluation is a systematic online survey of 17 items targeting blockchain specialists. Our quantitative analysis shows that several interesting metrics can show promising directions for systematically evaluating integration solutions.

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***Abstract*—Decentralized ledger technology (DLT) is becoming ubiquitous in today's society. However, organizations need to connect their existing systems and processes to blockchains (centralized, decentralized) securely and reliably, sometimes also implying that they need to connect blockchains (decentralized, decentralized). This challenge is known as blockchain interoperability.**

We put the case forward that academia and industry must propose evaluation frameworks for blockchain interoperability solutions that address the three interoperability modes. Those are data transfers, asset transfers, and asset exchanges. In this *position paper*, we illustrate the remaining challenges of interoperability, focusing on the systematic evaluation of interoperability mechanisms based on the state of the art and our own experience. Our evaluation is a systematic online survey of 17 items targeting blockchain specialists. Our quantitative analysis shows that several interesting metrics can show promising directions for systematically evaluating integration solutions.

***Index Terms*—Blockchain, DLT, Cross-chain bridge, Interoperability**

I. Introduction

Blockchains that are isolated siloes of data and value might have a hard time competing with open systems that leverage data from multiple sources [1]. If blockchain technology seeks to become a part of the IT infrastructure of mainstream economic systems – following the natural incentives in a free market and self-regulated family of ecosystems – then blockchains need to become more interoperable. A key aspect for the successful adoption of new technology by enterprises – including blockchain-based applications and blockchain platforms – is the ease with which these new technologies can be integrated into existing business processes [2]. Thus, the *integration capabilities* [3], [4] of a given blockchain system will be a gating factor in its successful adoption and deployment. To promote the interoperability [1] across processes, systems, organizations, and even jurisdictions [7], [4], [8], an *interoperability framework* will be needed together with standardization efforts based on that framework for common components that will become commoditized over time. As an example, the Internet Engineering Task Force (IETF) [9] has recently embarked on this standardization road through the establishment of a new working group – called the Secure Asset Transfer Protocol (SATP) Working Group – seeking to address the challenge of reliable transfers of digital assets [10].

The state of the art covers different fronts of the same problem: interoperability solutions are used to alleviate the problems of higher availability of liquidity across ecosystems, with a wide range of research papers on the topic [11], [1]. The statement we support in this position paper is the need for improving the *evaluation of interoperability mechanisms*. Although extensive work has been done comparing and benchmarking blockchains [12], [13], there is no consensus on how to compare blockchain interoperability systems systematically. In fact, despite almost a decade of research, very few papers tackle the need for interoperability benchmarks [4], [14], or in fact, conduct benchmarks, but only for one specific solution [15].

By comparing solutions systematically, we can: 1) discern the trade-offs between solutions and therefore choose the ideal for a given use case, 2) identify faults in current systems and improve the state of the art, and 3) build more resilient and secure systems. This latter aspect of security is particularly important when the year 2022 saw more than $2 billion in losses due to hacks in cross-chain bridges [16], [17], [11]. A reasonable question to start such an endeavor is, "What are the technical concepts that underline the evaluation of a cross-chain system?" There are two, in our view: *cross-chain transactions* [18], [16], [1], and *cross-chain rules* [16], [19]. Cross-chain transactions are a set of local transactions that realize business logic, i.e., cross-chain rules. Cross-chain rules define the sequence of transactions that should happen in more than one domain. They can be represented as datalog rules [16].

While these concepts have been introduced in the literature, we will refer to them briefly in the background section. From this starting point, we conduct a systematic study with practitioners and academics working in the field and raise the following research questions: (1) *What are the relevant metrics to study when comparing cross-chain solutions?*, (2) *What are the relevant metrics to assess cross-chain transactions and solutions?*, and (3) *How to systematically analyze and visualize cross-chain rules?*. We contribute to the community with our survey results, its discussion, and industry insights that can

[1] for a historical perspective on interoperability, the interested reader can consult [1], [5], [6].

help build a blockchain interoperability framework. By studying these research questions, practitioners can choose, develop, and deploy the solution with the best trade-off considering their use case (functionality, throughput, cost, and others).

This position paper is organized as follows: Section II presents background on the cross-chain research area. Section III presents our study. Finally, we present suggestions for future work and conclude the paper.

II. Background

A cross-chain rule (or cross-chain logic), i.e., the business logic a cross-chain application runs, is a mapping taking a set of transactions from a source ledger to a set of transactions in a target ledger, i.e., an abstraction taking a set of triggers from a system that fires a set of actions on another. Cross-chain logic tells if a set of cross-chain transactions is valid within the boundaries of a use case, which translate into local transactions on their respective blockchain (or centralized system) [16] (e.g., see the hash time-locked contract technology that implements simple cross-chain rules [20]).

A cross-chain transaction is a set of local transactions (happening in different chains) that are related by rules [16]. Applications issuing cross-chain transactions to implement their business logic (or cross-chain rules) are called cross-chain applications. A cross-chain transaction is a series of atomic transactions on different ledgers designed to accomplish a logical unit of work (follow cross-chain rules) [21]. For example, an asset transfer conducted via a cross-chain transaction is decomposed into two transactions: one locks an asset on a source blockchain, and another creates a representation of such assets in another blockchain.

The execution of cross-chain logic generates a cross-chain state, which can account for and track several metrics (e.g., *performance, end-to–to-end latency, energetic consumption*). Later in this paper, we will present some of our findings with regard to metrics that are considered desirable to measure. These measurements can provide the tools for developers to manage the life cycle of assets spawning across chains. On top of these metrics, visualization tools for cross-chain transactions could also help to analyze and infer implicit business rules. One could inspect if cross-chain logic conforms to the defined business processes - and improve those rules, similarly to common practice in the area of process mining [22]. Analysis can identify bottlenecks, paving the way to improve performance and cut costs.

> *Key Takeway 1:* Fundamental concepts
>
> The fundamental concepts in blockchain interoperability are cross-chain transactions, cross-chain rules, and cross-chain state.

We exemplify the concepts of cross-chain transactions and cross-chain rules using the Carbon Emission Application from the Carbon Accounting and Certification WG, under Linux Foundation's Hyperledger Climate Action and Accounting SIG [23], [4]. The Carbon Accounting and Certification WG aims to improve corporate carbon accounting by promoting transparency and accountability. To this end, a multiple blockchain approach is used. This use case is implemented in Hyperledger Cacti [19], an open-source blockchain interoperability project (see Figure 1). This project utilizes a permissioned network, Hyperledger Fabric (Fabric), that gathers the energy used by corporations and converts it to emissions (Rule #1). Then, these emissions are tokenized as emissions tokens on the public Ethereum network (Rule #2) so that one can trade emissions against allowances. When Rule #1 is triggered, Cacti creates Tx1 (converting the energy into emissions) on Fabric. When Rule #2 is triggered, Cacti creates Tx2 (tokenizing the emissions) on Ethereum. This combination of technologies allows maintaining sensitive data privacy while publicly rewarding the participants.

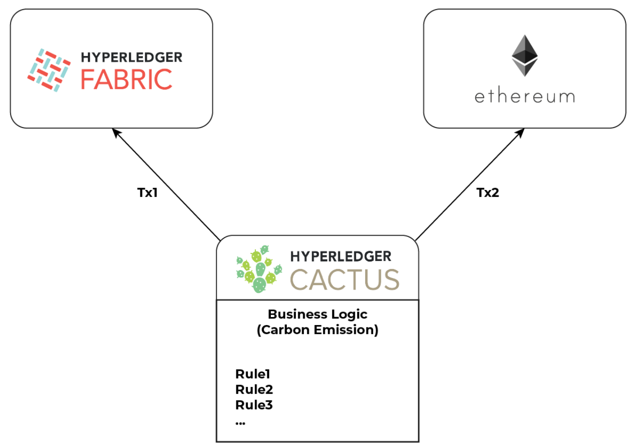

Fig. 1. System supporting cross-chain logic between two blockchains

III. Surveying The Interoperability Community

In this section, we showcase the methodology and findings of our survey.

A. Methodology

Analysis and visualization of cross-chain rules is a key factor for enterprise adoption of multiple DLT approaches [24]. In order to develop a better understanding of what metrics and pieces of information are the most relevant for end-users when performing cross-chain transactions and gather insight on how to visualize these transactions effectively, we used a quantitative approach through an online survey. The advantages of using online surveys - such as the "convenience of having automated data collection, which reduces researcher time and effort" [25] - are well-documented [26], [27].

Our survey was designed following some basic rules and principles described by literature [28], [29] and administered to both experts (i.e., individuals who have developed and/or managed - running and/or maintaining - a blockchain interoperability solution) and non-expert users. It should be pointed out that participants of the latter group, although are no experts in blockchain interoperability, are still to be considered experts in the area of blockchain technology. The survey comprised 17 items (open- and closed-ended questions) and was structured into the following three main parts:

1) collection of demographic information, e.g., experience and knowledge of blockchain technology.
2) section on cross-chain transactions, comprising nine questions (five open-ended and four closed-ended items) addressing aspects such as experience with decentralized applications (dApps), understanding of cross-chain logics, relevant metrics, and information needs.
3) optional open-ended questions for additional feedback and the opportunity to provide a contact for follow-up questions.

The survey was administered online for 24 days. We shared the survey link through the official channels of the Linux Foundation and Hyperledger[2]. A mixed approach (quantitative and qualitative) was used to analyze the data.

B. Results and Discussion

A total of 26 individuals participated in the survey. Most of them were software developers (n=9) and blockchain architects (n=9). The professions of the remaining respondents included academics (n=4), CEO/CTO (n=3), investor (n=3), and others (n =4). Among them, 6 out of 26 respondents (24%) are 'experts' - i.e., individuals who have developed and/or managed a blockchain interoperability solution. Most of the respondents in our sample are very experienced, with only five people having less than one year of blockchain experience. The experience of the remaining 21 individuals ranged from 2-3 years (n=6), 3-5 years (n=10), and more than five years (n=5). Projects developed by the expert group include protocols for verifiable data transfer between permissioned and permissionless blockchains and multi-chain payment channels. The non-experts group accounted for 76% of the population. Although a total of 26 participants may be considered a limited sample, considering that the blockchain interoperability field is in its inception, we believe that the number of responses to our survey is significant.

The survey results indicate that there is no system in production to help users track cross-chain logic or gather and view cross-chain transaction metrics, a conclusion backed up by recent research [1]. Only 5 out of 26 people (i.e., 20% of the respondents; a quite high percentage considering the novelty of the field) reported using general-purpose data traffic analysis systems (e.g., Grafana, and Prometheus to cross-analyze requests between servers) to answer this need partially. Although an excellent initial approach, the visualization could be limited to the base features of Prometheus or the other systems used. Furthermore, eight respondents reported actively gathering metrics over the cross-chain logic. Five of them further detailed their answer by reporting which metrics they gathered. These are: total transactions (2 respondents), throughput (1 respondent), transaction status (1 respondent), transaction propagation time (1 respondent), latency (1 respondent), and time consumption - execution and communication - for each step (1 respondent).

[2]The raw data from the survey can be accessed here.

TABLE I
MEAN, STANDARD DEVIATION, AND STANDARD ERROR OF THE METRICS

Metric	Mean	SD	SE
end to end latency	3.69	1.289	.253
end to end throughput	3.62	1.235	.242
energy consumption	2.65	1.198	.235
carbon footprint	2.73	1.402	.275
transaction fees	3.27	1.251	.245
parties endorsing transactions	3.5	1.175	.230
crosschain logic	3.42	1.172	.230

Besides exploring the current practices - which are ultimately influenced by the existing software solutions- we wanted to dive deep into the information needs of our target users. For this reason, as part of the survey section on cross-chain transactions, we have asked them:

1) to rank a set of seven metrics, using a Likert scale from 1 (least important) to 5 (most important), depending on the relevance of their work on blockchain interoperability solutions (see Figure 2);
2) for those ranked as 'most important', to provide a brief explanation of why such a metric is considered particularly relevant (optional); and
3) to list additional metrics - i.e., not included in the previous question - that they would like to access and why.

The data gathered was statistically analyzed using IBM SPSS Statistics Version 28 and found reliable with α = .865. Mean, Standard Deviation (SD), and Standard Error (SE) for each of the metrics included in the survey are presented in Table I. Except for "energy consumption" (2.65) and "carbon footprint" (2.73), all the metrics identified scored, on average, above 3 (on a 5-point scale). The average scores for end-to-end latency, end-to-end throughput, parties endorsing transactions, cross-chain logic, and total transaction fees were 3.69, 3.6, 3.5, 3.4, and 3.3. A 38% indicated that the most crucial metric is the end-to-end latency of cross-chain transactions, while 31% indicated end-to-end throughput as the most important feature. We hypothesize that the performance metrics (latency, throughput, fees) are more relevant to developers at this stage of the maturation of blockchain interoperability, as opposed to qualitative metrics (energy consumption, visualization of cross-chain logic, carbon footprint, and endorsing parties).

Around 31%, 35%, and 38% voted on parties endorsing the transaction, transaction fees, and the visualization of cross-chain rules, as their second most important metric, respectively. According to 27% of the respondents, the least important metric is the carbon footprint of cross-chain solutions.

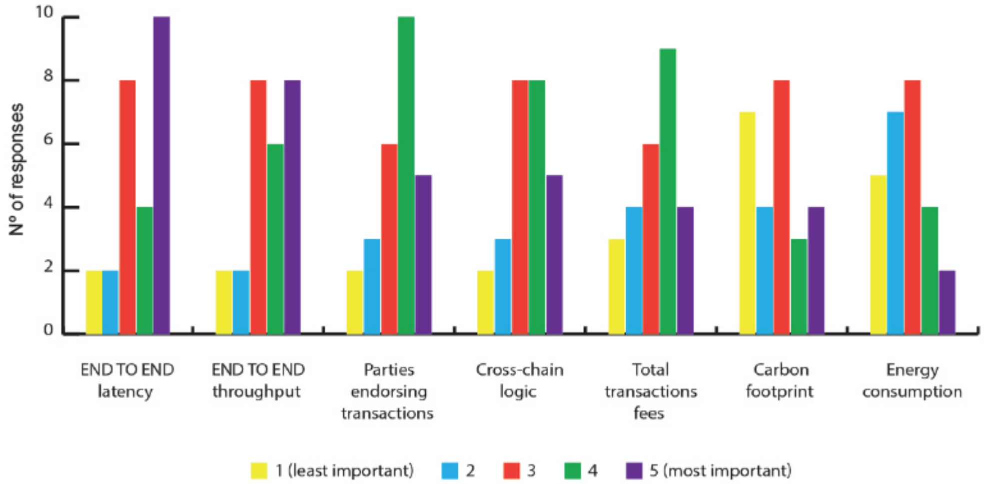

Fig. 2. Results from the survey: weighted average (1 to 5) of each proposed cross-chain transaction metric

Key Takeway 2: Most important metrics

Performance metrics, such as end-to-end latency, throughput, and cost (transaction fees), are currently the primary concerns for cross-chain analysis.

End-to-end latency and throughput are "what drives a better user experience, which is the prerequisite of success in many cases". While qualitative metrics would be a prerequisite for a good experience for cross-blockchain middleware [7], [30], [31], performance metrics are essential since they are indicators of the security and the resilience to crashes [32] of the network (e.g., a diminishing of the throughput occurs when gateways crash) and even attacks on the interoperable mechanism [16] (in bridges, an increase in the throughput, or the change in the expected order of transactions might be indicative of an attack). A trade-off between performance, cost, and a better user experience can and should be studied. Visualizing cross-chain rules, namely the lifecycle of the cross-chain process, can provide insights into a solution's security and sound operations. For instance, a sudden decrease in the total value locked in a bridge (encoded as part of the cross-chain state) could indicate an attack. Other hints could be high variance in transaction throughput or cost. This would allow understanding, for instance, if finality has been achieved for a specific cross-chain transaction (a set of atomic transactions on their respective ledgers).

IV. Conclusions and Recommendations

With blockchain interoperability solutions gaining popularity in academia and industry, there is a need to conduct systematic, comprehensive evaluations that follow the same model. In this position paper, we conducted a comprehensive survey within the blockchain community to derive the parameters for systematically evaluating blockchain interoperability systems. Our starting point was the foundational concepts of blockchain interoperability, including cross-chain transactions, cross-chain logic, and cross-chain state. Our survey showed the potential to explore the end-to-end latency, end-to-end throughput, cross-chain cost metrics, and cross-chain logic as the foundation for systematic comparison of solutions.

Cost, latency, and throughput will provide a foundation for comparing solutions because integration systems introduce yet another performance bottleneck to blockchains (thus measuring latency and throughput is important). Furthermore, measuring cost is important due to the interoperability mechanisms' operational expenses (on-chain fees, off-chain hardware, development effort). Thus, for an interoperability mechanism to stay competitive, a careful trade-off in these dimensions needs to be made.

The collection of such metrics enables the industry and academia to create supporting tools, innovative technologies, and different evaluation frameworks. We hope that advances in this area remove barriers to enterprises' adoption of blockchain.

Acknowledgements

This work was developed within the scope of the project nr. 51 "BLOCKCHAIN.PT - Agenda Descentralizar Portugal com Blockchain", financed by European Funds, namely "Recovery and Resilience Plan - Component 5: Agendas Mobilizadoras para a Inovação Empresarial", included in the NextGenerationEU funding program. This work was supported by the European Commission under project BIG ERA Chair (grant agreement 952226). Rafael Belchior was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UIDB/50021/2020 (INESC-ID), 2020.06837.BD.

We thank Iulia Mihaiu for implementing software related to these ideas in a project supported by *The Linux Foundation* as part of the *Hyperledger Summer Internships* program under the *Visualization and Analysis of Cross-chain Transactions* project. We thank all the respondents of our survey and the open-source community for supporting this work. We warmly thank Peter Somogyvari for valuable discussions on the topic and for providing support on Cacti. We thank Si Chen, Pritam Singh, Miguel Correia, and Luke Riley for their insightful discussions.

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