Inter Blockchain Communication: A Survey

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ABSTRACT

Blockchain technology is growing massively where the number of blockchain platforms and decentralized applications are increasing rapidly in the last years. However, most of the existing blockchain networks are operating in a standalone environment isolated from each other, which increases scalability and connectivity issues in the current blockchain platforms as well as limiting the blockchain adoption in industry ecosystems. In the current phase, different blockchain networks don't have mutual trust where they cannot interact with each other and their capacity level has only reached a level similar to LAN. Due to the high barriers between the independent isolated blockchain platforms, researchers have started to focus on the concept of Blockchain interoperability. Blockchain interoperability is the ability of connecting multiple blockchain networks together, which significantly increases and solves scalability and connectivity issues in the blockchain platforms. Given the potential of blockchain interoperability and cross blockchain communication, many researchers are working on finding the optimal cross blockchain communication solution. As blockchain interoperability is emerging as an essential blockchain feature, the number of proposed blockchain interoperability solutions have been increasing within the last few years. In this paper, a survey of all the available cross blockchain communication solutions are discussed with a comparison of the proposed architectures.

CCS CONCEPTS

• Scalability → Distributed systems Scalability • Computer systems organization → Peer-to-peer architectures

KEYWORDS

Blockchain Technology, Inter Blockchain Communication, Blockchain Interoperability, Scalability

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1 Introduction

With the fast development of Blockchain technology, the number of applications has increased massively in many different fields such as finance, asset-management, cloud storage and identity management. However, industry adoption of the blockchain technology is limited due to some issues in current blockchain platforms such as scalability, privacy and lack of governance. Blockchain interoperability can be shown to increase the scalability of the blockchain networks significantly and also increase user adoption of the blockchain technology. An interoperable blockchain architecture as defined by NIST [1] is a group of homogeneous or heterogonous blockchain platforms, each with its own distributed data ledger, where the execution of a transaction can be participated in by multiple platforms, and where the recorded data in one platform or ledger is accessible and verifiable by another external transaction in a semantic way. Interoperability allows exchanging and transferring data between systems, but interpreting and interacting with the exchanged data depends on the interoperability level, whether it is foundational, structural or at the semantic level. At the foundational level the data exchange is allowed between the systems but interpreting the exchanged data is not allowed. At the structural level, the transferred data can be interpreted, but the data cannot be interacted with nor used. On the other hand, at the semantic level, the data exchanged between systems can be interpreted and used. Blockchain interoperability can achieve many possible use cases [2] such as:

- Portable assets where the assets can be transferred from one application or chain to another.
- Transfer-for-transfer or Atomic Swap where two assets are exchanged between two users on different blockchain networks in a secure manner.
- Asset Locking where an asset can be released and transferred from a certain chain, if and only if, a payment is secured and transferred from another chain.
- Cross-chain oracles use case is when one-way data reading is required to perform an action from a different chain.
- General cross-chain contracts where a smart contract is dependent on multi-chains data to trigger an action on the smart contract.

The main contribution of this paper is as follow:

1. We have done a comprehensive survey of all the available cross communication solutions and classified them into four categories.

2. We have discussed the current state of blockchain interoperability, its challenges, and possible future directions in this field.

2 Inter Blockchain Communication Solutions

In this section, a review of all the available inter blockchain communication solutions are discussed. We have classified the available solutions into four categories, sidechains solutions, blockchain router, smart contracts and industrial solutions. the criteria used in the following tables differs as they describe different approaches and solutions.

2.1 Sidechains

Sidechain is one possible implementation to achieve interoperability between multiple different blockchains and used in many blockchain projects as shown in table 1. The term was first introduced by Back et al. [3], where a pegged sidechain was proposed to allow asset transfer between bitcoin and other cryptocurrencies and vice versa.

Sidechain interoperability is limited to transferring assets in a 1 to 1 relationship and the number of total assets doesn't increase. Another tradeoff of sidechain implementation is that the vulnerability might increase in the main chain or other sidechains if there is a compromised sidechain in the network [9]. Also, the sidechain approach focusses only on homogeneous blockchain system.

Drivechain[9] was proposed to limit the effect of sidechains on the main chain in terms of needed efforts to validate a transaction. However, the inherent limitation in sidechain security was not discussed in Drivechain.

Table 1 Sidechain projects

Project	Main chain	Type	Sub chain	Architecture	Consensus Mechanism	Scripting language
RSK [4]	Bitcoin	2-way peg	RSK	Miners, nodes, and federation	Proof of Work	compatible with Solidity
Elements Alpha [5]	Bitcoin	Federated 2-way Peg	Elements	Watchmen Block Signer	Strong Federation	Elements Alpha script language
Plasma [6]	Ethereum	Tee hierarchy	Plasma	Minors, nodes	Proof of stake	Solidity
POA network [7]	Ethereum	Connects POA network to Ethereum and vice versa	POA Network	Validators, nodes	Proof of Authority	Solidity
Mimblewimble [8]	Bitcoin	Connects Grin to Bitcoin and vice versa	Grin	Miners, and nodes	Mimblewimble	No scripting language

2.2 Blockchain Router

In this section, approaches that require some blockchain nodes to act as routers that transmits requests between different blockchain networks are discussed.

Wang et al. [10] introduced a blockchain router that enables multiple blockchains to communicate with each other. The architecture of the approach consists of four participants; validator, surveillant, nominator and connector. The consensus algorithm applied in this approach is similar to PBFT.

Kan et al. [11] proposed a multiple blockchain architectures for reliable asset transfer across the different blockchain network. For routing management in the network, the paper introduced inter-blockchain connection model. The proposed architecture has four layers: basic layer, blockchain layer, multi-chain communication layer and application layer. The paper also introduced a unified packet for the transaction and routing.

Anlink Blockchain [12] introduced an enterprise blockchain architecture that connects multiple blockchains and enables cross chain communication by using an inter blockchain communication protocol (CBCP). The proposed architecture consists of Ann-Router, AnnChain combined with other blockchain systems. This approach uses Delegated Stake-PBFT as the consensus algorithm.

Ding et al. [13] proposed Interchain which is a framework for cross communication between any pair of blockchains. The proposed framework architecture consists of subchain, InterChain, interchain nodes, validating nodes, and gateway nodes. To complete asset transfer between different blockchains three handshaking method is used. However, the paper didn't include any consensus algorithm to support the framework.

Chen et al. [14] introduced a private token-based inter-Blockchain communication to support cross communication between separate blockchain without any intermediaries. Chen et al. used a routing algorithm and PBFT as the consensus algorithm. The main limitation in this work is that it highly affected the system throughput.

2.3 Smart Contracts

In the section, approaches that use smart contract to create interoperable protocol between homogeneous blockchain are discussed.

Li et al [15] proposed a satellite chain which is a blockchain architecture that meets the industrial standards. The architecture

consists of independent subchains that run their own different consensus algorithms and a regulator that administrates the whole network and specific roles using smart contract. Satellite chain supports heterogeneous consensus algorithms to run in parallel in different sub chains. A proof of concept was implemented on Hyperledger fabric 0.6 platform.

Dagher et al. [16] investigated the ability to achieve interoperability between heterogeneous blockchains using smart contract. The proposed solution consists of a smart contract that enables data sharing between independent heterogonous blockchains. As proof of concept, the proposed on two Ethereum network, one is public and the other is a private network. The authors didn't succeed to apply their solution between two hybrid systems.

P. Bennink et al. [17] studied and analyzed the different available approaches to perform atomic swap on Ethereum blockchain platforms. A cross-chain atomic swap is a transferring or exchanging assets between multiple participants across multiple blockchain platforms such as exchanging ether for bitcoin. Engineering also designed swap contracts for single usage to be created for every swap.

Table 2 shows the summary of the available solutions in the categories of blockchain router and smart contract.

Table 2 List of the available solutions in the categories of blockchain router and smart contract

Category	Scheme	Architecture	Summary	Consensus Mechanism
Blockchain Router	Wang et al. [10]	Validator, surveillant, nominator and connector	Introduced blockchain router that enables multiple blockchains to communicate with each other.	Similar to PBFT
	Kan et al. [11]	Basic layer, blockchain layer, multi-chain communication layer and application layer	Proposed multiple blockchain architectures for reliable asset transfer across the different blockchain network.	-
	Anlink Blockchain [12]	Ann-Router, AnnChain combined with other blockchain systems	Introduced an enterprise blockchain architecture that connects multiple blockchains and enables cross chain communication by using a cross blockchain communication protocol (CBCP).	Delegated Stake-PBFT
	Ding et al. [13]	Subchain, InterChain, interchain nodes, validating nodes, and gateway nodes	Proposed Interchain which is a framework for cross communication between any pair of blockchain	-
	Chen et al. [14]	-	Introduced a private token-based inter-Blockchain communication to support cross communication between separate blockchain without any intermediaries.	PBFT
Smart Contracts	Li et al. [15]	Independent subchains and regulator	Proposed satellite chain which is a blockchain architecture that meets the industrial standards.	Heterogeneous consensus algorithms
	Dagher et al. [16]	Independent heterogonous blockchains (Ethereum)	Investigated the ability to achieve interoperability between heterogeneous blockchains using smart contract	Proof of Stake
	P. Bennink et al. [17]	-	Studied and analyzed the different available approaches to perform atomic swap on Ethereum blockchain platforms.	-

2.4 Industrial Solution

In this section, available industrial solutions that are currently on the market are discussed.

Cosmos project [18] aims to implement network of blockchains, where Inter-Blockchain Communication (IBC) protocol is used to connect independent blockchains. Cosmos blockchain has its own token called "Atom". Cosmos architecture consists of two main components which are shared cosmos hubs and zones. Zones are the independent blockchains while the hubs connect between different zones. The tendermint core is used to underline architecture of the zones and the cosmos hub. It provides PBFT-like consensus engine.

Polkadot project [19] is a cross communication technology between heterogeneous blockchains. The token used in this project is Dot. The architecture of Polkadot has three main classes: Parachains Relay chains, and Bridges. Parachains represent the heterogeneous blockchains, relay chains manage transaction consensus and delivery, while the bridges act as a connector between the parachains to their consensus, Also, in Polkadot network, the members can serve as one of the four roles available which are Validators, Nominators, Collators, and Fishermen.

The consensus algorithm that will be implemented in Polkadot is proof of stake protocol. The project is still in its early development state, with a lunch date proposed by the third quarter of 2019.

The ICON Project [20] targets connections between different blockchain entities and communities such as financial institutions, government offices, hospitals, and universities through its

platform. The platform consists of Nexus and ICON Republic. Nexus is a group of the independent blockchain entities which are connected through ICON Republic portals. ICON uses Loop Fault Tolerance (LFT)as its consensus algorithm and its official token is ICX. LFT is an improvement of BFT consensus algorithms using tendermint. The main limitation of the project is that it is focused and designed for Korea and it follows the policies regulated for blockchain and crypto companies in Korea.

Aion Project [21] aims to allow different blockchain platforms to communicate and create cross chain interoperability. Aion architecture is a multi-tier blockchain network that has four main components which are Connecting Networks, Interchain transactions, Bridges, and Participating Networks. Connecting networks are the protocols which different and independent blockchains can use to communicate within the AION Platform. Interchain transactions allow for the transfer of data between the connected blockchains to the ecosystem. The interchain transactions are validated by the bridges which are a group of validators. While any blockchain network can be a participating network if it has satisfied some requirements defined by the Aion ecosystem. The consensus algorithm used by Aion ecosystem is a hybrid staking and proof-of-intelligence system. Aion blockchain token is called AION.

Wanchain blockchain [22] is a fork of Ethereum project, which is based on financial infrastructure. The aim of the project is to allow asset transfer between unconnected and independent blockchains. Wanchain consists of three main modules: registration module, cross chain transaction data transmission module and transaction status query module. Wanchain will use the proof of stake consensus mechanism like Ethereum. The token of the wanchain project is WAN. Although Wanchain project has a very promising business vision as the distributed banks, its roadmap currently has only the connectivity between Bitcoin and Ethereum as milestones.

The Blocknet [23] protocol provides inter-blockchain services such as decentralized exchange (DEX) to cryptocurrency and token based blockchains. The protocol supports most of the existing cryptocurrencies that exist nowadays. The architecture of Blocknet consists of three main components Blockchain router, Decentralized asset exchange protocol, and Inter-chain data transport. The router is used to choose the proper service nodes to direct the requested service. The purpose of the exchange component is to allow for cross chain transactions between different cryptocurrencies. The third component allows for data transfer from one chain to another. The consensus mechanism used in this protocol is Proof-of-Stake (POS) consensus algorithm.

Ripple introduced an Interledger protocol (ILP) [24], is a protocol that supports atomic swap between different blockchain platforms. Interledger protocol is not a blockchain platform nor does it require a consensus mechanism. It provides sender and receiver isolation to avoid any intermediary failure risks. A secure transfer is enabled in the protocol by using hash locking, where the payment is conditionally locked until the transfer is secured.

ARK project [25] aims to increase the adoption of blockchain technology by creating a framework that enables any user to build their own blockchain in a small amount of time. The key feature of this project is smart bridges. Smart bridges are used to make connections between incomplete and independent blockchains, where ARK will act as the intermediate layer between the blockchains. ARK has its own token called "ARK". The consensus algorithm used in this project is the Delegated Proof of Stake (dPoS) consensus mechanism.

Hyperledger Quilt [26] is the implementation of the interledger protocol [24] in Java. The protocol is designed to provide interoperability by transferring value across systems (atomic swap). The project is in its early stage in development, and there is no available whitepaper for it.

Metronome [27] is a project that aims to create a better cryptocurrency solution by enhancing current crypto systems. Along with enhancing the throughput, Metronome enables cross-blockchain transfer, where a user can transfer its token from one blockchain to another using a proof-of-exit receipt. The token used in this project is MTN.

Block Collider [28] is a multi-chain platform built on a group of existing exported blocks from other blockchains in the network, integrating the chains together to provide cross-chain features. The Block collection from the connected blockchains is done by peer-to-peer decentralized miners with no centralized validators. Block collider uses a proof of distance consensus mechanism which is a modified version of the proof of work consensus algorithm.

Table 3 Industrial available solutions

Project	Architecture	Type of connected Blockchains	Consensus Mechanism/ Protocol	Token
Cosmos [18]	Shared cosmos hubs and Zones	Public Ethereum and Bitcoin	Inter-blockchain Communication protocol	Atom
Polkadot [19]	Parachains Relay chains and Bridges	Public Ethereum and Bitcoin	Polkadot	Dot
ICON [20]	Nexus and ICON republic	Cryptocurrencies	Loopchain	ICX
Aion [21]	Connecting Networks, Interchain transactions, Bridges and Participating Networks	Focus on Ethereum as the main chain	Aion	AION
Wanchain [22]	Registration module, Cross chain transaction and Data transmission module	Cryptocurrencies	Wanchain Cross-Chain protocol	WAN

Blocknet [23]	Blockchain router, Decentralized asset Exchange protocol and Inter-chain data transport	Cryptocurrencies	Blocknet	-
Interledger protocol [24]	-	Cryptocurrencies	Interledger protocol	-
ARK [25]	Smart bridges	Cryptocurrencies	Delegated Proof of Stake (dPoS)	ARK
Hyperledger Quilt [26]	-	Cryptocurrencies	Interledger protocol	-
Metronome [27]	-	Cryptocurrencies	Proof-of-exit receipt	MTN
Block Collider [28]	Miners and Multi-chain platforms	Cryptocurrencies	Proof of distance	-

3 Discussion

We have classified the available solutions into four categories, sidechains solutions, blockchain router, smart contracts and industrial solutions. Table 4 shows a comparison between the different categories and discuss their weakness and limitation.

As shown in tables 1,2 and 3, most of the available solutions either address the crypto ecosystem or support homogeneous blockchain systems. Unfortunately, the focus on connecting heterogeneous blockchain platforms might seem complicated and need a few more years to exist. It's a challenging task to connect multiple heterogeneous platforms, where each platform has its own architecture, protocol and consensus algorithm. Also, the ability to share applications or smart contract between the connected blockchain networks are not discussed where the focus was on only sharing assets or exchanging tokens. Most of the existing industrial projects use validators (also called hub, masternode, etc.) to validate and guarantee the node state and their honesty. The drawback of this approach is that if the validator is attacked then the trust in the network is compromised and destroyed.

There are some challenges that researchers should address and ensure when designing for inter blockchain communication solutions which are the reliability of the proposed solution, the performance of the solution compared to the blockchain networks and the ability to reach the nodes in the system. One of the important features for having a successful interoperable blockchain is alliance. Any interoperability solution will work the best with the cooperation of the participating blockchain platforms.

Table 4 Comparison between different categories

Category	Description	Weakness and limitation
Sidechains	In this approach, a two-way peg is used to connect a separate blockchain to a main blockchain which enables transactions and digital assets to flow between different blockchains.	• Only Implemented for cryptocurrencies. • The main blockchain should be upgraded in order to communicate with the sidechain blockchain.
Industry Solutions	Most of the industrial solutions use a trusted entity or a group of trusted entities (validators) is used to validate transactions and nodes.	• Single point of failure if the validator or the trusted entity is compromised or down.
Routers	In this approach, some blockchain nodes act as routers to transmit requests between different blockchain networks.	• All the proposed solutions in this category are not Implemented yet, where they only proposed the architecture and the design. • The node structure of the platform should be changed so it can act as router.
Smart Contract	smart contracts are used to create interoperable protocol between different blockchain networks.	• There is a research gap in studying the use of smart contract to create interoperable protocol. • The ability to share smart contracts is not available.

4 Conclusion and Future Work

This Survey explores the available blockchain interoperability solutions and compares between the proposed architectures. Unfortunately, from the current available solutions, there is no complete interoperable architecture that can address the requirement of the industry ecosystem.

Once interoperability is reached among the major blockchain platforms it will unlock diverse applications, including in finance, data storage, and smart contracts, where a successful cross blockchain communication protocol could become the new backbone of the internet.

Future research directions in blockchain interoperability field will rely on solving the current challenges of available systems. Also connecting heterogeneous blockchain platforms will be a huge paradigm shift for the blockchain network. Another research gap exists in investigating the use of smart contract to create interoperable protocol between homogeneous blockchain. Also, the ability to share applications and smart contracts between different blockchain networks can be a good case study where the current focus is on transferring assets or exchanging token.

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