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Empirical Investigation on Blockchain Interoperability

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ABSTRACT
With the emerging employment of blockchains in different fields a need for blockchain intercommunication has arisen but there is no set standard yet for blockchain development, adoption and implementation due to which its interoperability has become a challenge. Interoperability refers to the mechanism of exchange and utilization of information between two software or computer systems etc. In blockchain, interoperability is the process of data creation, transfer and storage between two blockchains or blockchain applications. Blockchain interoperability is complex as every blockchain may have a different implementation platform and protocol for consensus mechanism. Bringing together two different blockchains and enabling communication between them without modifying their underlying implementation structure is a challenge today. There has been ongoing research in this domain to achieve interoperability in blockchains effectively. Its importance is evident from the fact that blockchain interoperability is vital for promoting scalability which is another research challenge presently. Apart from this, blockchain interoperability also promotes data privacy, application flexibility and portability and provides new opportunities in business. In this paper we have discussed in detail the three approaches and the solutions they provide for implementing blockchain interoperability. An empirical based analysis has been used to strengthen our methodology, which takes into consideration the selection of known & established blockchain network with state-of-the-art tools and technology. In order to have seamless communication across different chains, light clients (representing the respective chain) have been enabled to store each other's information such as protocol version etc. In this way, the handshake between both the chain has resulted in a successful IBC (Inter Blockchain Communication) inside the Cosmos environment. It is concluded that although blockchain interoperability is being implemented today, this implementation is highly restricted to specific organizations or software tools. Moreover interoperability between two different blockchains is still an ongoing challenge. This study will assist the future work in the domain of blockchain interoperability as it makes the understanding and implementation of blockchain interoperability easier.

KEYWORDS
Blockchain, Blockchain Interoperability, Interoperability

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INTRODUCTION

Blockchain is a technique of recording information in such a way that once that information is saved it becomes impossible to modify or manipulate it. As evident from the name blockchain is a blocks' chain in which each block is a storage of different transactional records and the chain is a distributed database shared to each node in a peer-to-peer network [1]

Blockchain is a decentralized and immutable ledger that has a chain of blocks[2]. The length of the blockchain is increased by adding blocks. Block is a data structure used to hold transactions by a peer in the blockchain network[3]. These transactions are locked in an irreversible chain. Every block has a hash value that links it to the block before it forming a chain. Due to the accuracy ,transparency, immutability and security of the blockchain technology, it is well suited for application in various domains. Blockchain was created behind bitcoin, a decentralized digital currency, in 2009. Every Bitcoin transaction is recorded on the blockchain. Over the whole network this bitcoin blockchain is distributed without any involvement of any country or third party. There are multiple permissioned and permissionless platforms of block chain. Amongst them ethereum is a well known platform. It is a decentralized transaction based platform which has its own cryptocurrency called Ether or Eth. Transactions on this platform are made through ethereum accounts[4]. Blockchain interoperability refers to transfer of the assets and value and sharing of information across different blockchains.The interoperability of blockchain is a challenge because there is no protocol which can be used as a standard to integrate two blockchains together. Blockchain interoperability consists of three aspects namely cross-authentication, oracle and API gateway. These methods have their own advantages and disadvantages [5]. There are some softwares available for providing interoperability solutions including cosmos, polkadot, Wanchain, Chain Link , Hybrix and many more. Blockchain interoperability has many applications as it can make the transactions more easy and secure but due to some challenges it is still to be implied. There are several interoperability solutions that are side chain ,bridging solutions, pooled security and inter blockchain communication.these solutions are yet to be refined in order to make it applicable to the real world applications. This paper provides an overview of blockchain technology with its types ,architectures and platforms. We describe the blockchain interoperability in detail ,its importance and the challenges of blockchain interoperability to make it a real case. The solutions to make the blockchains interoperable have also been elaborated in detail .We have implemented the cosmos' inter blockchain communication protocol by a handshake among two blockchains.

The entire paper is splitted into five sections. Section I gives a brief introduction of blockchain interoperability. The following section gives a detailed review of the previous work related to the topic. Section III outlines the blockchain technology , the definition, the architectures, its working, platforms and importance. Section IV describes the definition of blockchain interoperability with its challenges, use cases, advantages and disadvantages.section V gives the detailed overview of the blockchain interoperability solutions with its types and examples along with their working.Section VI illustrates the implementation of cosmos interoperable platform to make handshake among the two concerned blockchains. Section VII describes the limitations of the research and the future work that can be done and section VIII gives the conclusion.

RELATED WORK

Blockchain is a decentralized, immutable, distributed ledger and the interoperability is the ability of several blockchains to exchange information, and use it. In the paper [2] the authors conducted a comparative study of blockchain tradeoffs, architecture and discussed categories of blockchain and various challenges faced by this technology such as scalability, interoperability, regulatory issues etc. The application areas of blockchain along with the transaction process are also explained. The future scope of this technology is also discussed in this survey. The purpose of conducting this survey was to provide guidelines about the above-mentioned areas of blockchain for future research [6].

Transferring particular kinds of digital assets between the networks of the blockchain is an impossible task under the traditional definition of the blockchain.A survey was conducted in [7] on blockchain interoperability's history, present and possible future challenges. The authors conducted a literature review of 102 documents. They divided their study into three main categories Public Connectors, Blockchain of Blockchains, and Hybrid Connectors and then further into various subcategories of each of these. The prime goal of conducting this study was to gather the information on the domain of blockchain interoperability together to ease the process of its understanding and implementation in academics and industry.

The paper [8] shows that creating a "2-in-1" blockchain that incorporates the ledgers required to become interoperable is necessary to achieve interoperability. Instead of allowing token transfers from one blockchain to another, the existing framework for interoperability exchanges already-created tokens between two blockchains.

This paper [9] presents a hyperService platform for the programmability and interoperability among different blockchains. HyperService platform has UIP, the Universal Blockchain Interoperability protocol to implement the complex operation in dApps on blockchain and HSL, which is a programming framework for creating cross chain dApps by using smart contracts. This hyperservice is implemented by 35000 lines of code to evaluate the delay in the execution of the dApps practically and throughput of the platform

This paper [10] presents the importance and the challenges in interoperability of the blockchains .The research proposes a novel framework with five layered architecture to counter challenges like efficiency,atomicity ,security and usability. It also recommends the MMR techniqueTo reduce reading overhead and keep interoperation timely.

Another paper[11] presents a review of the industrially available solutions of blockchain interoperability and the comparison of the architectures.The solutions are divided into four groups but none of the solution focussed on interoperability of two or more heterogeneous blockchain platforms as each platform follow a different consensus algorithm protocol and has variable architecture

This paper [12] presents InterTrust, an efficient architecture for interoperability across homogenous and heterogenous blockchains.InterTrust is an atomic intercommunication protocol for smooth integration of blockchain.the two techniques of InterTrust guarantee the target blockchain systems' consistency, for the provision of trusted services among different blockchain system, to support the robustness in the interoperable architecture.

There has been an upsurge in the use of permissioned blockchain networks in business contexts. Realizing the technology's potential requires mechanisms for facilitating network interoperability. Ermyas Abebe et al [13] in their [1]study propose an architecture and a set of building blocks that may be customized for usage in a variety of network implementations.

The report by Monika and R. Bhatia [14] lists the interoperability strategies applied to the blockchain by businesses and academics. There aren't many smart contract interoperability options available. There's a dearth of research on side chains which are SPV-based, and the majority of the sidechain solutions addressed in the literature are based on architecture federated two-way peg.

Supply chains and the industrial Internet of Things, for instance, can both benefit from blockchain as a potentially disruptive technology. Current blockchain design concepts will certainly influence as blockchains become more interoperable. The study by Gang Wang[15] offers a methodical and thorough analysis of the state of blockchain interoperability at the moment.

By examining it from several angles, this paper helps us to understand the possibilities of blockchain interoperability (BI). By concentrating on their research goals and chosen approach during design and development, the authors in [16] evaluated and contrasted cutting-edge BI projects. They also suggested a study taxonomy to accommodate the wide range of practical considerations that might be enforced while creating BI solutions or methods.

The lack of interoperability among blockchains was discussed in [17]. The authors considered the need of interoperability at three levels i.e. between various blockchains, between different projects running on the same blockchain and between software required along with blockchain in creating decentralized applications. They proposed an architecture for connecting blockchains and decentralized technologies and evaluated its impact in the video gaming industry.

In [18] the importance of resilience in gateways that allow different organizations to connect to blockchains was discussed. The authors stated that gateways should have the ability to bear the impact of crashes so that the ledgers are maintained in a consistent state. To achieve this idea, they proposed a fault-tolerant gateway called Hermes for blockchain interoperability based on ODAP (Open Digital Access Protocol). They also implemented a use case scenario for illustrating Hermes's support in employing cross-chain transactions acquiescent with regulatory and legal bodies.

In [19] the problem of blockchain interoperability was addressed by developing an interoperability API (Application Program Interface) called Bifröst. This API allows storage, retrieval and migration of data across blockchains and no modification is required in blockchains structure for its implementation. A python prototype of the proposed API was used for implementing seven blockchain adapters. It was concluded that Bifröst is likely to solve major problems of blockchain interoperability.

The voting-based blockchain interoperability oracle that S. Schulte et al [20] propose, makes use of an off-chain aggregation technique based on BLS threshold signatures. One aggregator and several validators make up the oracle nodes. The on-chain component can save a significant amount of money by only having to validate one signature.

BLOCKCHAIN: AN OVERVIEW

Blockchain is a shared, distributed and immutable digital ledger containing records of transactions saved across a peer-to-peer computer network [1]. Every node in the network can view all the transactions occurring in the blockchain but only the owner can modify them [1]. Blockchains can be centralized as well as decentralized. A centralized blockchain can only be transacted by known people across the network while a decentralized blockchain allows anyone to modify the chain. In decentralized blockchain some mechanism is used to maintain the integrity of the chain [21].

BLOCKCHAIN ARCHITECTURE AND WORKING

A blockchain comprises a peer-to-peer network. A node in the network can start a transaction by implementing their digital signatures in it. A transaction in blockchain is like a data structure which shows all the conveyance of digital assets across that blockchain network [2]. All the transactions occurring in the network are stored in an unverified transaction pool. To communicate these transactions across the network a flooding protocol called Gossip protocol is used. It propagates the transactions present in the transaction pool across each node and the nodes validate the transactions based on some prespecified rules [2]. Figure 1 shows the working of a blockchain network.

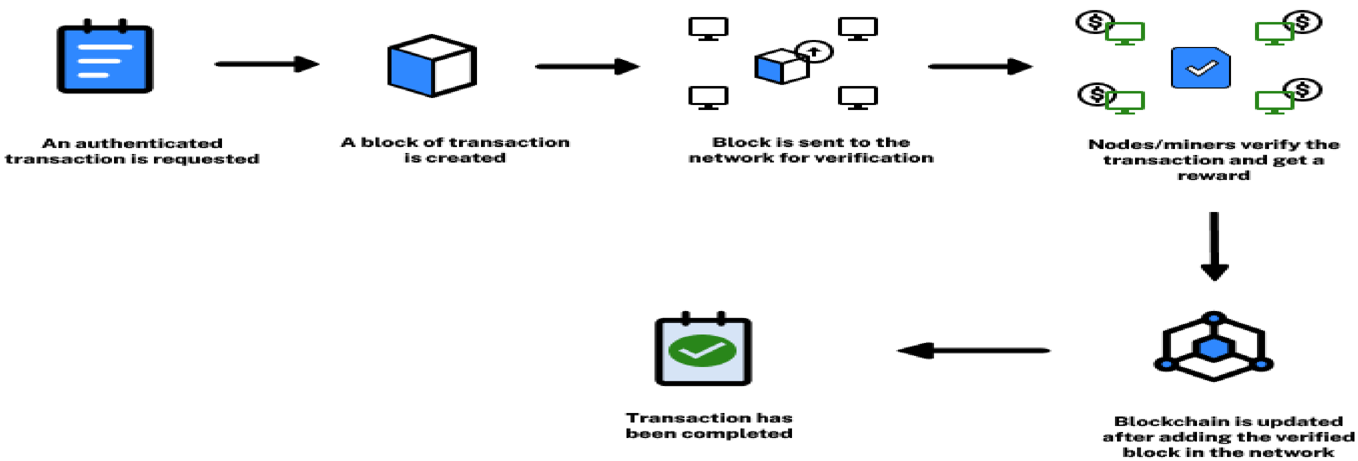

Figure.1. Working of a Blockchain Network.

The nodes which take part in verification and validation of the transaction are called miners. Miners utilize their computational power and solve a complex puzzle to validate a transaction and include it in a block. The miner who succeeds in solving the puzzle quickest is deemed as the winner and earns an opportunity of creating a new block in the chain [2]. Once a new block is created successfully, that miner is awarded with a small incentive and all the other peers in the network verify it using a predefined consensus mechanism [2].

After verification is done the block is added to the existing chain and the immutable ledger, of each node, is also updated. It is connected to the next block using a hash pointer which is cryptographic. The block is verified now for the first time by all peers while the transaction is confirmed for the second time. In the same way whenever a new block is added all the transactions are reconfirmed. When the transaction confirmation is done six times then it becomes permanent [2]. Once a transaction becomes final it can still be viewed but not updated [2].

STRUCTURE OF A BLOCK

A block chain is made up of a sequence of blocks. Each block in the chain contains a reference hash (to link all the blocks to each other) which is actually the hash of the previous block. The predecessor block of a given block is called its parent block. However the first block in the chain does not have a parent and it is called genesis block. Each block is divided into two parts: block header and block body [2].

Block header contains metadata about the block. This includes this block's hash, hash of the parent block, Merkle root, nonce, etc. Merkle root is a hash that is made up by the hierarchical combination of hashes of each individual transaction in a block and nonce is the only mutable element of the block often used by miners [22].

The body of a block in blockchain contains a transactions counter and transaction. The maximum quantity of transactions that can be held by a block depends solely upon the block size and individual transmission size [2]. An asymmetric cryptography mechanism is employed to validate the authenticity of each transaction present in the block [2].Figure 2 illustrates the structure of blocks.

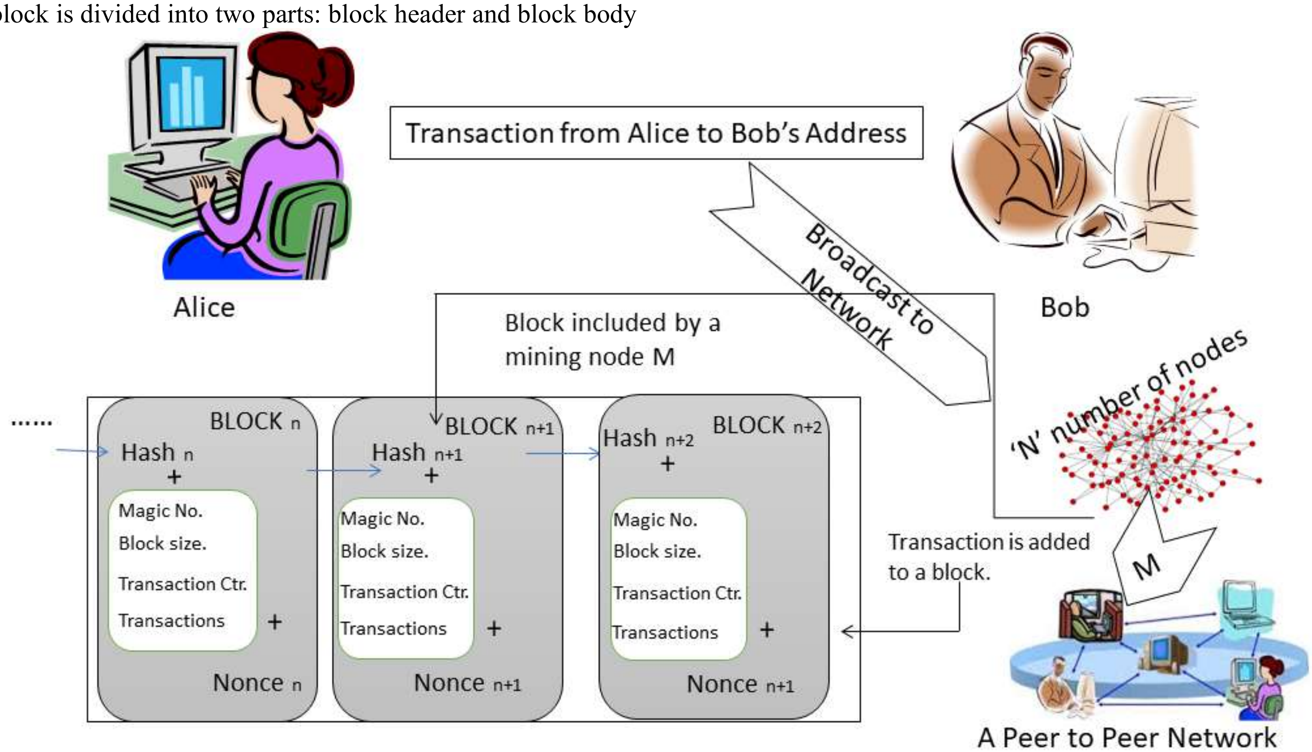

Figure 2. Block Structure and Formation in Blockchain

TYPES OF BLOCKCHAIN

Broadly speaking there are four types of blockchains. These types are defined based on some properties such as ledger immutability, blockchain efficiency, viewing permission and consensus authority etc. The four types of blockchain are briefly elaborated below:

A.. Public - A public blockchain network is also known as permissionless blockchain network. In this network anyone can take part through the internet and become a node in the blockchain network [23].

B. Private - A private blockchain belongs to a specific organization and they can decide who can have the access to their blockchain data. They are also known as permissoned or enterprise blockchains [23][24].

C. Hybrid - This type of blockchain is a combination of both public and private blockchains. The organization owning a hybrid blockchain can decide who can have access to what along with what should be opened for the public [24]. Usually hybrid blockchains data is not made public but access is allowed on the basis of smart contracts [24].

D. Consortium - Consortium or Federated blockchain is similar to hybrid blockchain. In this blockchain network the mining process is strictly controlled by a set of predefined nodes [23]. Among these nodes there is a validator node which validates transactions along with starting and acquiring them. Other member nodes can only start and receive transactions [24].

The Table 1 given below shows the advantages, disadvantages and use cases of different types of blockchain.

Table 1. Types of Blockchain

	Pros	Cons	Applications
Permissionless	Independence, Transparency,Trust	Performance, Scalability,Security,Costly	Digital Assets, Authentication of Documents
Permissioned	Access Control, Performance,Not so costly	Trust,Auditability	Finance, HealthCare
Hybrid	Access Control,Integrity, Performance,Scalability,Not so costly	Transparency,Upgrading	IBM Food Trust, SupplyChain
Consortium	Access Control, Security,High Scalability	Transparency	Banking,Research, SupplyChain

BLOCKCHAIN CHARACTERISTICS

Blockchain has a variety of features. Few of them are discussed below:

A. Decentralization - Decentralization makes the blockchain network fault tolerant. It reduces the rate of system failure due to security breaches or power failures. It eliminates the risk of breach of privacy or data theft due to the involvement of any third party as no middle man is required while using the blockchain network [25].
B. Data Immutability - Any transaction record on the blockchain network becomes permanent once it is finalized i.e. confirmed six times. After validation the record is irreversible and unchangeable forever. It can still be viewed by peers on the network but nobody can modify it [25].
C. Distributed Ledger - Changes to a distributed ledger are easier to track, implement and validate [25].
D. Confidentiality - A blockchain network also allows its users to maintain anonymity if they do not want to expose their identities by using randomly generated addresses and by using several addresses at once [2].
E. Inspection - The transactions taking place in a blockchain network are stored in a distributed ledger and validated. Hence all the transactions can be traced, audited and inspected through any node of the blockchain network [2].

APPLICATIONS OF BLOCKCHAIN

Blockchain has a vast variety of applications in different domains such as banking and finance in trading, regulatory compliance and audit, in healthcare, supply chain management, media etc [26]. Some of these applications are shown in the figure 3 below:

BLOCKCHAIN INTEROPERABILITY

Blockchain interoperability can be defined as the interaction of blockchain or networks of blockchain to share the services and information ,reference and verify data and access it [27].as per National Institute of Standards and Technology (NIST) blockchain interoperability can be defined as “An interoperable blockchain architecture is a composition of distinguishable blockchain systems, each representing a unique distributed data ledger, where atomic transaction execution may span multiple heterogeneous blockchain systems, and where data recorded in one blockchain are reachable, verifiable, and referenceable by another possibly foreign transaction in a semantically compatible manner”[44][28].

Every blockchain records different transactions which can share the transactions and access each other's data due to interoperability between them. In simple words, blockchain interoperability refers to the communication of the blockchains.Blockchain interoperability can be observed in homogenous blockchains (cross-chain interoperability) as well as in heterogeneous blockchains(cross-blockchain communication/interoperability)[29]. So, interoperability of the blockchains can also be defined as "A source blockchain's capacity to modify a destination blockchain's state through cross-chain or cross-blockchain transactions, extending across a composition of homogeneous and heterogeneous blockchain systems."[6].

USE CASES:

Some important use cases of interoperability among blockchains are :

1. Assets portability - The ability to trade assets from one distributed ledger to another with all the authority ,security and ownership without modifying any necessary legal constraints and platforms for third party exchange [30].
2. Finance decentralization - The ability to connect two blockchains via inter blockchain communication protocol (IBC) to transfer the assets or data from one blockchain to another having the same consensus mechanisms.
3. Cross chain oracles - A chain’s smart contract can do modification by receiving the address as proof of identity of another chain specifying the unique identity[31].
4. Supply chains - Supply chains, chain of transfer of value among parties, are also an important use case of interoperability for improving the process of auditability[32] .

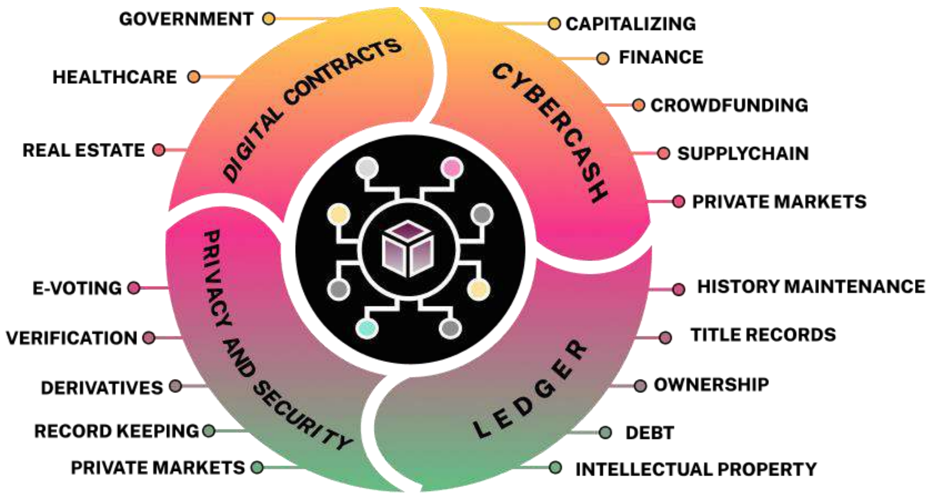

Figure 3. Applications of Blockchain.

IMPORTANCE

The interoperability in different blockchains is very important to create decentralized applications. The process of blockchain mining becomes easy as the interoperability will create a network of blockchains making the process more productive.it has a significant role in trading , cryptocurrencies and mining.the digital sharing of assets across blockchains to smoothen the process of many applications and making blockchain a success story requires the interoperability among blockchains to lay its part.the maintenance of the patient's data ,which is critical and expensive ,in health care sector also a main application of blockchain interoperability.some other applications of blockchain interoperability making it more significant are identity management, voting ,stock exchange ,cyber security ,digital records and many more.

ADVANTAGES

1. Blockchain interoperability has improved the process of cross-chain transactions.
2. It has provided ease in operation involving multi-token transactions.
3. It eliminates the chances of fraud making the transactions safe and secure.
4. It ease the sharing of data hence encourage the transactions among blockchain

DISADVANTAGES

1. The interoperability is currently impossible to be observed among the blockchains of the different network.it is only working for the different blockchains present in the same network.
2. Due to the highly restricted nature of the blockchain to provide security,it is sometimes difficult for the user to transfer data.
3. There is no possibility of the blockchain to be flowed in the reverse direction so the validation of data has to be done before the node submission.

CHALLENGES

Each blockchain works on different protocols or rules which has a consent on transaction accuracy in a decentralized way.the accuracy verification is integral which only works natively.the transaction accuracy outside that cannot be verified by the existing protocol.this makes the interoperability among the different blockchains a challenge as it is hard to ensure the security and accuracy like base chain[33].

Each blockchain has privacy levels that are distinct from each other hence the extent of sharing data in order to ensure the privacy cannot be specified.transfer of data in a secured manner is also a dilemma because of the different encryption methods used in the blockchains.more over there is no standard protocol to make the blockchain interoperable. Due to these reasons, blockchain interoperability is a challenge[34].the reliability insurance in transaction across interoperable blockchain at the application level is also a challenge[9].

The semantic layer is responsible for recording the data and maintaining it on the shared ledger through consensus The data sharing from the source to destination requires a verification mechanism on the semantic layer to verify the data according to the consensus but applying it to the blockchain interoperability till date is a challenge[12]

INTEROPERABILITY SOLUTIONS

1.SIDECHAIN

Sidechain is tethered to the primary blockchain in two directions. Assets are transferred between the sidechain and the mainchain through a two-way peg connection shown in figure 4. A sidechain's implementation may differ from the parent chain's and it may operate independently. The main purpose of a sidechain is to expand the functionality of the main blockchain or to increase its scalability. On sidechains, transaction times are often reduced[35].

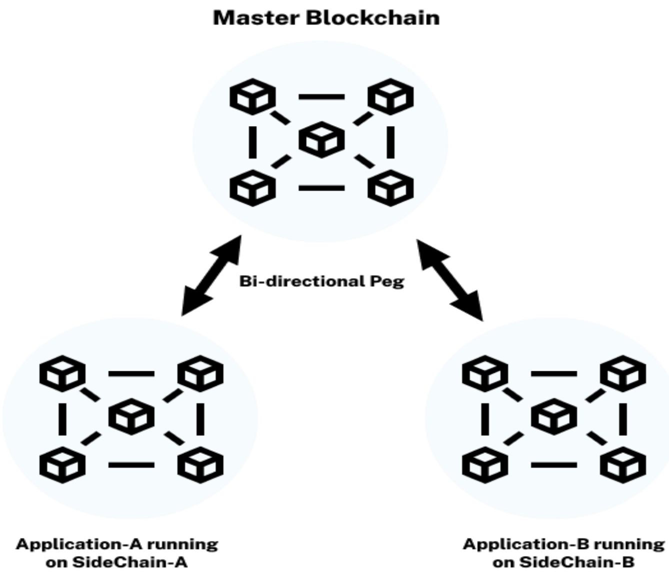

Figure 4. Working of Sidechain.

Example:

PLASMA

The Ethereum blockchain has a sidechain called Plasma. To implement each sidechain, a smart contract is made on the Ethereum main chain.. Every sidechain has its own set of guidelines and restrictions that are enforced by its smart contract.Despite the fact that mining occurs on the Ethereum mainchain, plasma chains use the Proof-of-Stake consensus algorithm. Plasma chains have control over the creation of blocks by modifying the list of nodes with the required permissions.The only place where transactions and state updates are kept is on sidechains. Node validators only give the Ethereum chain periodic activity data in the form of block header hashes. Applications for decentralization on Ethereum can scale thanks to plasma chains[36]. The goal of initiatives like OmiseGO[37], which aims to deliver quicker peer-to-peer financial transactions worldwide, is achieved by the usage of plasma[38]. Figure 5 shows the working of plasma.

2.BRIDGING SOLUTIONS

These solutions offers link between two chains so that data may be transferred or exchanged. Due to the absence of a primary chain, bridging solutions differ from notary schemes and sidechains. Two blockchains are connected via a bridge made of smart contracts or other modules[38]. Example:

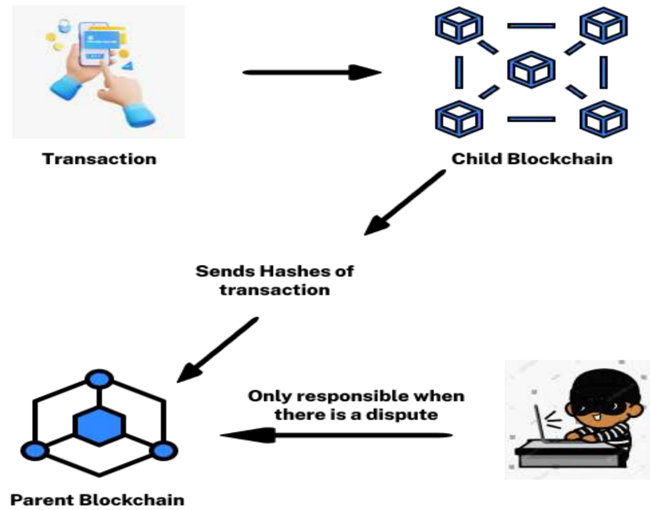

Figure 5. Working of Plasma

BLOCKNET

In order to provide a decentralised network for integrating and coordinating numerous blockchains, Blocknet is a fully accessible project that was launched in 2014. Additionally, it enables blockchains to connect to off-chain APIs and oracle services. Blocknet is a service blockchain that uses Proof-of-Stake, and BLOCK is its utility token[38]. It consists of three essential components: XRouter, XBridge, and XCloud. XRouter provides a communication layer to the Blocknet protocol that enables users to connect to blockchains and validate data without downloading the complete blockchain. XBridge provides a trustless exchange of digital assets made possible by Blockcnet through the usage of APIs. Thanks to XCloud, applications may use off-chain data on-chain[39].

3.POOLED SECURITY

Parachains transmit data from one application to another via a central shard on the mainnet. Pooled security enables validators from this central shard to verify that the data being transmitted is accurate in comparison to the application's present state[40]. Example:

POLKADOT

A seamless exchange of information between blockchain networks is made possible by the Polkadot protocol. An overview of Polkadot network is given in figure 6. Relay chains and parachains are concepts that are used in Polkadot. Transactions between Parachains are registered and completed on the Relay chain. Any blockchain, whether it has permissions or not, can be Parachain[38]. The DOT token is used by relay networks to conduct all management tasks using the proof of stake consensus mechanism[41].

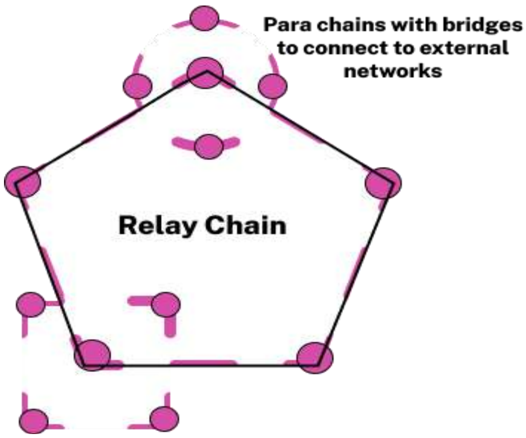

Figure 6. Overview of Polkadot.

4.INTER-BLOCKCHAIN COMMUNICATION

Every verification point must have an interoperable routing table in accordance with IBC (Inter-Blockchain communication). The work's network scenarios imply that there are several Blockchain systems, their topologies are complex, and not all of the systems can directly connect with one another. When a transaction is created that involves two distinct Blockchain systems, IBC performs some analysis and delivers the transaction in two separate systems(figure 7). Depending on whether this operation belongs to the system, the transaction is split into two pieces. Its first component initiates a pre-commit in the S1 system. IBC package and transport the second component to the other system S2 within this time.S2 will commit and respond when it receives the second component. S1 will take the ultimate decision. Both components are either successful or unsuccessful in an atomic operation. When there is a network problem, system S1 will retransmit the second part (figure 8) [42]. Example:

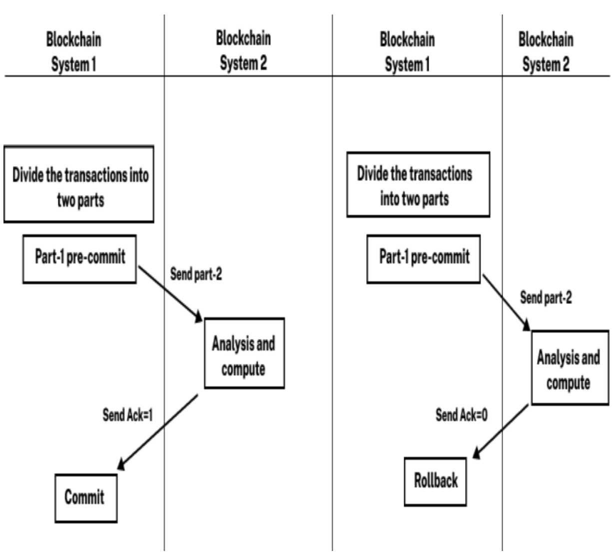

Figure 7. Deliver the transaction.

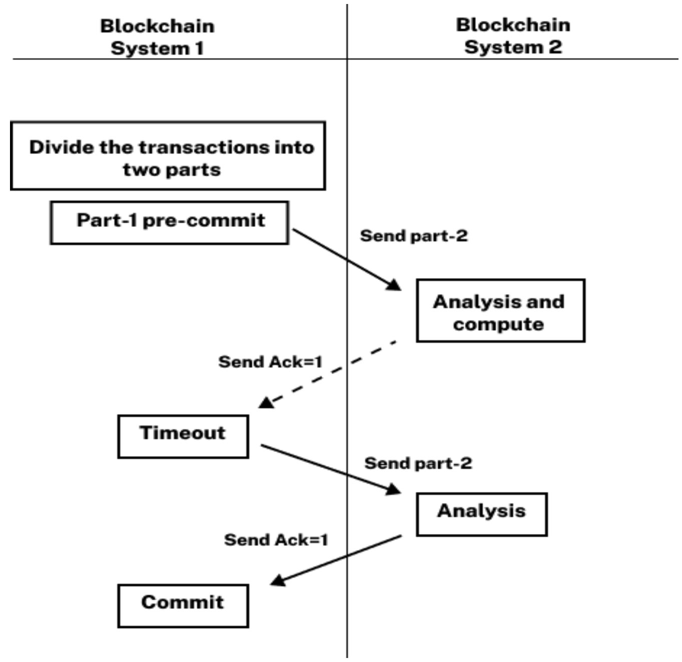

Figure 8. Time out retransmission.

COSMOS

The Cosmos project aims to establish a network of blockchains where various blockchains may connect with one another[43]. The Tendermint core, a BFT-based consensus engine, is included in Cosmos. Using The Application Blockchain Interface, Tendermint core communicates with the application layer (ABCI). The Cosmos network is made up of zones shown in figure 9 that are Tendermint-based Blockchains and a Cosmos hub. Using the InterBlockchain Communication (IBC) protocol, zones communicate with the Cosmos hub. Through the Cosmos hub, interactions between many zones are possible. Blockchains that are not Tendermint-based, like Ethereum, connect with one other via a unique class of zone called a peg-zone[38].

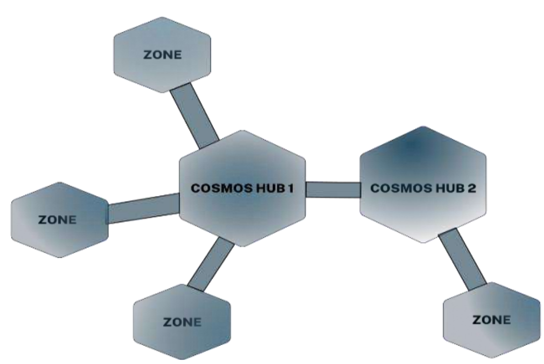

Figure 9. Overview of Cosmos.

CASE STUDY

To perform interoperability between blockchains we have used Cosmos software tool which utilizes Inter-Blockchain Communication Protocol to conduct communication between two blockchains. This choice was made after thorough examination of different properties of available solutions of blockchain interoperability. A comparison of these tools is also shown in Table 2.

IBC or Inter-Blockchain Communication Protocol works by establishing a connection between the two blockchains. This connection is established by a four-way handshake. Through this handshake the identity of the counterparty is verified and the chains become ready for any tokens, transactional record, etc. exchange that might take place in future through the built connection.

For initiating the interoperability process we have implemented this handshake in our work.

SETUP AND EXPERIMENTATION

The experiment was performed on a system containing intel core i5 with 8GB RAM and Windows 10 operating system. Some installations were necessary for performance so they were also done beforehand. These include setting up Docker and visual studio code.

The programming language used is Go language. Two blockchains were taken from Cosmos own learning repository and their local copies were created. The intercommunication was done between those locally stored checkers blockchains. The IBC protocol handshake consists of four steps. These steps are explained and implemented below:

A. OPENINIT

OpenInit starts the connection from the first chain's side. It suggests the protocol version to be used for connection and creates a unique connection id for this connection. This function is shown in Figure 10.

```
func (k Keeper) ConnOpenInit(
    ctx sdk.Context,
    clientID string,
    counterparty types.Counterparty, // counterpartyPrefix, counterpar
    version *types.Version,
    delayPeriod uint64,
) (string, error) {
  ...

    // connection defines chain A's ConnectionEnd
    connectionID := k.GenerateConnectionIdentifier(ctx)
    connection := types.NewConnectionEnd(types.INIT, clientID, counter
    k.SetConnection(ctx, connectionID, connection)

    if err := k.addConnectionToClient(ctx, clientID, connectionID); er
        return "", err
    }

    k.Logger(ctx).Info("connection state updated", "connection-id", co
```

Figure 10. Four-way handshake OpenInit.

B. OPENTRY

In response to OpenInit the OpenTry function executes. It verifies the identity of the first chain according to the already stored information in the second chain's light client. It accepts the protocol version suggested by the first chain in OpenInit and changes its state to OpenTry which indicates the start of connection from the second chain. The OpenTry function is depicted in Figure 11.

```
func (k Keeper) ConnOpenTry(
    ctx sdk.Context,
    previousConnectionID string, // previousIdentifier
    counterparty types.Counterparty, // counterpartyConn
    delayPeriod uint64,
    clientID string, // clientID of chainA
    clientState exported.ClientState, // clientState tha
    counterpartyVersions []exported.Version, // supporte
    proofInit []byte, // proof that chain A stored conne
    proofClient []byte, // proof that chain A stored a l
    proofConsensus []byte, // proof that chain A stored
    proofHeight exported.Height, // height at which rela
    consensusHeight exported.Height, // latest height of
) ...
```

Figure 11. Four-way handshake OpenTry.

C. OPENACK

OpenAck verifies the information of the first chain and changes its state to open which shows that it is available and verified for connection. It performs the same functions as OpenTry and verifies the connection state client state of the first chain. Figure 12 and 13 shows OpenAck.

```
func (k Keeper) ConnOpenAck(
    ctx sdk.Context,
    connectionID string,
    clientState exported.ClientState, // client state for
    version *types.Version, // version that Chain B chose
    counterpartyConnectionID string,
    proofTry []byte, // proof that connectionEnd was added
    proofClient []byte, // proof of client state on chain
    proofConsensus []byte, // proof that chain B has store
    proofHeight exported.Height, // height that relayer co
    consensusHeight exported.Height, // latest height of c
```

Figure 12. Four-way handshake OpenAck -1.

```
if err := k.VerifyConnectionState(
    ctx, connection, proofHeight, proofTry, counterparty.ConnectionId,
    expectedConnection,
); err != nil {
    return "", err
}

// This function verifies that the snapshot the counter-party chain ha
// Check that Chain A stored the clientState provided in the msg
if err := k.VerifyClientState(ctx, connection, proofHeight, proofClien
    return "", err
}
```

Figure 13. Four-way handshake OpenAck -2.

D. OPENCONFIRM

It is the last step of the handshake in which the second chain confirms the success of both its self identification and the identification of counterparty. As a result an IBC connection is formed between the two chains successfully. This function is shown in Figure 14.

```
func (k Keeper) ConnOpenConfirm(
    ctx sdk.Context,
    connectionID string,
    proofAck []byte, // proof that
    proofHeight exported.Height, //
)
```

Figure 14. Four-way handshake OpenConfirm.

Hence the above four steps were conducted and a connection was formed successfully between two blockchains inside the Cosmos environment using IBC protocol.

Table 2. Comparison of Interoperability Solutions.

	Cosmos	ZetaChain	LayerZero
Value Transfer	Yes	Yes	Yes
DEX	Yes	Yes	Yes
Message Passing	Requires IBC	Yes	Yes
Chain Agnostic	Requires IBC	Yes	Smart contract chains
Omnichain smart contracts	Requires IBC	Yes	No smart contract
Native bitcoin vault management	No	Yes	No
Settlement	Wrapped	Immediate native settlement	Either immediate or wrapped

LIMITATIONS AND FUTURE WORK

Blockchain interoperability is a challenge of today. In this study we have discussed some solutions to overcome this problem but all of these solutions have some limitations. They are all costly and they can only conduct communication between similar blockchains that are made up of their own technology. In future, the research is aimed to introduce a consensus based protocol transformation layer at the top of decentralized blockchain. This layer should aim at introducing application domain level compatibility to enable blockchain interoperability among blockchain networks to agree upon an equivalent standard for confirming blocks into the blockchain irrespective of their local mining approaches.

CONCLUSION

Several blockchain networks are being launched globally as blockchain technology gains traction in academics and industry. Data silos and asset silos come from these networks' extreme isolation and incompatibility. By facilitating asset and data transfers between h omogeneous and heterogeneous blockchains, blockchain interoperability solutions can revolutionize this technology[45].

In this study, we examined different interoperability solutions. The interoperability between two blockchains was also implemented on a very small extent by using Cosmos and the inter-blockchain communication protocol. Cosmos was chosen due to the variety it offers when it comes to blockchains and also because it has plenty of documentation available which the other tools don't. It is concluded from the above study that interoperability is still a huge challenge. Conducting communication between two different blockchains is still impossible today. However some software tools allow similar blockchains to communicate within their own customized environment. The demand for interoperability among various blockchain networks has been increasing rapidly. One if the reasons include the continuous rising of so many use-cases for blockchain technology in the form of decentralized applications. This paper is an effort to meet the demand of such need by demonstrating interoperability at blockchain core. This should result in a more interactive eco-system for decentralization across different blockchain networks.

CREDIT AUTHOR STATEMENT

Dr. Kashif Mehboob Khan: Conceptualization, Methodology, Software. **Aabira**: Data curation, Writing-

Original draft preparation. **Darakhshan M. Saleem**: Visualization, **Marvi**: Writing- Reviewing and Editing

COMPLIANCE WITH ETHICAL STANDARDS

It is declared that all authors don't have any conflict of interest. Furthermore, informed consent was obtained from all individual participants included in the study.

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