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Review Article

Review on Blockchain Technology: Architecture, Characteristics, Benefits, Algorithms, Challenges and Applications

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ABSTRACT

Today, blockchain technology is playing a vital role in the professional world as one of the most important discoveries and creative developments. Blockchain technology is continuously advancing and revolutionizing our society. An overview of blockchain technology is presented in this paper. The blockchain is a distributed ledger technology that allows different transactions and operations to be recorded in a chain of blocks without requiring a third party. A growing number of businesses and industrial communities are exploring blockchain technology as a technological option. In the last decade, blockchain technology has completely changed the paradigm of computer applications. Blockchain was created with the vision of creating an immutable, confidential, open-source, decentralized P2P network located on a decentralized network to facilitate data sharing. An overview of blockchain applications in different areas is presented. We provide a timely summary of blockchain research for individuals and organizations interested in this field. This paper presents an overview of blockchain technology, listing all the key characteristics, benefits, and features which make blockchain technology both superior and unique. We also discuss popular consensus protocols and taxonomy for blockchain systems.

1. INTRODUCTION

Today, blockchain technology is incredibly popular. Blockchains are chains of information blocks. A group of researchers first reported on this technology in 1991. The original aim was not to backdate or tamper with digital documents, but instead to timestamp them so they couldn't be tampered with. A cryptocurrency like Bitcoin uses blockchain technology as its underlying mechanism [1]. In December of 2017, the digital currency Bitcoin peaked at a record high valuation and created a buzz around digital currency [2]. Several cryptocurrencies have appeared in the market since the debut of Bitcoin, each with a market capitalization in the billions of dollars [3]. Satoshi Nakamoto, introduced the concept of blockchain in 2008 and used it as the basis for Bitcoin in 2009. Anyone can access a blockchain since it's a distributed ledger. An interesting property of blockchains is that once they have been inserted, they can't be altered. A blockchain block consists of some data, the hash of the block itself, and the hash of the block before it. There are different types of data stored in each block. An alternative to the traditional ledger, blockchain is essentially a multi-party "distributed database" where all the transactions are recorded and traceable. Essentially, a chain of blocks can be considered as a ledger, with each block representing a page. Mining continues to generate new blocks that are appended to the Blockchain continually [4]. A trusted third party is required for the traditional ledger technologies, as illustrated in Figure 1. Blockchain technology, as shown in Figure 2, operates on a peer-to-peer network, meaning that the transactions are not managed by a trusted third party.

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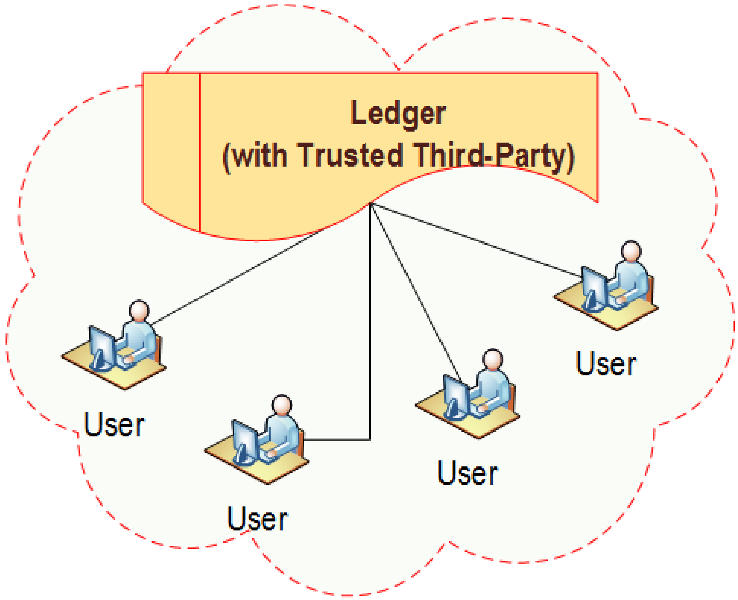

Fig.1. Traditional centralized ledger technology with a trusted third-party [4]

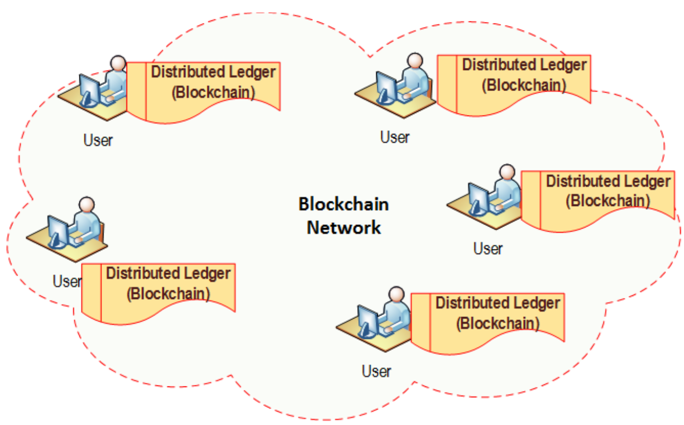

Fig.2. Distributed Ledger Technology without a trusted third-party.

The rapid uptake of digitization in healthcare has resulted in a massive amount of electronic patient records. This has created an unprecedented need for healthcare data protection while being used and exchanged. It is predicted that blockchain technology will solve serious privacy, security, and integrity issues in healthcare by creating a responsible and transparent mechanism to store and distribute data [5]. Academics and industry have begun to take an interest in blockchain technology over the past few years. New studies and applications of blockchain are launched every day [6-9]. This is a technology based on distributed ledgers for digital data transactions between peer-to-peer (P2P) networks. The system allows any type of data to be recorded in a trusted and secure manner [10]. Blockchains are also known for their smart contracts, which are legally enforceable sets of rules that govern interactions between different parties under decentralized automation [11-12]. Numerous smart contracts have been developed using blockchain technology in several fields, including energy resources [13], financial services [14-15], voting [16-18] and healthcare [19]. By eliminating third-party administrators and intermediaries, blockchain technology offers transparency [6]. The validation of legitimacy is performed using consensus mechanisms and cryptography in a trustless and unreliable environment [20]. If the message is correct, the receiving node stores it in a block of a blockchain distributed P2P network of transactions. We are providing a timely review of blockchain technology applications in this paper. The open literature currently contains several papers discussing blockchain technology's application in fields like finance [21-24] internet of things (IoT) [19, 25-31], energy sector [32-33], government [34-36], and privacy and security [37-39].

2. ARCHITECTURE OF BLOCKCHAIN TECHNOLOGY

Blockchains are composed of blocks. Blockchain databases maintain records in blocks in a distributed, fault-tolerant and shared manner. Even though blockchain users have access to all blocks, they cannot be deleted or altered. Blocks make up blockchain databases. Several verified transactions are in each block and it contains its hash value from the previous block. A genesis block is the first block in a blockchain, and its hash value is entirely zero, since it has no parent block [40]. Blockchains, as shown in Figure 3, are chronological sequences of blocks containing a list of all the transactions. Linked lists use the hash value of the previous block to reference each subsequent block, also known as parental blocks. The genesis block does not point to any other blocks in a Blockchain. There is a block header (metadata) and a block body (list of transactions). In addition to block version, parent block hash, Merkle tree root hash, timestamps, and nonce, the metadata includes. Nonce is an arbitrary number that is used to communicate cryptographically between users. Each participant digitally signs the block body and it contains data, records, or transactions [41].

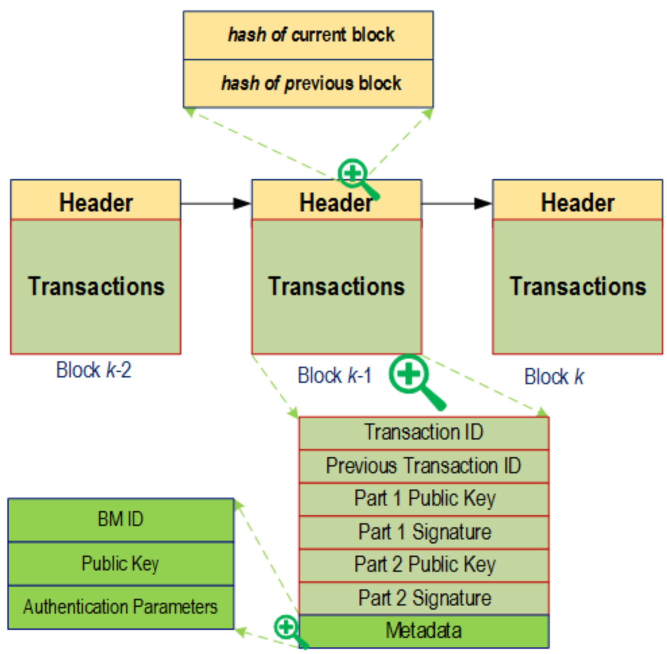

Fig.3. Blocks in Blockchain technology

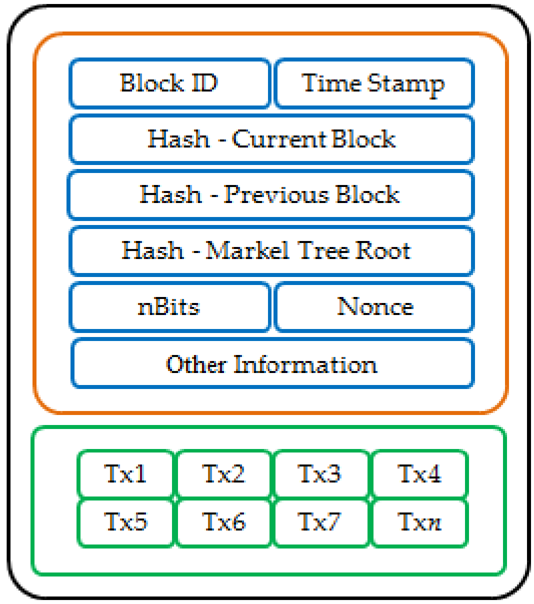

Fig.4. Block Structure

Digital Signature : Private keys and public keys are owned by each user. Transactions are signed using the confidential private key. Transactions digitally signed are transmitted to every computer in the network. There are usually two phases to the digital signature process: the signing phase and the verification phase [42]. A user such as Alice wants to send a message to a user Bob. Once Alice's data is signed with her private key, she encrypts the result with her private key and sends it to Bob encrypted as well. Bob verifies Alice's public key in the verification phase. Then Bob could easily see if there had been any alterations made to the data. The elliptic curve digital signature algorithm (ECDSA), the most commonly used digital signature algorithm in blockchains, is used [43].

Block : There are two parts to a block: a header and a body. It contains the following information:

Blockversion - Indicates which validation rules should apply to a block.

Merkle Tree Root Hash - A hash value associated with all transactions in a block

Timestamp - Universal time expressed in seconds.

nBits - This is the maximum number of bits in a valid block hash

Nonce - This field is comprised of four bytes starting at 0 and increasing with each calculation

Parent Block Hash - A hash value of 256 bits that identifies the previous block

3. CHARACTERISTICS OF BLOCKCHAIN TECHNOLOGY

Blockchain characteristics are discussed in detail here. These characteristics were also outlined in other research papers; however, some of these characteristics contributed to other specific characteristics, so it is possible to shorten the list.

3.1 Immutability

The immutability of blockchain technology is undoubtedly one of its most attractive features. This refers to the inability to change or alter the information. Blockchain tech is best known for the ability to provide a permanent, unalterable network, this is one of its top features. A blockchain is immutable, which means that data can never be changed. Moreover, all network nodes must approve the data before it is added to the block, thereby enabling secure transactions. Mining is the process of adding transactions to blocks by validating them.

3.2 Decentralization

Decentralization refers to the fact that there is no one in charge of the framework or any governing authority. Decentralized networks are maintained by a group of nodes. It is one of the key characteristics of blockchain technology. A conventional centralized transaction system requires each transaction to be validated by a central agency, which naturally causes performance and cost bottlenecks. Blockchain eliminates the need for third parties as opposed to the centralized mode. Data consistency is maintained in distributed networks by consensus algorithms. Decentralized and open ledger, blockchain is both. In an open ledger, the transactions are recorded and they are open to all, so the ledger is public. The transactions are not controlled by any individual or organization. There is one copy of the ledger for each connection in the blockchain network.

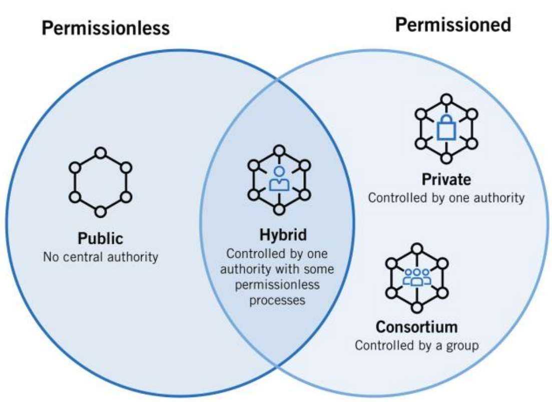

Figure 6. Types of Blockchain Structures

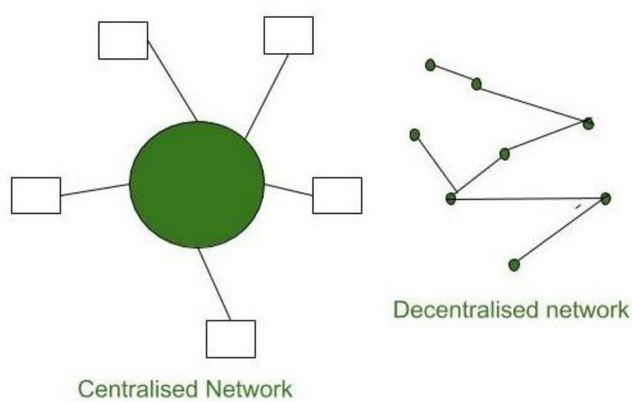

Figure 5. Centralized & Decentralized network

3.3 Persistency

Validating transactions is quick, and honest miners would not allow invalid transactions. Once transactions are included in the blockchain, they cannot be removed or rolled back. Irregular transactions in blocks can be discovered immediately. Because the structure of a chain can enable any transaction or block to be validated, stored data in the chain is persistent and traceable. There is only one ledger that records all transactions in Bitcoin, and this ledger is available on all nodes so there is a complete trail for every single coin. The difficulty of double-spending is addressed by this feature.

3.4 Anonymity

In a chain transaction, only the recipient's ID is required, and any further information is not disclosed. This means that parties involved in the transaction remain anonymous. Each user has a generated address for interacting with the blockchain, so that their true identity is not revealed. Because of the inherent limitations of the blockchain, perfect privacy preservation cannot be guaranteed.

3.5 Auditability

According to the Unspent Transaction Output (UTXO) model created by the Bitcoin blockchain, any transaction must refer to a previous unspent transaction [44]. The status of the referred unspent transactions switches from unspent to spent once the current transaction is recorded into the blockchain. This allows fraud detection and tracking. Data stored on a blockchain can easily be traced and verified because transactions are validated and recorded with a timestamp. This enables data to be traced and verified easily. All users of the network have access to this recording through the use of computational algorithms. These algorithms ensure the permanence and chronological order of information on ledgers.

4. TYPES OF BLOCKCHAIN TECHNOLOGY

Blockchain networks can be classified into four types: public blockchains, private blockchains, consortium blockchains, and hybrid blockchains. Two main categories of blockchain systems can be distinguished: access to the blockchain system, as well as access to the blockchain data.

4.1 Public Blockchain

In blockchain technology, public blockchains are the first type. Cryptocurrencies like Bitcoin emerged in this region, which contributed to the popularity of distributed ledger technology (DLT). By removing centralization's problems, including security and transparency, the entire process becomes more efficient. In DLT, information is distributed as a peer-to-peer network, not stored in any one place. A method of ensuring data authenticity is required due to its decentralized nature. Essentially, it is a method of reaching consensus on the current state of the ledger by the participants in the blockchain. There are two common methods of reaching consensus: proof of work and proof of stake. Blockchain technology is permission less and non-restrictive, and anyone with internet access can sign on as a node to a blockchain platform. A user can access both current and previous records and conduct mining activities, a complex computation used to verify and include transactions in the ledger. The source code is usually open source, so anyone can verify transactions, find bugs, and propose changes since no valid record or transaction can be changed on the network.

4.2 Private Blockchain

Blockchain networks that operate in restrictive environments, such as closed networks or those controlled by a single company, are called private blockchains. Despite being peer-to-peer and decentralized, this type of blockchain network is much smaller than a public blockchain. In contrast to public blockchains, where anyone with computing power can participate, private blockchains operate on a network of people inside an organization. Blockchains with permission and enterprise blockchains are also known as permission blockchains.

4.3 Hybrid Blockchain

Many organizations want to take advantage of both public and private blockchain technology at once, so they'll use hybrid blockchain, which combines elements of both technology. By setting up a private permission system alongside a public permission less system, an organization is able to control what data in the blockchain is publicly accessible, as well as who can access it. A hybrid blockchain does not typically publish transactions and records, but can be verified through smart contracts when needed. It is still possible to verify the confidentiality of the information inside the network. The hybrid blockchain may be owned by a private entity, but it is not able to alter transactions. The user has full network access when they join a hybrid blockchain. Unless other users engage in a transaction, the user's identity is protected. When this happens, the other parties' identities are revealed.

TABLE I. COMPARISON OF TYPES OF BLOCKCHAIN

• Type	• Advantages	• Disadvantages	• Uses
• Public	• Independent • Transparency • Trust	• Performance • Scalability • Security	• Cryptocurrency • Document Validation
• private	• Access control • Performance	• Trust • Auditability	• Supply chain • Asset ownership
• Hybrid	• Access control • Performance • Scalability	• Transparency • Upgrading	• Medical records • Real estate
• Consortium	• Access control • Security • Scalability	• Transparency •	• Banking • Research • Supply chain

4.4 Consortium blockchain

Consortia blockchains, also called federated blockchains, have the characteristics of hybrid blockchains in that they combine private and public features. A decentralized network, however, allows multiple members of the organization to collaborate. Consortium blockchains are essentially private blockchains that can only be accessed by a particular group, eliminating the risks associated with just one entity controlling the network on a private blockchain. A consortium blockchain has nodes that control the consensus procedures. Transactions are initiated, received, and validated by a validator node. Any node in the system can initiate or receive transactions.

5. CONSENSUS ALGORITHMS IN BLOCKCHAIN

Consensus algorithms establish consensus about the state of the distributed ledger amongst all peers of a Blockchain network. By establishing trust between anonymous peers in a distributed computing environment, consensus algorithms ensure the reliability of the Blockchain network. The consensus protocol ensures that every new block added to the Blockchain is the one and only version of truth that has been adopted by all the nodes.

5.1 Proof of Work (PoW)

Satoshi Nakamoto is credited with introducing Proof of Work (PoW) in the cryptocurrency Bitcoin by publishing a paper in 2008 that describes the idea. Cynthia Dwork and Moni Naor originally proposed the PoW concept in 1993. Majority of cryptocurrencies currently in circulation use Proof of Work consensus. Markus Jakobsson and Ari Juels used the term "proof of work" for the first time in a publication in 1999. Solving the mathematical problem may difficult. The solution can easily be verified to be correct. The next block generation is selected using this consensus algorithm. PoW is the consensus algorithm used by Bitcoin [3-2]. The idea behind this algorithm is to find an easy solution to a complex mathematical problem. A lot of computational power is required for solving this puzzle, so the node that solves it first gets to mine the next block.

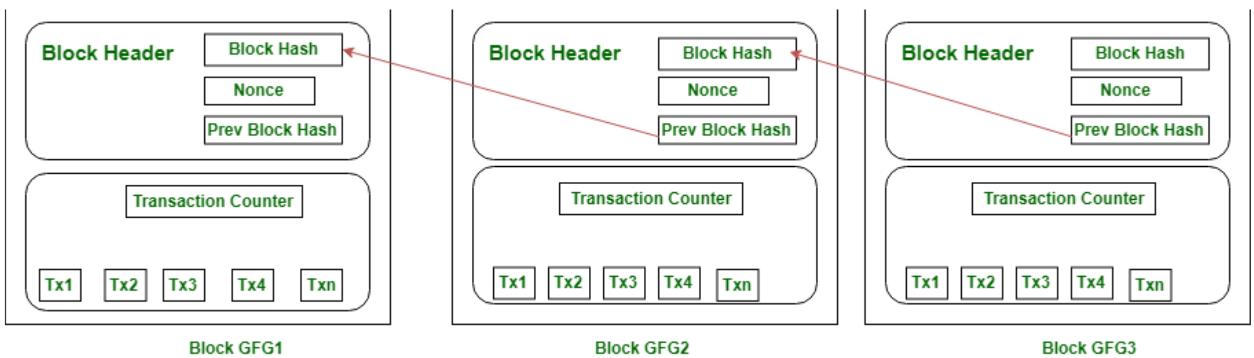

Figure 7. **Proof of Work**

5.2 Practical Byzantine Fault Tolerance (PBFT)

Barbara Liskov and Miguel Castro introduced PBFT in the late 90s. Asynchronous systems are designed to work efficiently with PBFT. Low overhead time is its main goal. Byzantine Fault Tolerance solutions already exist, but there are many problems associated with them. Some of the areas where it is used are distributed computing and blockchain. Benefits - Transaction finality, Energy efficiency, Low reward variance. Weaknesses - Scaling, Sybil attacks

5.3 Proof of Stake (PoS)

It's the most popular alternative to PoW. PoS is the consensus algorithm on Ethereum. An alternative to investing in expensive hardware is to hold some of a validator's coins as a stake instead of investing in complex puzzles. From there, everyone starts validating the blocks. When validators come across a block that is worth adding to the chain, they will place a bet on it. The stake increase is proportional to the amount of blocks added to the Blockchain, based on the involvement of all the validators. An economic stake in the network is used to select a validator to generate a new block. In this way, PoS encourages agreement between validators by providing incentives.

5.4 Proof of Burn (PoB)

PoB validators do not invest in expensive hardware equipment, but rather send tokens to an unrecoverable address and will not be able to retrieve them. Validators earn mining privileges on the system through committing coins to an unreachable address based on a random selection process. Therefore, validators are committing to long-term commitments in exchange for their short-term loss through burning coins. PoB implementers may burn the native currency of a Blockchain application or a currency from another chain, like bitcoin, depending on how the PoB is implemented. Burning coins makes them more likely to be selected to mine the next block. In spite of the fact that PoB is an interesting alternative to PoW, it still wastes resources unnecessary.

5.5 Proof of Capacity (PoC)

Rather than investing in expensive hardware or burning coins, validators should invest their hard drive space in PoC consensus. Validators with large hard drive space have a better chance of being selected to mine the next block and earning the block reward.

5.6 Proof of Elapsed Time (PoET)

A fair consensus algorithm, PoET uses only fair methods to choose the next block. Many permission blockchain networks use it. This algorithm ensures that each validator gets a chance to write their own block. By waiting for random periods of time, the nodes add a proof of their waiting into the block. New blocks are broadcast to the network to be captured by the rest of the network. Validators with the lowest timer values win. Appending the block to the blockchain is the responsibility of the winning validator node. Additional checks are incorporated into the algorithm to prevent nodes from winning the election forever or from generating the lowest timer value.

6. LIMITATION OF BLOCKCHAIN TECHNOLOGY

Developing trustless, decentralized applications with blockchain technology has enormous potential. It does not achieve its full potential. In order for blockchain technology to be used in mainstream applications, there are certain barriers. Lack of Awareness : Blockchain is currently being discussed a lot, but people do not know how to utilize it in various situations. Limited availability of technical talent : Developers today are available in many different fields, and can do many things. Compared to other technologies, however, blockchain technology has fewer developers who have specialized knowledge of the technology. Because of this, blockchain development has been hampered due to the scarcity of developers. Immutable: Immutable means that we can never modify the records in any way. It's a way to make sure that the integrity of a record is protected and that no one tampers with it. But immutability has a disadvantage.

Key Management : In addition to the public and private keys that blockchain has as its foundation, it is built on cryptography. Private keys present one more risk: someone may regain access to your key if you lose it. It happened a lot in the early days when bitcoin wasn't worth a lot. A lot of people would accumulate bitcoins and suddenly forget what the keys were, and some of these would now be worth millions of dollars.

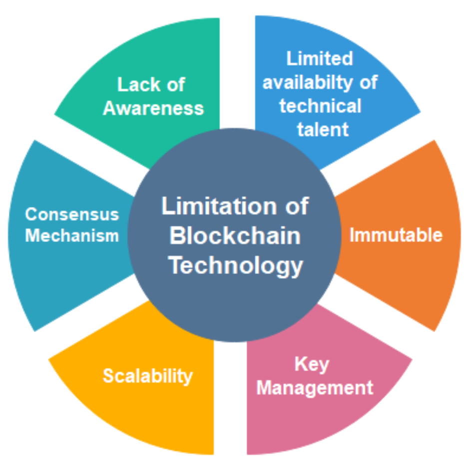

Fig.8. Limitations of Blockchain Technology

Scalabilit : Every participating node in a blockchain, like bitcoin, verifies the transaction. Blockchain networks can only handle a limited number of transactions. The bitcoin network was not designed to handle the high volume of transactions conducted by many other institutions. Bitcoin can currently manage up to seven transactions per second. A majority of nodes must approve a transaction for blockchain architecture to be valid. This process can take several minutes. Bitcoins are based on the Proof-of-Work model, despite being secure and slow at the same time. The Proof-of-Stake protocol is an alternative to distributed consensus, which provides faster entry validation, but is not regarded as a viable option.

Complexity of Blockchain : It is the complexity of the network that makes blockchain so attractive. Blockchain is more effective when there are many parties involved in a transaction. Due to the lack of nodes running the blockchain, many of the early Proof of Concepts were unpractical on an operational and cost-efficient level. In addition, most companies and banks are currently experimenting with blockchain. Organizations have taken a hybrid approach rather than going fully centralized or decentralized. Such an approach greatly increases complexity. Even if their existing applications are small, companies need to deploy blockchain experts.

High Energy Consumption : The first application of the blockchain, Bitcoin, is one of the most popular. Every node that is part of the blockchain network must have around 200 GB of storage space. Additionally, a daily upload of 5GB and a download of 500MB are required. In India, the Bharatmala Broadband project is still a struggle to implement, and 4G is unreliable and not available in every state, so implementing blockchains certainly requires a substantial upgrade to support it. A major problem with Bitcoin miners continues to be energy consumption. Apparently, Bitcoin consumes more energy than the entire nation of Switzerland according to a study by researchers at the University of Cambridge.

7. BENEFITS OF BLOCKCHAIN TECHNOLOGY

Trust in a network is one of the key issues that blockchain technology resolves. Organizations can focus on solving their problems by altering the key parameters, trust. Blockchain technology has also been embraced by governments and deemed important.

Fig.9. Benefits of Blockchain Technology

7.1 Energy Sector

Environmental Sustainability: Blockchain helps to reduce the environmental impact of the energy sector. In addition to providing an efficient network for storing, producing, and distributing energy, it also deals with legacy efficiency problems in the energy sector. Reduced Costs: The energy sector suffers from a reduction of costs associated with infrastructure and operational aspects. Improved Transparency: Distributed ledger systems offer enhanced transparency.

7.2 Real Estate

Tokenization: The blockchain will enable tokenization of actions. A pre-defined code is used to rent out properties for a specified period of time. In addition to adding any business logic, tokens can be used to secure transactions against fraud. Proper Tenant and Investor Identity: Creating digital identities that are easy to verify and use is beneficial to both investors and tenants. A proper identity management system will enable KYC/AML procedures to be streamlined. Additionally, sharing and accessing documentation will become easier. Property Sale: Smart contracts can automate the sale of property. By doing so, as long as a certain condition is met, legal agreements can be tracked and executed. Real-Time Accounting: The Blockchain enables real-time accounting.

7.3 Trade Finance

Data Integrity: In terms of data integrity, authenticity, and proper asset provenance, blockchain technology improves the trade finance industry.

Streamlined Process: With blockchain-based smart contracts and blockchain-based dApps, automation has also become a norm. The process efficiency was improved, including the ability to perform real-time settlements. Since intermediaries were not involved, the process was also error-free.

Programmable: A blockchain platform enables organizations to code multiple business aspects such as identity management, data privacy, and governance.

Market Reactivity: A trade finance organization can also make changes as needed by using digital security. The ability to customize is a major benefit.

Cost Reduction: Automating your network means reducing operational, infrastructure, and transactional costs.

7.4 Government

Proper Identity Management: Identity management is a tool that can be used by the government for every citizen. Thus, they are able to manage transactions, credentials, and data in a simplified way.

Fair Elections: As well as conducting transparent elections with no chance of fraud, they can also use the blockchain.

Finance Management: Engage in more effective financial management. Also, budgets can be allocated in a transparent, efficient, and effective manner.

7.5 Healthcare

Patient Profile Privacy: Unified patient profiles are created when decentralized ledgers are used. A secure ledger allows patients to store and share all their papers online without carrying them. As patients are in control of who can see or use their data, it will also increase their privacy. Drug Traceability: Blockchain will also enhance drug traceability. The fact that everything is tracked in real-time in a decentralized network virtually eliminates any chance of its being compromised.

Better Clinical Trials: A decentralized network secures and stores patient data. By using public health data, researchers can do better clinical trials and research, which could help develop drugs to treat different diseases. Electronic Health Records (EHRs): Electronic records can be easily managed by health organizations using blockchain.

7.6 Logistics

Better Freight Tracking: There is no way for anyone to alter the data available on the network, since blockchain offers a proper authentication channel, which also includes verification. In this way, all deliveries can be tracked and managed in real time.

Better Carrier Onboarding: Blockchain is equipped to handle the situation; onboarding new drivers takes only minutes.

Vehicle to Vehicle Communication: Vehicle communication processes can be streamlined with blockchain technology, allowing companies to secure all the data quickly and efficiently.

Security for the Internet of Things (IoT) Devices: Security can be offered for IoT devices as well as monitoring all the data generated by all the devices.

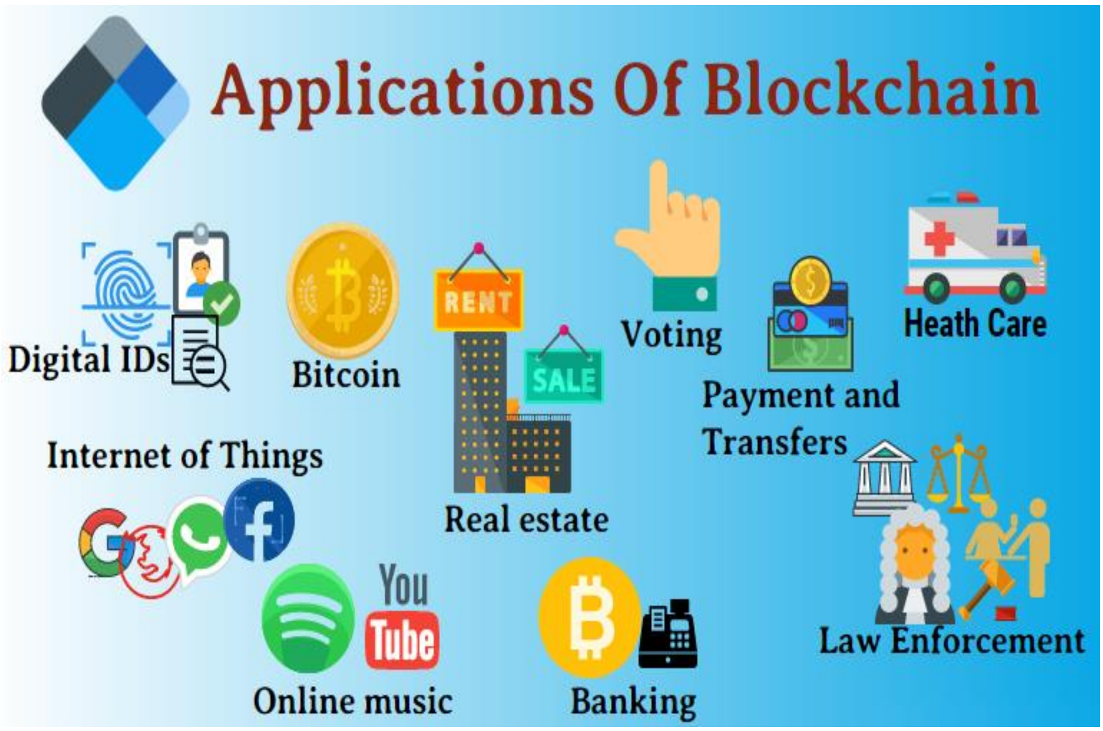

Fig.10. Applications of Blockchain

8. CONCLUSION

An overview of blockchain is presented in this paper. Blockchain technology has become increasingly popular around the world. Decentralized infrastructure and peer-to-peer nature make blockchain an excellent technology and highly valued and acclaimed. We investigate blockchain applications in various fields. Key characteristics and architecture are described. Discussed typical consensus algorithms of blockchain. More blockchain-based applications are emerging nowadays, we will investigate blockchain-based applications extensively in the future. We will examine more closely in detail the privacy and security issues of Blockchain architecture in future research.

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Conflicts Of Interest

The authors declare no conflicts of interest.

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