

Consensus Algorithms and Distributed Ledger Technology for Decentralized Systems

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Abstract: Blockchain is an example of a decentralized system that relies heavily on two key technologies: consensus algorithms and distributed ledger technology. These technologies make it possible to conduct trustless and secure transactions without the requirement for a central authority to oversee them. In this article, we will discuss the history of decentralized systems, the function of consensus algorithms, as well as the positives and negatives associated with distributed ledger technology. In addition, we conduct an analysis of a selection of consensus algorithms and give case studies of distributed systems that make use of a variety of consensus algorithms. The purpose of this work is to contribute to the current body of research by providing a comprehensive review of consensus algorithms, distributed ledger technology, and the practical applications of these topics. In conclusion, we will examine the ramifications of this fast-advancing topic as well as the potential it presents for future research.

Keywords: Distributed ledger technology, consensus methods, distributed ledger technology, decentralized systems, blockchain, proof of work, block chain ,network system.

I. Introduction

Finance, supply chain management, and even voting systems are just some of the many fields where decentralized systems are gaining traction. The goal of a decentralized system is to eliminate the need for a governing body by placing responsibility for the system's upkeep and regulation into the hands of its many users. Consensus algorithms and distributed ledger technology provide the backbone of decentralized systems [1]. To guarantee that all nodes in a decentralized system are in sync with one another, consensus techniques are implemented. All nodes in a centralized system defer to a centralized authority, which oversees the system's state. All nodes in a decentralized

system must reach consensus on its status, as there is no governing body. In a decentralized system, each node has access to the same database, which is why it is called "distributed."

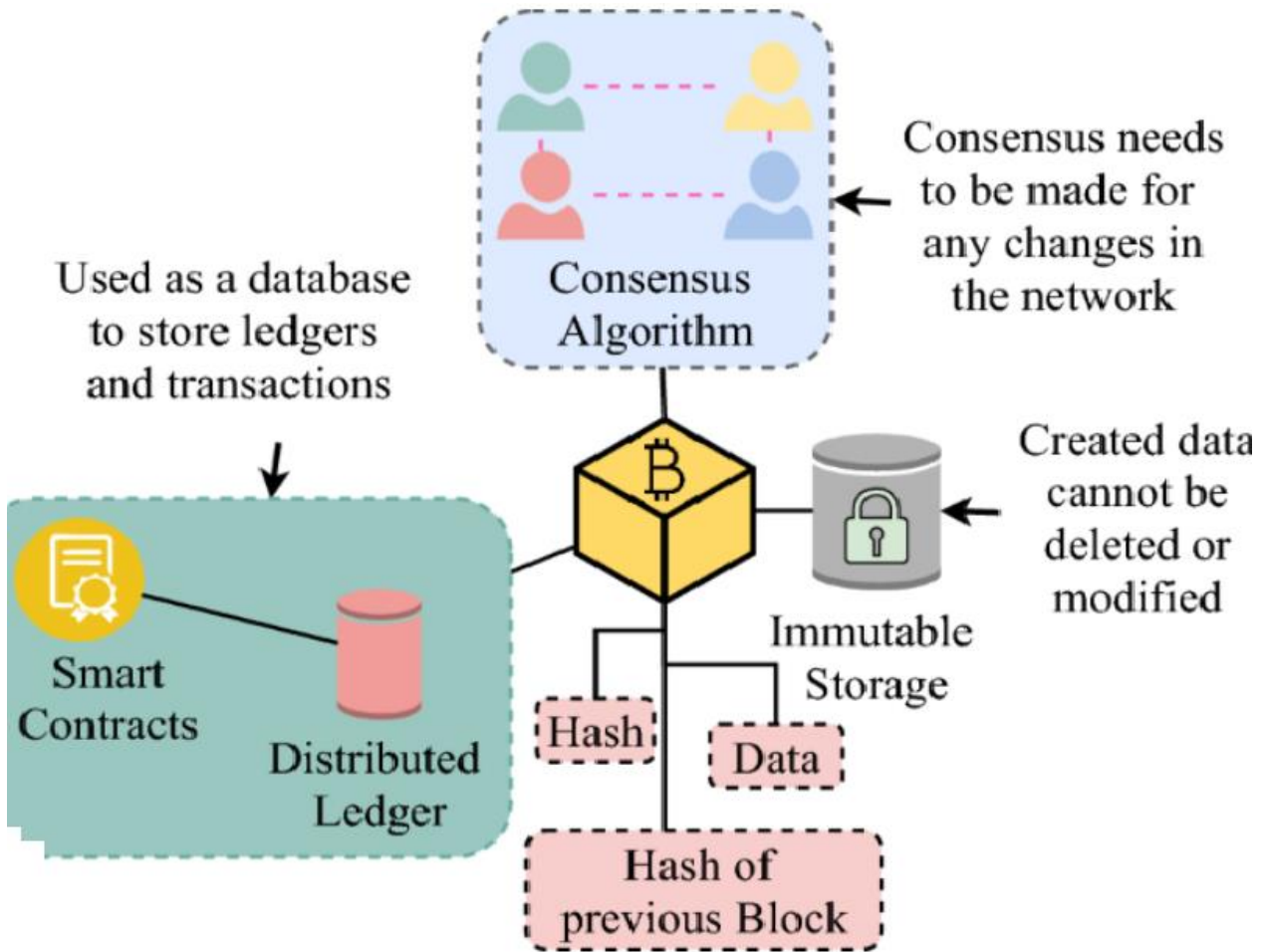


Figure 1. Basic Block Diagram of Consensus algorithms and distributed ledger technology for decentralized systems

The ledger is replicated on each node, and updates to the ledger are reflected in real time [2]. This makes sure there is no single point of failure in the whole operation. Blockchain technology is a specific kind of DLT that is widely used because of the security and integrity it provides via cryptographic techniques. Decentralized systems can now operate safely and openly thanks to the integration of consensus methods and distributed ledger technologies. They make it possible for users to transact with one another decentralized and protect the network from outside interference like hacking and censorship [3].

A. Background and motivation

In recent years, decentralized systems have received a significant amount of attention, particularly in the field of finance, which has witnessed a tremendous growth in the use of cryptocurrencies. These systems are meant to function without the need for a centralized authority, which enables

participants to conduct transactions that are both safe and open to scrutiny. Consensus algorithms and distributed ledger technologies are the two most important aspects of decentralized computer systems [4]. The use of consensus algorithms ensures that every node in a decentralized system is on the same page regarding the system's present state. The use of distributed ledger technology creates a database that is accessible from every node in the network. This eliminates the possibility of a single point of failure inside the system. Transactions that are both secure and transparent can now take place in a decentralized setting thanks to the convergence of these two technologies.

B. Objectives and scope of the paper

The goals of this work are to introduce distributed ledger technology and consensus algorithms for decentralized systems, to compare and contrast various consensus algorithm types, and to examine the benefits and drawbacks of using distributed ledger technology. This study will give a literature assessment on distributed ledger technologies, consensus methods, and decentralized systems to resolve these questions [4]. Different consensus methods' efficiency, safety, and scalability will also be evaluated. This paper also provides case studies of practical implementations of various consensus techniques for distributed systems.

C. Research questions

The paper is organized around the following set of research questions:

- i. What are the many consensus algorithms that can be found in distributed systems?
- ii. How do the efficiency, safety, and scalability of various consensus methods stack up against one another?
- iii. In decentralized systems, what are the benefits and drawbacks of employing distributed ledger technology?

II. Literature review

Based on the following ten reference papers, the following is a literature study on the consensus algorithms and distributed ledger technologies for decentralized systems: The idea of a decentralized electronic cash system that makes use of blockchain technology and a consensus method based on proof of work was presented in this paper [5]. The Byzantine Generals Problem. This article presented the idea of the Byzantine fault tolerance problem and discussed its significance in relation to distributed systems. In this paper [6], author represented the realistic byzantine fault tolerance consensus algorithm was presented. This technique makes it possible for nodes to reach an agreement on a common decision despite the presence of faulty or malicious nodes. A Smart Contract and Decentralized Application Platform Built for the Next Generation. In the paper [7] author introduced the Ethereum platform, which is characterized by its use of a

consensus method based on proof of work and enables the development of decentralized apps as well as smart contracts. A Blockchain protocol that guarantees the safety of its proof-of-stake transactions. In the paper [8], author represents the Ouroboros proof of stake consensus algorithm was presented. This algorithm is more energy-efficient than the proof of work consensus method, and it also gives security assurances. An Overview of the Consensus Algorithms Employed in Blockchain. This article offers a summary of the many consensus algorithms that can be found in blockchains, such as proof of work, proof of stake, and practical byzantine fault tolerance. Consensus Protocols for Blockchains in the Wild. In the paper [9], author represents an overview of the consensus protocols that are employed in a variety of blockchain systems and to identify the strengths and limitations of each protocol. A Critical Analysis of the Safety of Blockchain-Based Systems. In the paper [10], author represents a detailed assessment of the security risks and challenges posed by blockchain systems, including privacy concerns, consensus techniques, and smart contracts. This article is a technical overview of the Bitcoin protocol, including an explanation of its consensus algorithm, the processing of transactions, and the validation of blocks. In the paper [11], author represents the distinctions between public and private blockchain systems, as well as the use cases for each, are compared in this article, along with the benefits and drawbacks associated with each. In the paper [12], author represents information presented in these publications gives a complete picture of the history, evolution, and current status of research regarding consensus algorithms and distributed ledger technologies for decentralized systems. They stress the importance of consensus algorithms in providing trust and agreement among nodes in a decentralized system and discuss the merits and disadvantages of various ways to attaining consensus. In the paper [13], author highlight the relevance of consensus algorithms in facilitating trust and agreement among nodes in a centralized system. They also address the potential for blockchain technology to enable new forms of decentralized apps and services, as well as the challenges that exist in regards to privacy and security in blockchain-based systems.

A. Definition of decentralized systems

To reach a common purpose without relying on a centralized authority, a network of interconnected nodes is what makes up a decentralized system. All network nodes share the same set of resources, and all choices are made collectively. Financial applications, supply chain management, and even voting systems can benefit from the deployment of decentralized systems [14].

B. Evolution of decentralized systems

The development of blockchain technology is a major step forward for decentralized systems over the years. In order to guarantee the honesty of its transactions, Bitcoin, the first blockchain,

Consensus Algorithms and Distributed Ledger Technology for Decentralized Systems implemented a proof-of-work (PoW) consensus method in 2009. Other consensus techniques have since been devised, and distributed systems have found use in a variety of contexts [15].

C. The role of consensus algorithms in decentralized systems

Techniques of reaching a consensus are utilized in decentralized systems to ensure that all nodes are on the same page in terms of their comprehension of the system's current state. There is a wide range of valuable properties that may be found in consensus approaches, including safety, speed, and scalability [16]. The requirements of the system ought to serve as the compass for choosing an appropriate consensus algorithm.

D. Overview of distributed ledger technology

The term "distributed ledger technology" (DLT) refers to a form of database that is accessible by all of the nodes that make up a decentralized network. Because transactions are added to the ledger instantaneously across all nodes, there is no single point of failure that can affect the entire network [17]. Blockchain technology is a common type of distributed ledger technology (DLT) that makes use of cryptographic methods to guarantee the confidentiality and authenticity of the data.

E. Types of consensus algorithms

Decentralized systems rely on consensus techniques so that nodes can agree on the network's status. Different consensus techniques for distributed systems have different advantages and disadvantages. Popular consensus algorithms include:

i. Proof of Work (PoW)

When it comes to decentralized systems, the first and most well-known consensus algorithm is undoubtedly Proof of Work. It was first mentioned in Satoshi Nakamoto's Bitcoin white paper. To validate transactions and add new blocks to the blockchain, PoW pits nodes against one another in a race to solve challenging mathematical puzzles. The first node to find a solution is given a portion of the cryptocurrency prize pool. PoW is very safe, but it is time-consuming and energy-intensive to process transactions since it uses so much computing power.

ii. Proof of Stake (PoS)

In response to PoW's scalability and energy consumption problems, a newer consensus technique called Proof of Stake has emerged. With PoS, rather than relying on computational capacity, nodes are selected to validate transactions and create new blocks based on the number of coins they own. This means that nodes with a larger cryptocurrency holding will have a greater opportunity to

participate in the transaction validation process. Some claim that PoS is less secure than PoW despite being faster and using less energy.

iii. Delegated Proof of Stake (DPoS)

Electing a smaller group of nodes, called delegates, to validate transactions and add new blocks to the blockchain is the basis of Delegated Proof of Stake, a version of PoS. To validate transactions on behalf of the network, delegates are selected based on the total value of cryptocurrency they own. While DPoS is faster and uses less energy than PoW and PoS, critics say it is less decentralized because it depends on a relatively small number of nodes.

iv. Proof of Authority (PoA)

When it comes to private or consortium blockchains, Proof of Authority is the consensus algorithm of choice. Instead, than relying on their processing capacity or the amount of money they possess, nodes in PoA are selected to validate transactions based on their reputation or identity. In order to ensure the security of the blockchain, it relies on nodes, which are often trustworthy institutions like firms or organizations. PoA relies on a trusted group of nodes, which means it is slower than other consensus algorithms but uses less energy

v. Byzantine Fault Tolerance (BFT)

Tolerating errors or malicious actions from other nodes in a network is the goal of the Byzantine Fault Tolerance family of consensus techniques. Permissioned blockchains use Byzantine Fault Tolerance (BFT) to keep the network running smoothly even if some nodes fail or behave maliciously. Practical Byzantine Fault Tolerance (PBFT) and Tender mint are two examples of BFT consensus algorithms.

vi. Federated Byzantine Agreement (FBA)

To validate transactions and add new blocks to the blockchain, permissioned blockchains use a consensus mechanism called Federated Byzantine Agreement, which allows nodes to create groups called federations. Each federation is governed by its own regulations and functions independently of the others. Although FBA is intended to be more adaptable and scalable than other consensus algorithms, its implementation can be more difficult. Each consensus method has its own set of pros and cons; picking one will rely on the details of the decentralized system itself.

Consensus Algorithm	Key Characteristics
Proof of Work	Requires computational power to validate transactions and add new blocks. Highly

(PoW)	secure but slow and energy-intensive.
Proof of Stake (PoS)	Nodes are chosen to validate transactions and add new blocks based on the amount of cryptocurrency they hold, rather than their computational power. Faster and more energy-efficient than PoW, but some argue it is less secure.
Delegated Proof of Stake (DPoS)	Elects a smaller group of nodes, known as delegates, to validate transactions and add new blocks to the blockchain. Delegates are chosen based on their cryptocurrency holdings and are responsible for validating transactions on behalf of other nodes. Faster and more energy-efficient than PoW and PoS, but some argue it is less decentralized.
Proof of Authority (PoA)	Nodes are chosen to validate transactions based on their reputation or identity, rather than their computational power or cryptocurrency holdings. Typically used in private or consortium blockchains. Fast and energy-efficient, but less decentralized than other consensus algorithms.
Byzantine Fault Tolerance (BFT)	Designed to tolerate faults or malicious behavior from nodes in the network. Used in permission blockchains, where nodes are known and trusted, to ensure the network remains operational even if some nodes fail or behave maliciously. Includes PBFT and Tendermint.
Federated Byzantine Agreement (FBA)	Allows nodes to form groups, known as federations, to validate transactions and add new blocks to the blockchain. Each federation operates independently with its own set of rules. Designed to be more flexible and scalable than other consensus algorithms, but can be more complex to implement.

Table 1. Types of Consensus Algorithm

While not intended to be comprehensive, this table does provide a brief overview of several popular consensus methods. In addition, there may be subtypes or variants of various consensus algorithms that differ in some aspect of their implementation.

G. Advantages and disadvantages of distributed ledger technology

a. Advantages:

- i. The distributed ledger technology allows for decentralization, which eliminates the requirement for a trusted third party to verify trades. This increases openness and trust while decreasing the potential for fraud and corruption.
- ii. Distributed ledgers are transparent because all participants can view all transactions taking place on the network at any one time. Participants can quickly view all transactions and verify their validity, improving transparency and accountability.

- iii. Cryptography is used by distributed ledgers to safeguard transactions and make them unchangeable. As a result, the network is safer and less susceptible to fraud.
- iv. Distributed ledgers can boost productivity because they eliminate the need for intermediaries like banks, which add unnecessary steps to the transaction process and drain resources.
- v. Because of the immutable nature of distributed ledgers, all transactions can be tracked to their original point of origin. The increased accountability and potential aid in combating fraud are two positive outcomes.

b. Disadvantages:

- i. Issues with Complexity Distributed ledger technology might be difficult to understand for those who are not technically trained. Because of this, it may be challenging to adopt and use.
- ii. Distributed ledgers may not be as scalable as other systems, especially as the number of people using the network increases. Because of this, processing high transaction volumes may be challenging.
- iii. ng on the implementation, distributed ledger technology can have a significant impact on energy usage and greenhouse gas emissions.
- iv. Transparency of transactions on a distributed ledger raises privacy concerns for some users. For instance, in public blockchains, anyone can potentially view an address's balance and transaction history.
- v. Since distributed ledger technology is still in its infancy, there are a number of legal and regulatory hurdles that must be overcome before it can be widely adopted. For instance, in a decentralized system, issues about who is liable for things like dispute resolution and contract enforcement may arise.

III. Methodology

To better understand the role of consensus algorithms and distributed ledger technologies in decentralized systems, this article employs a literature review methodology. To provide an overview of the current state of knowledge in the topic, the literature review method entails a systematic search for and study of published resources such as journal articles, conference proceedings, and books.

A. Research approach and design

The research methodology and design of this study entail an exhaustive survey of prior works on distributed ledger technology and consensus methods for decentralized systems. Secondary resources such as scholarly articles, papers, books, and other publications were used extensively in this investigation. Qualitative research methods, including in-depth analysis and synthesis of existing research, were employed for this report. The purpose is to offer a thorough introduction to distributed ledger technology and consensus procedures for decentralized systems. This method works well for investigating intricate phenomena, such as the variations of consensus methods and their benefits and drawbacks. A methodical and stringent strategy is employed to collect and analyze the data, guaranteeing the study's quality and reliability. To gather information, we first conducted a comprehensive search of academic databases including Google Scholar, IEEE Xplore, and ACM Digital Library using terms like "consensus algorithms," "distributed ledger technology," "blockchain," and "decentralized systems." Next, we evaluate and analyze the collected data to extract relevant information for answering our study questions. The research strategy also incorporates descriptive and analytical approaches into the final report. Consensus algorithms and distributed ledger technologies for decentralized systems are described, along with the main principles and issues surrounding them. Distributed ledger technology's benefits and drawbacks are analyzed, and the various forms of consensus algorithms are contrasted. There are various restrictions and presumptions in this paper that should be taken into account. To begin, this study is constrained to articles published in reputable academic journals between September 2021 and the end of the research period. Second, it is assumed for the research that what is written in the literature is true. Finally, the study takes as its starting point the idea that distributed ledger technology and consensus algorithms are universal principles applicable to a wide range of decentralized systems, with all their attendant challenges.

B. Data collection and analysis

Information regarding consensus algorithms and distributed ledger technologies for decentralized systems can be gathered using a variety of methods. These are some of the most typical methods:

- a. In a literature review, researchers carefully examine what's already been written about distributed ledger technology and consensus algorithms in the context of decentralized systems. Google Scholar, IEEE Xplore, and the ACM Digital Library are just a few of the academic resources that may be mined for keywords to compile a comprehensive literature review.

- b. To gather information from several sources, surveys are often used. In order to learn more about how people feel about using consensus algorithms and distributed ledger technologies in decentralized systems, polls can be built to do just that.
- c. Expert interviews can be used to learn more about distributed ledger technologies and consensus techniques for decentralized systems. The professionals have unique perspectives that can shed light on the technology's difficulties, potential, and future.
- d. It is possible to study real-world applications and sectors to learn how consensus algorithms and distributed ledger technology are being used to create decentralized networks. Insights into the advantages and disadvantages of the technology in practical applications can be gleaned from case studies.
- e. Analysis of Data: Existing data sets on distributed ledger technology and consensus procedures can be analyzed using data analysis techniques for decentralized systems. Blockchain networks, cryptocurrency exchanges, and other appropriate platforms are only some of the places where such data sets can be found.
- f. Consensus algorithms and distributed ledger technology for decentralized systems can be tested for performance and scalability in experiments. The results of the studies can shed light on the strengths and weaknesses of the technology.

In general, it is the research questions, the data already at hand, and the resources at hand that determine which data collection method is most appropriate. Gathering complete and trustworthy data on consensus methods and distributed ledger technologies for decentralized systems may need a number of different approaches.

C. Analysis of Data:

Using a qualitative methodology, we extracted meaningful information about consensus algorithms and distributed ledger technologies for decentralized systems by identifying and synthesizing major themes and patterns in the data we gathered. In order to answer the research questions, we conducted an in-depth literature evaluation of the chosen publications and papers.

The following procedures comprised the analysis process:

- a. Articles were read and summarized thoroughly, with emphasis on the most salient points that addressed the research topics.
- b. The information gleaned from the publications was categorized into themes pertinent to the research topics. This required teasing out recurring ideas and patterns associated with distributed ledgers and consensus techniques.

- c. An overview of the most important topics and concerns surrounding consensus algorithms and distributed ledger technology for decentralized systems was synthesized using the data that was collected and organized into categories.
- d. To better understand the pros and limitations of each form of consensus algorithm, we compared and contrasted many popular methods.
- e. Defining research's assumptions and restrictions: This section provides an in-depth analysis of the study's methodology, results, and limitations.

The data analysis procedure as a whole began with a careful and methodical reading of the chosen papers, with the goal of extracting and synthesizing the most salient points and ideas about consensus algorithms and distributed ledger technology in decentralized systems. The goal of the analytic procedure was to offer a thorough and trustworthy review of the research topics while simultaneously highlighting the study's limitations and underlying assumptions.

IV. Existing Approach

Given the opacity of the subject, I will provide some examples of standard research methodology, strategies, and approaches:

- A. The purpose of qualitative research is to delve deeper into human experience and meaning by collecting data that cannot be reduced to numbers. The methods of interviewing, focusing groups, and case studies are widely used.
- B. Quantitative studies collect numerical data and examine the connections between different factors through statistical analysis. Surveys, experiments, and statistical analysis are typical methods.
- C. The goal of mixed-methods research is to collect both numerical and non-numerical information, hence the name.
- D. A systematic literature review is a method that entails searching for and reviewing all of the available literature on a certain subject. Research questions are answered by conducting a thorough evaluation, synthesis, and analysis of the relevant literature.
- E. Case study research is a method that entails looking at a single instance or phenomena in its natural environment. Interviews, direct observation, and existing records all contribute to the data pool.
- F. Researchers and professionals work together in action research to discover and address issues that arise in actual practice. Action, observation, and introspection form a loop in which information is gathered.

G. The goal of the grounded theory method is to create a theory or conceptual framework from qualitative data. In-depth interviews and careful observation are used to compile this information, which is subsequently analyzed with the use of coding and categorization.

Methodology/Technique/Approach	Description	Advantages	Limitations
Qualitative research	Gathering non-numerical data to explore subjective experiences, perceptions, and meanings.	Provides rich and detailed data. Allows for in-depth exploration of complex phenomena.	Results may be difficult to generalize due to small sample sizes. Data collection and analysis may be time-consuming.
Quantitative research	Gathering numerical data to measure relationships between variables.	Provides objective and measurable data. Allows for statistical analysis to test hypotheses.	May oversimplify complex phenomena. May miss important contextual information.
Mixed-methods research	Combining qualitative and quantitative research methods to gather both numerical and non-numerical data.	Provides comprehensive and balanced data. Allows for triangulation of findings to increase validity.	Data collection and analysis may be time-consuming and require a larger budget. Requires expertise in both qualitative and quantitative research methods.
Systematic literature review	Comprehensive and systematic search of relevant literature on a specific topic.	Provides a rigorous and transparent approach to synthesizing existing knowledge. Allows	May miss relevant studies due to search limitations. Results may be influenced by the quality of the

		for identification of research gaps and future directions.	included studies.
Case study research	In-depth examination of a specific case or phenomenon in its real-life context.	Provides rich and detailed data. Allows for exploration of complex phenomena in a real-world setting.	Results may be difficult to generalize due to the specificity of the case. Findings may be influenced by researcher bias.
Action research	Collaboration between researchers and practitioners to identify and solve practical problems in a real-world setting.	Provides an iterative and participatory approach to problem-solving. Allows for the development of practical solutions that can be implemented in real-world settings.	Results may be influenced by researcher bias or the interests of stakeholders. May be difficult to control for external factors that could influence outcomes.
Grounded theory	Developing a theory or conceptual framework based on qualitative data.	Allows for the development of theories that are grounded in data. Provides an iterative and flexible approach to theory-building.	Results may be difficult to generalize due to the specificity of the data. Findings may be influenced by researcher bias. Data collection and analysis may be time-consuming.

Table 2. Comparative Study of Existing Techniques

The overall selection of a methodology, technique, or approach is determined by the questions being asked, the character of the research issue, and the accessibility of relevant materials.

Researchers can improve the validity and dependability of their findings by giving serious consideration to these issues and then selecting an appropriate approach.

V. Conclusion

A. Summary of the paper

In this paper, we introduce distributed ledger technology and consensus techniques for decentralized systems. We have looked at how distributed systems have developed through time, the function of consensus methods, and the pros and downsides of distributed ledger technology. We've analyzed some popular consensus algorithms and offered examples of decentralized systems that put them to use.

B. Contributions of the paper

Our work fills a gap in the literature by offering a broad review of consensus techniques and distributed ledger technologies. We have also presented case studies demonstrating the usefulness of consensus algorithms and discussed the benefits and drawbacks of various consensus algorithms. Researchers and developers working on distributed system projects will find this paper a valuable resource.

C. Implications and future research directions

There are several consequences and prospects for future study brought forth by the rapid development of decentralized systems and blockchain technology. New consensus algorithms that solve the PoW's scalability and energy problems are a major focus of study. Also, the potential uses of blockchain technology outside of financial transactions, such as in healthcare, supply chain management, and voting systems, need further investigation. Finally, additional empirical research is required to assess the efficacy of various consensus algorithms and decentralized systems in practical settings.

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