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PERSPECTIVES ON THE USE OF BLOCKCHAIN FOR DECENTRALIZED AND SECURE DATA EXCHANGE

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ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ БЛОКЧЕЙНА ДЛЯ ДЕЦЕНТРАЛИЗОВАННОГО И БЕЗОПАСНОГО ОБМЕНА ДАННЫМИ

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Abstract. The article examines the application of blockchain technology for decentralized and secure data exchange. The primary focus is on blockchain's advantages, such as high security, data immutability, and the potential for process automation through smart contracts. Key challenges in implementing the technology are also discussed, including scalability issues, high energy consumption, and legal restrictions. The article suggests solutions to these challenges through the development of efficient consensus algorithms and integration with advanced technologies, such as artificial intelligence. The research findings highlight blockchain's potential as a viable solution for secure data exchange across various industries.

Аннотация. Рассматривается применение технологии блокчейн для обеспечения децентрализованного и безопасного обмена данными. Основное внимание уделяется преимуществам блокчейна, таким как высокая степень защиты, неизменность данных и возможность автоматизации процессов с помощью смарт-контрактов. Обсуждаются ключевые вызовы внедрения технологии, включая проблемы масштабируемости, высокие энергетические затраты и правовые ограничения. Предлагаются пути решения этих проблем через развитие эффективных алгоритмов консенсуса и интеграцию с передовыми технологиями, такими как искусственный интеллект. Результаты исследования подчеркивают потенциал блокчейна как решения для безопасного обмена данными в различных отраслях.

Keywords: blockchain, data security, decentralization, smart contracts, scalability, technologies.

Ключевые слова: блокчейн, безопасность данных, децентрализация, интеллектуальные контракты, масштабируемость, технологии.

In the modern world, data transmission has become an integral part of all spheres of human activity, from business to healthcare and government. As the volume and importance of information increase, traditional centralized data exchange systems face new security threats, including hacks, cyberattacks, and data breaches. Ensuring the confidentiality and security of information has become a top priority for many organizations and states, as data compromise can lead to significant financial and reputational losses.

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Blockchain is a decentralized and distributed data storage technology, organized as a chain of blocks that are sequentially linked to each other and secured through cryptography. Originally developed to support cryptocurrencies, the technology is now seen as a potential solution for building decentralized data exchange systems capable of ensuring security and transparency. Unlike centralized systems, blockchain allows for trust among network participants without the need for a central governing authority, which can enhance the system's resilience to various attacks.

However, the application of blockchain for data transmission faces a number of challenges. These include scalability issues, low transaction processing speed, and high resource costs. There are also legal barriers and difficulties in integrating blockchain with existing systems. The aim of this study is to analyze the prospects and challenges that blockchain faces in the field of secure data exchange and to propose possible solutions to current problems.

Main part. Principles of blockchain for secure data transmission

As previously mentioned, blockchain is a decentralized distributed system organized as a chain of blocks, where each block is linked to the previous one and secured through cryptography. The main features of the technology include immutability, decentralization, and the use of cryptographic methods to ensure security. Due to the characteristic of immutability, each block in the blockchain network contains the hash of the previous block, timestamps, and transaction information, preventing retroactive changes to the data. These qualities make the technology resistant to forgery, as an attacker would need to alter all previous blocks to modify one.

Unlike centralized databases, where data is stored and controlled by a single node, in blockchain, each node in the network stores a complete copy of the entire chain of blocks—this is the feature of decentralization. This characteristic helps to avoid dependencies on a single central element, making the system less vulnerable to external attacks and failures.

There are consensus mechanisms that allow participants in the blockchain network to agree on the authenticity of data without centralized control. The main types are Proof of Work (PoW), where participants solve complex problems to add a new block, and Proof of Stake (PoS), which reduces energy consumption by linking the probability of adding a block to the stake of cryptocurrency. There is also Delegated Proof of Stake (DPoS), where users vote for delegates, increasing the speed and efficiency of consensus. These principles can be beneficial for systems requiring guarantees against forgery and maintaining data integrity [1].

Blockchain can become an alternative for ensuring the security and decentralization of data exchange. For instance, in the field of medical data, blockchain can be used to create a decentralized database where patient information is stored immutably and accessible only to authorized individuals. The data is protected and cannot be changed without the consensus of all network participants. In the corporate environment, blockchain can be used for secure document transfer between partners and clients.

Smart contracts based on blockchain automate data exchange upon meeting conditions, eliminating the need for intermediaries and reducing the likelihood of errors. This is especially relevant in highly regulated industries such as banking and pharmaceuticals. Additionally, blockchain finds applications in Internet of Things (IoT) networks, where millions of devices exchange data. In traditional centralized IoT networks, there is a threat of hacking a centralized server, which can jeopardize the security of the entire system. In a distributed blockchain system, such a server is unnecessary, reducing the risk of attacks and increasing trust between devices [2].

Limitations and paths for improving blockchain technology

Despite its numerous advantages, blockchain technology encounters significant technological and organizational limitations that extend beyond its applications in cryptocurrencies. One of the

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primary challenges is scalability. Traditional blockchain networks, such as those supporting Bitcoin and Ethereum, require substantial computational resources and time to add each block, constraining their transaction processing capacity. For instance, the Bitcoin network can handle approximately 7 transactions per second, whereas traditional payment systems, such as Visa, process around 1700 transactions per second (https://lyl.su/PRSv; https://chainspect.app/dashboard). This relatively low transaction speed limits blockchain's utility for high-volume, real-time applications, particularly in contexts requiring rapid data exchange. The figure below illustrates a comparison of transaction speeds across popular blockchain networks and traditional payment systems, highlighting these performance disparities.

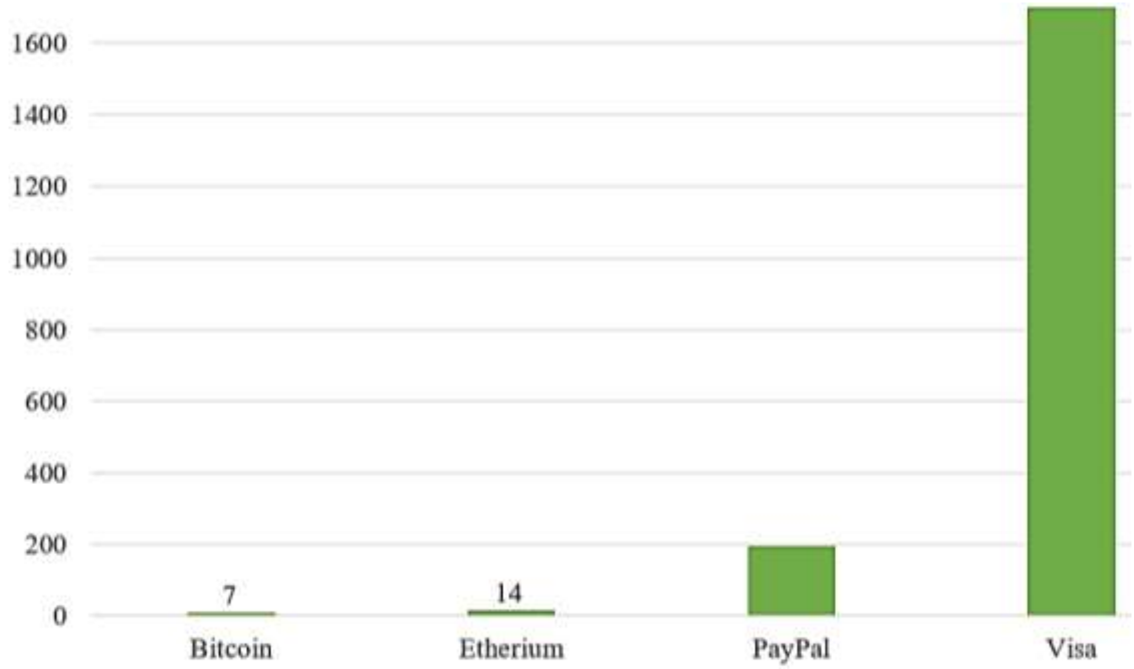

Figure. Number of transactions per second between popular payment systems and blockchains

Another significant limitation is the high operational costs of blockchain networks. The consensus mechanism PoW used to secure these networks requires enormous computational power, making them extremely energy-intensive. Estimates suggest that the energy consumption of the Bitcoin network is comparable to that of small countries. For example, in 2024, Bitcoin is expected to consume approximately 150 TWh per year, exceeding the energy consumption of Argentina (121 TWh) and the Netherlands (108.8 TWh) (https://ccaf.io/cbnsi/cbeci).

This results in high costs and complicates the use of blockchain for creating environmentally sustainable data transmission systems [3].

Additionally, there are legal barriers and challenges in integrating blockchain with existing systems. In several countries, legal regulations limit the use of decentralized systems, complicating the implementation of blockchain technology. Privacy concerns, such as compliance with GDPR in the European Union, also present challenges, as the immutability of data in blockchain can conflict with the right to be "forgotten" guaranteed by this legislation. In the United States, regulatory challenges arise due to varying federal and state-level approaches, creating a complex legal landscape that can hinder widespread adoption of blockchain technology.

Social and organizational barriers also hinder the adoption of blockchain in traditional business processes. Many organizations adhere to established procedures, and transitioning to blockchain requires significant changes in data management and operational activities. It is also

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important to consider that the lack of knowledge and skills among professionals can restrict the successful implementation of the technology.

Despite these limitations, the development of blockchain technology continues, and new approaches are emerging to help overcome its challenges. One such approach is the use of second-layer protocols, such as the Lightning Network for Bitcoin. These solutions allow transactions to be processed outside the main blockchain, recording only their final values on the blockchain, which improves data processing speed and reduces the load on the network. The Lightning Network enhances scalability potential, enabling thousands of transactions per second, making it suitable for widespread use [4].

To address the high costs and energy consumption of blockchain networks, more efficient consensus algorithms are being actively developed, such as PoS, which require significantly fewer computational resources than PoW. Additionally, hybrid models that combine centralized and decentralized elements provide flexibility in data management and reduce operational costs (Table).

Table

ENERGY CONSUMPTION OF BLOCKCHAINS BASED
ON THEIR CONSENSUS MECHANISM (https://lyl.su/Fehv)

Consensus mechanism	Energy consumption (TWh/year)	Comments
Proof of Work (PoW)	100-150	High energy consumption, requires substantial computational resources (e.g., Bitcoin).
Proof of Stake (PoS)	0,01-0.1	Significantly lower energy costs, utilizes minimal computations (e.g., Ethereum after transitioning to PoS).
Centralized Systems	20-50	Energy consumption depends on infrastructure, but generally lower than PoW.

Blockchain technologies can be successfully integrated with advanced solutions such as artificial intelligence (AI) and cloud computing. The combination of blockchain and AI can aid in analyzing large volumes of data, identifying anomalies, and enhancing security. For instance, AI can analyze anomalous patterns in the network and predict potential security threats, thereby increasing the security of decentralized systems. Cloud computing, in turn, enables data storage in a distributed network without being tied to a specific server, which enhances fault tolerance and reduces the risk of data loss. Thus, the future of blockchain technology in decentralized data exchange largely depends on developers' ability to address current technical and organizational challenges. The development and refinement of protocols, increasing the speed and efficiency of systems, as well as integrating blockchain with advanced technologies, can facilitate its successful application for secure data transmission.

Conclusion

Blockchain represents an innovative technology capable of transforming approaches to secure data exchange. Its decentralized nature**,** data immutability, and application of cryptographic methods provide a high level of protection and transparency. However, despite the technology's advantages, it faces challenges, including scalability, high energy costs, and legal restrictions. The prospects for successful blockchain implementation depend on further research, the development of effective consensus algorithms, and integration with advanced technologies such as artificial intelligence. These efforts could make blockchain a viable solution for secure data exchange in the future.

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