Section 6.5 An Exploration of Blockchain Technology

Juhyun Jeon

Introduction

This report provides an in-depth analysis of blockchain technology, which has demonstrated innovative potential across various industries since first becoming known as the underlying technology of Bitcoin. Beyond cryptocurrency, blockchain is emerging as a technological paradigm that enables the creation of new value and reshapes existing centralized systems based on its fundamental characteristics of decentralization, immutability, and transparency. The purpose of this report is to clarify the basic concepts and working principles of blockchain, explore its future applicability in key industries such as finance, supply chain, and healthcare, and analyze the major challenges that must be overcome for the maturation of its ecosystem. Through this multifaceted analysis, this report aims to present strategic insights into the future prospects and challenges of blockchain.

Basic Concepts and Working Principles of Blockchain

To understand blockchain technology, one must first grasp the broader concept of Distributed Ledger Technology (DLT). DLT refers to a form of distributed digital database where ledger data, which records transaction information, is jointly recorded and managed by all participants in a network, rather than by a single entity like a central server [1]. This distributed management method provides higher security and transparency compared to traditional systems.

Although many equate DLT with blockchain, blockchain is one of the most prominent methods of implementing DLT [2]. Blockchain has a unique structure where transaction records are stored in data units called 'blocks,' and these blocks are sequentially linked using hashes to form a 'chain,' thus constituting the ledger [2]. This structure plays a crucial role in ensuring the immutability of data.

However, the DLT ecosystem is not limited to blockchain alone. Various DLT implementation methods such as Hashgraph, Holochain, Tempo, and Directed Acyclic Graph (DAG) are emerging competitively to solve specific limitations of blockchain, particularly scalability issues [2]. For example, Hashgraph provides faster processing speeds than traditional blockchains through a random gossip protocol and virtual voting, while Holochain pursues efficiency by adopting a method where each node independently maintains its own records [2]. The existence of such diverse technical approaches suggests that DLT is not a monolithic technology but a dynamic ecosystem that is constantly evolving and competing to solve the so-called 'blockchain trilemma' of decentralization, scalability, and security. This technological diversity provides a basis for selecting the optimal DLT solution that meets the requirements of a specific industry or application.

The Technology of Blocks, Chains, and Consensus

As its name suggests, the basic structure of a blockchain consists of 'Blocks' and a 'Chain.' Each block is a bundle of transaction data and is sequentially linked by including the unique identifier (hash value) of the previous block, forming a robust chain of data [3]. The very first block in this chain is called the 'Genesis Block,' which serves a role similar to the first row in a database [3].

For a new block to be created and added to the chain, consensus among network participants is required. The mechanism that enables this process is the Consensus Mechanism. The most well-known consensus algorithms are Proof of Work (PoW) and Proof of Stake (PoS).

Proof of Work (PoW) is a method where the node that first solves a complex computational problem earns the right to create a block [4]. This process involves a massive amount of power consumption, which has been pointed out as a major environmental concern for PoW-based blockchain networks [5]. In contrast, Proof of Stake (PoS) is a method where block validation rights are granted in proportion to the amount of coins (stake) held by network participants [4]. This mechanism is significantly more energy-efficient than PoW because no additional computing resources are invested in the consensus process itself [4]. This energy efficiency is a decisive factor driving the technological transition of blockchain to align with the macro-trend of environmental sustainability.

Table 1: The Technology of Blocks, Chains, and Consensus

Feature	**Proof of Work (PoW)**	**Proof of Stake (PoS)**
Consensus Principle	Solving complex computational problems (mining)	Authority proportional to held coins (stake)
Energy Consumption	Very high (environmental concern)	Very low (energy efficient)
Participation Cost	High-performance hardware and electricity costs	Coin staking (economic cost)
Security	Prevents attacks via massive computational resources	Prevents attacks via threat of economic stake loss
Scalability	Relatively low	Relatively high

Core Characteristics of Blockchain

Blockchain technology is differentiated from existing centralized systems through the following four core characteristics.

1. **Decentralization:** Blockchain operates on a distributed Peer-to-Peer (P2P) network without a single central server or administrator [3]. Each node in the network jointly holds a copy of the ledger data, and a new block must be verified by multiple nodes before it is added [3]. This fundamentally

prevents any single entity from arbitrarily manipulating data or controlling the system.

2. **Immutability:** Once data is recorded, it is extremely difficult to alter or delete. Each block is linked by including the hash of the previous block, creating a technical constraint where modifying data in one block would require modifying all subsequent blocks [3]. This immutability strongly guarantees the integrity and reliability of the recorded information.
3. **Transparency:** In a public blockchain network, all participants can view transaction histories in real-time [6]. This transparency helps resolve the information asymmetry that can occur in centralized systems and contributes to building trust among all participants.
4. **Security:** Due to the decentralized and immutable nature of blockchain, data manipulation is extremely difficult [3]. Attempting to hack the network would require controlling over 50% of it, which entails enormous technical and economic costs.

However, the core value of transparency in blockchain paradoxically presents the greatest challenge in its real-world application. The fact that all transaction details are public directly conflicts with the protection of personal information and confidential data [7]. This fundamental contradiction implies that a cautious technical and institutional approach is necessary when applying blockchain to fields where privacy is critical, such as healthcare and personal identity verification.

Major Changes in Blockchain Technology (2020-2025)

Over the past five years, blockchain technology has been evolving to overcome technical limitations such as scalability, interoperability, and energy efficiency, as follows.

Table 2: Major Changes in Blockchain Technology

Category	**2020 (Early Stage)**	**2025 (Current)**	**Key Changes & Features**
Scalability	Slow processing speeds of Bitcoin (PoW), Ethereum 1.0 (PoW) revealed limitations for large-scale commercialization.	Speed and efficiency improved through Ethereum 2.0 (PoS), Sharding, and Layer 2 solutions (Optimistic Rollups, ZK Rollups).	Improvement of consensus algorithms and development of Layer 2 technologies that distribute network load.
Interoperability	Difficult data exchange between mainnets like Bitcoin and Ethereum, forming isolated ecosystems.	Connection and asset movement between different blockchains made possible through various technologies.	As multi-chain environments become common, the importance of inter-chain connectivity is highlighted.

Energy Efficiency	Bitcoin's PoW method caused environmental issues due to massive power consumption.	Ethereum's successful transition to PoS improved energy efficiency by over 99%.	Transition to eco-friendly consensus algorithms as ESG management becomes more important.
Development Env.	Complex development languages (Solidity), high entry barriers.	Entry barriers lowered with the emergence of various development frameworks and easier environments (Rust, Go). Blockchain-as-a-Service (BaaS) becomes common.	An environment where businesses can easily adopt and utilize blockchain technology is established.
Application Areas	Primarily focused on cryptocurrency and finance (DeFi).	Expanded beyond DeFi and NFTs to various industries like supply chain, healthcare, digital identity (DID), and entertainment.	The reliability and transparency of blockchain technology are gaining attention, accelerating integration with the real economy.
Regulatory Env.	Market contraction due to insufficient regulation and uncertainty.	Began institutionalization by establishing regulatory frameworks in various countries (EU's MiCA, Korea's Digital Asset Basic Act).	Regulatory clarity resolves uncertainty and accelerates the influx of new participants.

Applications and Industry-Specific Use Cases

Financial Services: Decentralized Finance (DeFi) and Security Token Offerings (STO)

Blockchain technology is most actively driving innovation in the financial sector. Decentralized Finance (DeFi) enables direct peer-to-peer transactions by implementing traditional financial services such as lending, insurance, and payments on the blockchain without intermediaries like banks [6]. Concurrently, Security Token Offerings (STO) present a new financial model that automates the issuance, settlement, dividend distribution, and liquidation processes of traditional assets like stocks and bonds through smart contracts by listing them on the blockchain [8].

Recently, the convergence between this blockchain financial ecosystem and the traditional financial system has been accelerating. Discussions around the potential approval of spot Bitcoin and Ethereum ETFs, along with the application of traditional financial regulatory standards like KYC (Know Your Customer) and AML (Anti-Money Laundering) to the blockchain market, have significantly increased market credibility [8]. This regulatory clarity is facilitating the entry of conservative institutional capital, such as pension funds and insurance companies, into the market, leading to a significant shift where decentralized financial services are being incorporated into the institutional framework [8]. This shows that blockchain is not simply replacing the existing financial system but is interacting with it to build a new hybrid economy.

Innovation in Supply Chain Management through Blockchain

Blockchain innovates the efficiency and reliability of supply chain management by transparently recording every process from production to distribution, sales, and maintenance [6]. The application of this technology goes beyond mere cost reduction or speed improvement; it creates new value by technologically guaranteeing 'trust' throughout the entire process from producer to consumer.

Blockchain-based supply chain management solutions are being actively adopted across various industries. Walmart, the world's largest retailer, has built a system that enhances food safety and allows for early identification of defective products by tracing the production history of agricultural goods via blockchain [11]. LVMH (Louis Vuitton Moët Hennessy) is attempting to solve the problem of counterfeiting by developing 'AURA,' a blockchain platform that authenticates luxury goods [10]. Similarly, diamond company De Beers and car manufacturer Ford also guarantee product authenticity by tracing the history of raw materials from mining to distribution [11]. Furthermore, 'TradeLens,' co-developed by the world's largest shipping company Maersk and IBM, is dramatically reducing time and costs by sharing real-time cargo transport information and replacing paper documents required for trade transactions with a blockchain platform [10]. These cases demonstrate that blockchain technology not only improves the inefficiencies of the supply chain but also enhances qualitative values such as product authenticity and safety, thereby contributing to the rebuilding of corporate brand value and consumer trust.

Applications in Healthcare and Digital Identity

In the healthcare sector, blockchain technology can address the information asymmetry problem of existing centralized medical systems by establishing patient-centric medical information platforms [12]. It is possible to create new business models where patients have control over their own medical data (treatment records, MRI/CT scans, etc.), reducing redundant tests or utilizing data for new drug development [12].

In the digital identity field, Decentralized Identifier (DID) technology is gaining attention [14]. DID is an innovative technology that allows individuals, not institutions, to manage and prove their own identity directly. Its great significance lies in the ability to selectively provide trusted information based on one's own will without a central authority [14]. Unlike existing centralized identity management systems, this grants data sovereignty to the individual, directly connecting to the core Web3.0 value of 'strengthening individual data ownership.'

Overseas, there are already cases where blockchain-based identity and healthcare systems have been implemented. Estonia introduced blockchain technology in 2008 to manage access to e-Health records and enhance data security through its electronic ID (e-ID) [12]. In Korea, the Korea Disease Control and Prevention Agency's COVID-19 electronic vaccination certificate applies blockchain and DID technology to prevent forgery and alteration. LG CNS is developing a blockchain-based mobile driver's license business, and SKT is expanding its electronic certificate services through its 'Initial' app [13].

Table 3: Industry-Specific Applications of Blockchain and Their Key Effects

Industry	Application Area	Key Effect
Finance	Decentralized Finance (DeFi), Security Token Offering (STO)	Direct transactions without intermediaries, reduced transaction costs, increased asset liquidity
Supply Chain	Origin/Distribution history tracking, anti-counterfeiting	Ensuring transparency, enhancing trust, improving logistics efficiency and stability
Healthcare	Patient-centric medical information platform, new drug development data utilization	Reduced costs from redundant tests, securing data control rights, efficient information sharing
Digital Identity	Decentralized Identifier (DID), electronic signatures	Securing data sovereignty, reliable non-face-to-face identity verification

Synergy with Advanced Technologies: AI, IoT, and Blockchain

Blockchain is creating a new dimension of value through its convergence with other advanced technologies like Artificial Intelligence (AI) and the Internet of Things (IoT). In particular, blockchain functions as a 'Trust Layer' that complements the fundamental vulnerabilities of these technologies.

- **Blockchain-AI Synergy:** AI often faces data dependency and centralization issues as it learns and makes decisions on centralized servers based on vast amounts of data [16]. Blockchain has the potential to solve these problems. For example, computing resources like GPUs can be shared in a decentralized manner through a blockchain network [16], or an 'agent economy' can be built where AI agents interact and collaborate autonomously on the blockchain. Blockchain acts as a catalyst to maximize trust in AI systems by transparently recording the decision-making processes and the integrity of learning data.

- **Blockchain-IoT Synergy:** IoT creates an environment where numerous devices generate and transmit data in real-time [17]. However, this data can be vulnerable to tampering or exposed to security risks by relying on central servers [18]. Blockchain enhances the integrity and reliability of data generated from IoT devices by recording it on an immutable ledger [18]. Specific application examples include recording IoT sensor data such as temperature and location during cargo transport on the blockchain to prevent data tampering [18], or recording firmware update histories of IoT devices like CCTVs on the blockchain to prevent malicious intrusions [17]. As such, blockchain functions as a core infrastructure that adds trust and security to the IoT environment.

Technical Limitations and Solutions to Overcome

Despite the potential of blockchain technology, there are still technical challenges that must be overcome to accommodate large-scale commercial services.

First is the **Scalability** problem. Blockchain networks have a limit to the number of transactions they can process per second (TPS), making it difficult to support applications with a large user base. The main solutions to this problem are to improve the performance of the mainnet itself and to utilize Layer 2 solutions that process transactions off-chain to reduce the load on the mainnet [8]. Ethereum's Dencun upgrade and the emergence of new Layer 2 projects are part of the evolutionary efforts to solve this scalability issue [8].

Second is the **Interoperability** problem. Different blockchain networks exist like isolated 'islands,' making it difficult to seamlessly share data or assets. To solve this problem, technical frameworks like 'Automated Gateways' that utilize smart contracts are being researched [21]. This is an attempt to enhance the connectivity of the entire blockchain ecosystem by facilitating the sharing of data and services between different blockchains [21].

Thus, the technical limitations (the trilemma) of blockchain technology are creating an ecosystem where specialized technologies for each problem are differentiating and evolving, rather than a single solution. This includes Layer 2 solutions for scalability, bridging technologies for interoperability, and various DLT methods for consensus efficiency. This shows that blockchain is evolving not as a 'single technology' but as a 'suite of technologies for problem-solving.'

Security and Privacy Issues

Although blockchain technology boasts high security, vulnerabilities in the underlying smart contract code can pose serious security risks. The core characteristic of 'immutability' in blockchain paradoxically makes it difficult to correct inherent errors in the code, and once a hacking incident occurs, it is nearly impossible to reverse the damage [22].

Prominent examples include the hacking of 'The DAO' project in 2016 and the 'Parity Wallet' hack in 2017 [22]. The DAO hack resulted in the theft of 3.6 million Ether, worth about $50 million at the time, by exploiting a recursive call bug. The Parity Wallet hack was an attack targeting a vulnerability in a multi-signature wallet, resulting in the theft of Ether worth approximately $32 million [23]. These cases emphasize the importance of thorough code verification and security audits during the smart contract development phase and clearly show the two-sided nature of blockchain technology.

Furthermore, as mentioned in the first section, the transparency of blockchain fundamentally conflicts with privacy protection [7]. Since all transaction details are recorded on a public ledger, technical and institutional solutions are essential for handling sensitive personal information or confidential data.

Regulatory and Institutional Uncertainty

With the spread of blockchain technology, governments and international organizations are making efforts to establish regulatory frameworks. The European Union's MiCA, the U.S. SEC's STO guidelines, and South Korea's Digital Asset Basic Act are representative examples [8]. In addition, traditional financial regulations such as KYC/AML are being applied to the blockchain market through measures like the Travel Rule [8].

This regulatory clarification brings about two contrasting effects simultaneously. On one hand, it has the positive effect of increasing market credibility and facilitating the entry of conservative institutional investors, such as pension funds, by securing institutional stability [8]. On the other hand, there are concerns that excessive regulation could undermine the technology's intrinsic value of decentralization and may intensify the phenomenon of 'Regulatory Arbitrage,' where companies and projects move to regulation-friendly countries (e.g., UAE, Singapore) [8]. This duality suggests that the future of blockchain technology depends not only on technological innovation but also on the policy challenge of finding a balance between innovation and stability [8].

Challenges, Opportunities, and a Sustainable Blockchain Ecosystem

Blockchain technology has presented a new paradigm for overcoming the limitations of centralized systems and building a transparent, secure, and efficient trust system. Over the past five years, blockchain has moved beyond being a simple digital currency technology to drive substantial changes in various fields, including finance, supply chain, and healthcare. In particular, Ethereum's transition to PoS and the development of on/off-chain scalability solutions demonstrate its technical maturity, and its convergence with advanced technologies like AI and IoT presents new possibilities.

Blockchain technology has proven its potential to lead a paradigm shift in a wide range of fields, from finance and supply chain to healthcare and digital identity. Especially through its convergence with other advanced technologies like AI and IoT, it is establishing itself as a core foundational technology that guarantees data reliability and ushers in a new era.

However, for the blockchain ecosystem to reach full maturity, there are still challenges to be resolved. Technical limitations such as scalability, interoperability, and security vulnerabilities must be overcome, along with institutional and social issues like privacy protection and regulatory uncertainty.

The future of the blockchain ecosystem will be determined by how these challenges are addressed. When technological innovation (Layer 2 solutions, new DLTs) and institutional stability (balanced regulation) are pursued in harmony, blockchain will firmly establish itself not just as a technology, but as a foundational technology for a social and economic paradigm shift that reconfigures trust and returns data sovereignty to individuals. The ultimate success of this technology requires not only overcoming technical limitations but also efforts to reach a societal consensus on how to coexist with a new system of trust. Blockchain is a technology with the potential to bring about fundamental changes to human society. When accompanied by efforts to solve technical, institutional, and ethical issues, blockchain will build true trust and establish itself as the core infrastructure of the digital society.

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