Chapter 11
Engineering Applications of Blockchain in This Smart Era

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ABSTRACT

The advent of blockchain technology has revolutionized various industries, offering novel solutions to age-old problems. In this smart era, characterized by interconnected devices and burgeoning digital ecosystems, blockchain stands out as a transformative force. This chapter explores the emerging applications of blockchain technology in this paradigm shift towards smart systems. One prominent application of blockchain lies in the domain of decentralized finance (DeFi). Blockchain facilitates peer-to-peer transactions, eliminating the need for intermediaries like banks. Smart contracts, powered by blockchain, automate and execute agreements, enabling programmable finance, lending, and asset management. Moreover, blockchain's transparency and immutability enhance trust in financial transactions, fostering financial inclusion and security. In the realm of SCM, blockchain offers unprecedented transparency and traceability. By recording every transaction on an immutable ledger, blockchain enables users to track the journey of products from raw materials to end consumers.

1. INTRODUCTION TO BLOCKCHAIN TECHNOLOGY: KEY COMPONENTS, TYPES, FEATURES AND BENEFITS

Blockchain technology, originally introduced for Bitcoin, has rapidly evolved into a versatile and transformative tool with applications across various industries (Swan, 2015; Yli-Huumo et al., 2016). At its core, blockchain is a distributed ledger technology that enables secure, transparent, and decentralized recording of transactions and data. In this introduction, we'll discuss the key components, types, features, and benefits of blockchain technology. Here are few Key Components which can be discussed as:

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Blocks: Blocks are the fundamental units of data in a blockchain. Each block contains a batch of transactions, along with a unique identifier called a cryptographic hash that links it to the previous block, forming a chronological chain of blocks.

Decentralized Network: Blockchain operates on a decentralized network of nodes, where each node maintains a copy of the entire blockchain ledger. This decentralized architecture ensures redundancy, fault tolerance, and resistance to censorship or tampering.

Consensus Mechanisms: Consensus mechanisms are protocols used to achieve agreement among network participants regarding the validity of transactions and the state of the ledger. Popular consensus mechanisms include Proof of Work (PoW), Proof of Stake (PoS), and Delegated Proof of Stake (DPoS).

Cryptographic Security: Blockchain relies on cryptographic techniques to secure transactions and data. Public-key cryptography enables users to generate unique digital signatures, proving ownership of assets and authorizing transactions. Hash functions ensure data integrity by generating fixed-size, unique identifiers for data stored on the blockchain.

Types of Blockchains

Public Blockchains: Public blockchains, such as Bitcoin and Ethereum, are open and permissionless networks where anyone can participate, transact, and validate transactions. These blockchains provide transparency, censorship resistance, and decentralization but may have scalability and privacy limitations.

Private Blockchains: Private blockchains are permissioned networks where access and participation are restricted to authorized entities. Private blockchains are often used within organizations or consortia to provide secure and efficient data sharing and collaboration.

Consortium Blockchains: Consortium blockchains are semi-decentralized networks controlled by a group of trusted entities or organizations. Consortium blockchains combine the benefits of public and private blockchains, providing scalability, privacy, and governance features tailored to the specific needs of the consortium members.

Features of Blockchain Technology

Transparency: Blockchain provides a transparent and immutable ledger of transactions, visible to all network participants. This transparency fosters trust and accountability by enabling real-time auditing and verification of transactions.

Security: Blockchain's decentralized architecture, cryptographic security, and consensus mechanisms ensure the integrity and security of transactions and data. Immutability and tamper resistance protect against fraud, manipulation, and unauthorized modifications.

Decentralization: Blockchain operates on a decentralized network of nodes, eliminating the need for central authorities or intermediaries to validate transactions. Decentralization enhances resilience, censorship resistance, and inclusivity in blockchain networks.

Efficiency: Blockchain enables automation of transactions and smart contracts, reducing manual processes, administrative overheads, and intermediation costs. This automation enhances efficiency, speed, and accuracy in transaction processing and contract execution.

Benefits of Blockchain Technology

Trust and Transparency: Blockchain's transparent and immutable ledger enhances trust and transparency in transactions and data management, reducing the need for intermediaries and facilitating peer-to-peer interactions.

Security and Data Integrity: Cryptographic security, decentralization, and consensus mechanisms ensure the security and integrity of transactions and data on the blockchain, protecting against fraud, tampering, and unauthorized access.

Cost Savings: By eliminating intermediaries, reducing administrative overheads, and automating processes, blockchain technology can lead to significant cost savings for businesses in various industries, including finance, supply chain management, and healthcare.

Innovation and Disruption: Blockchain technology enables new business models, decentralized applications, and innovative use cases across industries. Its versatility and potential for disruption drive innovation, competition, and value creation in the global economy.

Financial Inclusion: Blockchain provides access to financial services for underserved populations by enabling peer-to-peer transactions, micropayments, and decentralized finance (DeFi) solutions, fostering financial inclusion and empowerment.

In summary, blockchain technology provides a revolutionary approach to data management, transaction processing, and trust creation in the digital age. With its decentralized, transparent, and secure nature, blockchain has the potential to reshape industries, drive innovation, and empower individuals and organizations worldwide.

2. BACKGROUND WORK

Blockchain technology, despite its recent surge in popularity, has roots dating back to the early 1990s. The concept was initially introduced by Stuart Haber and W. Scott Stornetta in 1991, aiming to create a system where document timestamps couldn't be tampered with or altered. However, it wasn't until 2008, with the publication of a whitepaper by an anonymous entity known as Satoshi Nakamoto, that blockchain gained widespread recognition through its association with Bitcoin, the first decentralized cryptocurrency (Tapscott & Tapscott, 2016; Crosby et al., 2016; Al Omar, Rahman, & Basu, 2019). The foundational principles behind blockchain technology involve several key components:

Decentralization: Traditional systems rely on central authorities to validate and authorize transactions. Blockchain, on the other hand, operates in a decentralized manner, distributing transaction validation across a network of nodes. This decentralization enhances security, as there's no single point of failure vulnerable to attacks or manipulation.

Distributed Ledger: Blockchain maintains a distributed ledger, which is a chronological record of all transactions across the network. Each block in the chain contains a batch of transactions, along with a cryptographic hash of the previous block, creating an immutable link between them. This structure ensures transparency, accountability, and tamper resistance.

Consensus Mechanisms: Consensus mechanisms are protocols used to achieve agreement among network participants regarding the validity of transactions and the state of the ledger. Popular consensus mechanisms include Proof of Work (PoW), used in Bitcoin, and Proof of Stake (PoS), employed by several other blockchain platforms. These mechanisms ensure the integrity of the blockchain network by preventing malicious actors from controlling the consensus process.

Cryptographic Security: Cryptography plays a important role in securing blockchain networks. Public-key cryptography enables users to generate unique digital signatures, proving ownership of assets and authorizing transactions. Hash functions are used to generate fixed-size, unique identifiers for data stored on the blockchain, ensuring data integrity and tamper resistance.

Smart Contracts: Smart contracts are self-executing contracts with the terms of the agreement directly written into code. They automatically enforce the terms and conditions of the agreement, eliminating the need for intermediaries and reducing the risk of fraud or manipulation. Smart contracts enable programmable transactions, opening up a wide range of applications beyond simple asset transfers.

Over the years, blockchain technology has evolved beyond cryptocurrencies, finding applications in various industries such as finance, supply chain management, healthcare, and more. Its ability to provide transparency, security, and efficiency in data management and transaction processing has sparked widespread interest and investment in exploring its potential across diverse sectors. As research and development continue, blockchain technology is poised to reshape industries and redefine how value is created and exchanged in the digital age.

3. EMERGING APPLICATIONS OF BLOCKCHAIN IN THIS SMART ERA

There are several Applications of Blockchain in the Smart Era (Zhang, Xue, & Li, 2019; Yao et al., 2019; Li & Yu, 2019), which can be discussed as:

Decentralized Finance (DeFi):

- DeFi platforms use blockchain technology to provide decentralized financial services such as lending, borrowing, and trading without the need for traditional intermediaries like banks.
- Smart contracts enable automated execution of financial agreements, ensuring transparency and security while reducing costs.
- Yield farming, decentralized exchanges (DEXs), and liquidity pools are some of the innovative DeFi applications powered by blockchain.

Supply Chain Management:

- Blockchain enhances transparency and traceability in supply chains by recording every transaction on an immutable ledger.
- It enables real-time tracking of products from manufacturing to delivery, reducing counterfeiting, ensuring product authenticity, and optimizing logistics.
- Smart contracts automate processes like payment upon delivery, improving efficiency and trust among supply chain participants.

Healthcare:

- Blockchain secures patient data by providing a tamper-proof and interoperable platform for storing medical records.

- It provides secure sharing of patient information among healthcare providers while ensuring patient privacy and data integrity.
- Integration with Internet of Things (IoT) devices enables real-time monitoring of patient health data, improving diagnostics and treatment outcomes.

Smart Energy:

- Blockchain enables peer-to-peer energy trading and management in decentralized energy systems, known as microgrids.
- Consumers can buy and sell excess renewable energy directly to each other, promoting renewable energy adoption and reducing reliance on centralized utilities.
- Smart contracts automate energy transactions, ensuring transparency, efficiency, and fair compensation for energy producers.

Digital Identity:

- Blockchain-based digital identity solutions provide secure and portable identities, empowering individuals to control their personal data.
- Users can selectively share identity attributes with trusted parties, reducing the risk of identity theft and fraud.
- Digital identity on blockchain has applications in areas such as financial services, healthcare, and government services.

Tokenization of Assets:

- Blockchain enables the tokenization of real-world assets such as real estate, art, and commodities, representing ownership in a digital form.
- Fractional ownership and increased liquidity of assets are provided through tokenization, opening up investment opportunities to a wider audience.
- Smart contracts govern the transfer and management of tokenized assets, ensuring transparency and compliance with regulations.

Digital Voting:

- Blockchain-based voting systems provide secure and transparent voting processes, reducing the risk of fraud and manipulation.
- Each vote is recorded on the blockchain, ensuring immutability and auditability of election results.
- Digital voting systems can increase voter participation and trust in democratic processes.

Hence, these emerging applications of blockchain demonstrate its potential to revolutionize various industries by providing decentralized, secure, and efficient solutions in the smart era (Li & Yu, 2019; Wang et al., 2019; Wang et al., 2019). As blockchain technology continues to evolve, it is expected to drive further innovation and disrupt traditional business models across diverse sectors.

4. EMERGING APPLICATIONS OF BLOCKCHAIN WITH OTHER FUTURISTICS/ CUTTING EDGE TECHNOLOGIES IN THIS SMART ERA

There are several Applications of Blockchain with Futuristic Technologies in the Smart Era (Huang et al., 2019; Fanning & Centers, 2016; Zheng et al., 2017), which can be discussed here as:

Blockchain with Internet of Things (IoT):

- Integration of blockchain with IoT devices enables secure and decentralized data exchange and automation of transactions.
- Smart contracts deployed on the blockchain can provide automatic execution of agreements based on real-time IoT data, such as in smart home systems, industrial automation, and environmental monitoring.

Blockchain with Artificial Intelligence (AI):

- Combining blockchain with AI technologies can enhance data privacy, security, and trust in AI-driven applications.
- Blockchain can be used to securely store and share AI models and training data, ensuring transparency and accountability in AI decision-making processes.

Blockchain with Edge Computing:

- Edge computing, which processes data closer to its source, can benefit from blockchain's decentralized nature to securely manage and authenticate data transactions.
- Blockchain-enabled edge devices can autonomously transact and exchange data, enabling real-time decision-making and reducing latency in applications like autonomous vehicles and smart cities.

Blockchain with Quantum Computing:

- Quantum computing faces both challenges and opportunities for blockchain technology. Quantum-resistant cryptographic techniques are being discussed to ensure blockchain security in the era of quantum computing.
- Additionally, quantum blockchain protocols are being developed to use quantum computing power for tasks like secure key distribution and consensus mechanisms.

Blockchain with Augmented Reality (AR) and Virtual Reality (VR):

- Blockchain can authenticate digital assets and ownership in AR and VR environments, enabling secure trading and ownership of virtual goods.

- Smart contracts on blockchain can automate transactions related to virtual asset creation, licensing, and distribution, ensuring fair compensation for creators and preventing piracy.

Blockchain with 5G Networks:

- Integration of blockchain with 5G networks can enhance security, privacy, and scalability in communication and data exchange.
- Blockchain can provide decentralized identity management, secure communication, and efficient network resource allocation in 5G-enabled applications such as smart cities, autonomous vehicles, and remote healthcare.

Blockchain with Biotechnology and Genomics:

- Blockchain can provide a transparent and immutable ledger for tracking and tracing genetic data, ensuring privacy and security in genomic research and healthcare applications.
- Smart contracts on blockchain can provide consent management, incentivize data sharing, and ensure fair and transparent compensation for genomic data contributors.

Hence, these emerging applications demonstrate the potential synergies between blockchain technology and other cutting-edge technologies in the smart era, paving the way for innovative solutions across diverse industries and domains.

5. CASE STUDIES AND IMPLEMENTATIONS

5.1 Power Ledger: Peer-to-Peer Energy Trading

Power Ledger is an Australian-based blockchain technology company that aims to revolutionize the energy sector by facilitating peer-to-peer (P2P) energy trading. Founded in 2016 by Dr. Jemma Green and Dr. John Bulich, Power Ledger uses blockchain technology to create a transparent, decentralized platform for buying and selling renewable energy. Here is a problem:

Traditional energy markets are centralized and inefficient, with limited options for consumers to participate in energy trading. Moreover, renewable energy producers often face challenges in monetizing excess energy generated from solar panels or other renewable sources.

As a Solution, Power Ledger introduced a blockchain-based platform that enables P2P energy trading, allowing consumers to buy and sell renewable energy directly to each other. The platform utilizes smart contracts to automate transactions, ensuring secure and transparent energy trading without the need for intermediaries. For that we use Key Features as:

Decentralized Marketplace: Power Ledger's platform serves as a decentralized marketplace where energy producers and consumers can connect and trade energy in real-time. This eliminates the need for centralized utilities as intermediaries.

Smart Contracts: Smart contracts are deployed on the blockchain to provide automated energy trading. These contracts execute predefined terms and conditions agreed upon by the participants, ensuring trustless transactions.

Renewable Energy Tracking: The platform tracks the source of energy generation, providing consumers with visibility into the origin and sustainability of the energy they purchase. This promotes the use of renewable energy sources and supports environmental sustainability.

Transparent Pricing: Power Ledger's platform provides transparent pricing based on supply and demand dynamics, enabling fair and competitive energy trading. Consumers can choose from a variety of energy sources and select the most cost-effective options.

Real-Time Settlement: Transactions on the platform are settled in near real-time, allowing energy producers to monetize excess energy immediately and consumers to access energy when needed without delays.

Implementation: Power Ledger has partnered with utility companies, renewable energy developers, and local governments worldwide to pilot its P2P energy trading platform. One notable pilot project was conducted in the Fremantle suburb of Western Australia, where residents were able to trade solar energy generated from rooftop panels using Power Ledger's blockchain platform.

As results, the implementation of Power Ledger's P2P energy trading platform has led to several positive outcomes:

Increased Efficiency: The platform has streamlined energy trading processes, reducing inefficiencies associated with traditional centralized energy markets.

Empowered Consumers: Consumers have greater control over their energy usage and expenditure, as they can choose to buy renewable energy directly from local producers.

Environmental Benefits: The use of renewable energy sources promoted by the platform contributes to reducing carbon emissions and mitigating climate change.

Innovation in Energy Sector: Power Ledger's innovative approach to energy trading has sparked interest and investment in blockchain technology within the energy sector, paving the way for further innovation and adoption.

Note that Power Ledger's P2P energy trading platform demonstrates the transformative potential of blockchain technology in revolutionizing traditional energy markets. By enabling direct, transparent, and efficient energy trading, Power Ledger empowers consumers, promotes renewable energy adoption, and fosters innovation in the transition towards a sustainable energy future.

5.2 Civic: Secure Identity Verification

Civic is a blockchain-based identity verification platform founded in 2015 by Vinny Lingham and Jonathan Smith. It aims to provide secure and decentralized identity verification solutions, providing individuals control over their personal information while eliminating the risks associated with traditional identity verification methods. Here is a Problem:

Traditional identity verification processes are often cumbersome, time-consuming, and prone to security breaches. Individuals are required to provide sensitive personal information to various service providers, increasing the risk of identity theft and fraud. Moreover, centralized storage of personal data leaves it vulnerable to hacking and misuse.

As a solution, Civic uses blockchain technology to provide a secure, decentralized identity verification ecosystem. The platform allows individuals to verify their identity without sharing sensitive information directly with service providers. Instead, individuals' personal information is stored locally on their devices and encrypted on the blockchain. When verification is required, users authorize the release of specific information through a secure and encrypted channel.

Implementation:

Civic App: Users download the Civic app, which serves as their digital identity wallet. They complete a one-time verification process, including biometric authentication and document validation, to establish their digital identity.

Decentralized Identity Verification: Civic uses blockchain technology to create and manage decentralized identifiers (DIDs) for users. These DIDs are anchored to the blockchain, ensuring immutability and tamper resistance.

Secure Authentication: When individuals need to verify their identity with a service provider, they scan a QR code or initiate a request through the Civic app. The app cryptographically signs the identity verification request and securely transmits the necessary information to the service provider.

Zero-Knowledge Proofs: Civic employs zero-knowledge proofs (ZKPs) to enable selective disclosure of information. This allows users to prove the validity of their identity without revealing sensitive details such as their date of birth or address.

Benefits:

Enhanced Security: Civic's decentralized approach reduces the risk of data breaches and identity theft associated with centralized databases. Users retain control over their personal information and can choose when and with whom to share it.

Convenience: The Civic app streamlines the identity verification process, eliminating the need for repeated document submissions and manual verification. Users can quickly and securely verify their identity across multiple platforms and services.

Compliance: Civic's identity verification solutions help businesses comply with regulatory requirements such as Know Your Customer (KYC) and Anti-Money Laundering (AML) regulations. By using blockchain technology, Civic provides auditable and tamper-proof records of identity verification activities.

Note that Civic partnered with BitGo to enhance the security of its platform by integrating BitGo's multi-signature wallet technology. The Civic platform has been integrated into various industries, including finance, healthcare, and e-commerce, enabling secure and seamless identity verification for users. Civic's Secure Identity Platform (SIP) token, used for identity verification transactions on the platform, has provided secure and efficient transactions while incentivizing participants through rewards and discounts. Hence, Civic's blockchain-based identity verification platform provides a promising solution to the challenges associated with traditional identity verification methods. By using blockchain technology, Civic provides individuals with greater control over their personal information while enhancing security, privacy, and convenience for businesses and users alike. As the demand for secure and decentralized identity solutions continues to grow, Civic remains at the forefront of innovation in the identity verification space.

5.3 Ethereum-Based Smart Contracts in Engineering Projects

Smart contracts, self-executing contracts with the terms of the agreement directly written into code, have found extensive application in various industries. In engineering projects, where contractual agreements, payments, and project milestones are important, implementing Ethereum-based smart contracts provides transparency, automation, and efficiency. Here is a Problem:

Traditional contract management processes in engineering projects are often cumbersome, time-consuming, and prone to disputes. Delays in payments, disagreements over project milestones, and lack of transparency can lead to friction between project stakeholders. Additionally, manual contract enforcement processes increase administrative overheads and may result in errors or delays.

As a solution, we implement Ethereum-based smart contracts in engineering projects provides a decentralized, transparent, and automated solution for contract management, payments, and project milestone tracking. Ethereum's programmable blockchain platform enables the execution of complex contractual agreements without the need for intermediaries, enhancing efficiency and reducing the risk of disputes.

Implementation

Smart Contract Development: Smart contracts are developed using Ethereum's Solidity programming language or other compatible languages. Contracts are coded to include the terms and conditions of the engineering project, including payment schedules, milestones, and performance metrics.

Contract Deployment: Once developed, smart contracts are deployed onto the Ethereum blockchain, where they become immutable and tamper-proof. Each contract is assigned a unique address on the blockchain, accessible to all parties involved in the project.

Automated Execution: Smart contracts automatically execute predefined actions based on the fulfillment of specified conditions. For example, payments can be automatically released to contractors upon completion of project milestones, verified through predefined criteria such as project deliverables or inspection reports.

Transparency and Auditability: All transactions and interactions within the smart contract are recorded on the Ethereum blockchain, providing a transparent and auditable trail of contractual activities. Project stakeholders can access real-time updates on project progress, payments, and milestones, reducing the likelihood of disputes.

Decentralized Governance: Ethereum-based smart contracts operate on a decentralized network of nodes, eliminating the need for central authorities or intermediaries to enforce contracts. Dispute resolution mechanisms can be built into smart contracts, enabling automated arbitration or escalation processes in case of disagreements.

Benefits

Efficiency: Automation of contract execution and payment processes reduces administrative overheads and streamlines project management workflows, leading to faster project delivery and reduced costs.

Transparency: Blockchain's transparent and immutable nature ensures that all stakeholders have access to real-time information on project progress, payments, and milestones, enhancing trust and collaboration.

Security: Smart contracts deployed on the Ethereum blockchain benefit from the platform's robust security features, including cryptographic encryption and decentralized consensus mechanisms, reducing the risk of fraud or tampering.

Dispute Resolution: Built-in dispute resolution mechanisms enable automated arbitration or escalation processes, reducing the likelihood of contractual disputes and facilitating faster resolution.

Innovation: Ethereum's programmable blockchain platform allows for the integration of innovative features such as tokenization of project assets, crowdfunding, or decentralized autonomous organizations (DAOs), unlocking new possibilities for financing and project governance.

Note that a construction company adopts Ethereum-based smart contracts to automate payments to subcontractors based on predefined project milestones, reducing payment delays and improving cash flow management. An engineering consultancy firm utilizes smart contracts to track project deliverables and performance metrics, providing clients with real-time visibility into project progress and ensuring accountability. Hence, Ethereum-based smart contracts provide a transformative solution for contract management in engineering projects, providing transparency, efficiency, and security throughout the project lifecycle. By using blockchain technology, engineering firms can streamline processes, reduce costs, and enhance trust and collaboration among project stakeholders. As the adoption of smart contracts continues to grow, Ethereum remains at the forefront of innovation in decentralized contract management solutions.

6. OPEN ISSUES AND CHALLENGES TOWARDS BLOCKCHAIN IN THIS SMART ERA

There are several issues and challenges Towards Blockchain in the Smart Era (Kshetri, 2017; Tse, Chan & Cheng, 2020; Tyagi, Rekha, & Sreenath, 2021; Tyagi & Tiwari, 2024), which can be included here as:

Scalability: Blockchain networks, particularly public ones like Bitcoin and Ethereum, face scalability challenges as the number of transactions increases. Current consensus mechanisms and block size limitations hinder transaction throughput, leading to delays and higher transaction fees during peak times.

Interoperability: The lack of interoperability between different blockchain platforms and protocols limits their ability to communicate and share data seamlessly. This fragmentation hampers the development of comprehensive blockchain solutions that span multiple use cases and industries.

Regulatory Uncertainty: Regulatory frameworks governing blockchain and cryptocurrencies vary widely across jurisdictions, leading to uncertainty and ambiguity for businesses and users. Lack of regulatory clarity may deter mainstream adoption and investment in blockchain technology.

Privacy and Security: While blockchain provides transparency and immutability, ensuring the privacy and security of sensitive data remains a challenge. Public blockchains expose transaction details to all participants, raising issues about data privacy. Additionally, the risk of 51% attacks, consensus vulnerabilities, and smart contract bugs may face security threats to blockchain networks.

Energy Consumption: Proof of Work (PoW) consensus mechanisms, used by prominent blockchains like Bitcoin and Ethereum, consume significant amounts of energy for transaction validation. This energy-intensive process contributes to environmental issues and may not be sustainable in the long term.

Tokenization and Asset Backing: The valuation and regulation of tokenized assets, such as cryptocurrencies and digital tokens representing real-world assets, face challenges in terms of asset backing, valuation methodologies, and investor protection. Ensuring transparency and accountability in tokenized asset markets is essential for investor confidence.

Governance and Decentralization: The governance structures of blockchain networks, including decision-making processes and protocol upgrades, raise questions about decentralization and power dynamics. Balancing decentralization with governance efficiency and scalability remains a complex challenge for blockchain projects.

Environmental Impact: The environmental impact of blockchain, particularly energy-intensive consensus mechanisms like Proof of Work, has drawn criticism due to their carbon footprint. Addressing sustainability issues and exploring more eco-friendly consensus mechanisms are essential for mitigating blockchain's environmental impact.

Adoption Barriers: Education, awareness, and infrastructure barriers hinder widespread adoption of blockchain technology, particularly in developing regions. Bridging the digital divide and fostering an enabling environment for blockchain innovation are important for equitable access and participation in the smart era.

Hence, addressing these open issues and challenges requires collaboration among stakeholders, including technology developers, regulators, industry players, and the wider community. Through ongoing research, innovation, and responsible deployment, blockchain technology can realize its full potential as a transformative force in the smart era.

7. FUTURE RESEARCH OPPORTUNITIES TOWARDS BLOCKCHAIN IN THIS SMART ERA

There are several future research opportunities towards Blockchain in the Smart Era (Balamurugan, Tyagi, & Richa, 2023; Deshmukh et al., 2023; Srivastava et Al., 2023; Deshmukh et al., 2022), can be listed here as:

Scalability Solutions: Research into novel consensus mechanisms, sharding techniques, and layer 2 scaling solutions can address scalability challenges in blockchain networks. Exploring techniques to increase transaction throughput without compromising security and decentralization is important for enabling mass adoption of blockchain technology.

Interoperability Protocols: Developing standardized protocols and frameworks for interoperability between different blockchain platforms can provide seamless communication and data exchange. Research in cross-chain interoperability solutions can unlock new use cases and enable interoperable blockchain ecosystems.

Privacy-Preserving Technologies: Advancing privacy-preserving technologies such as zero-knowledge proofs, homomorphic encryption, and privacy-focused smart contract platforms can enhance privacy and confidentiality in blockchain transactions. Research into scalable and efficient privacy solutions that preserve data integrity while protecting user privacy is essential for broader adoption.

Energy-Efficient Consensus Mechanisms: Investigating alternative consensus mechanisms that are more energy-efficient than Proof of Work (PoW) can reduce the environmental impact of blockchain networks. Research into Proof of Stake (PoS), Proof of Authority (PoA), and other consensus algorithms can improve energy efficiency without compromising security or decentralization.

Security and Resilience: Enhancing blockchain security through formal verification methods, bug bounty programs, and robust auditing processes can mitigate vulnerabilities and prevent security breaches. Research into secure smart contract development practices, protocol-level security enhancements, and decentralized identity solutions can bolster the resilience of blockchain networks.

Regulatory Frameworks and Compliance: Researching regulatory frameworks that balance innovation with consumer protection and regulatory compliance is essential for fostering a conducive environment for blockchain adoption. Collaborative efforts between regulators, industry players, and academia can inform policy development and promote responsible blockchain innovation.

Tokenization and Asset Management: Exploring tokenization models for diverse asset classes, including real estate, intellectual property, and financial derivatives, can unlock new opportunities for asset digitization and decentralized finance (DeFi). Research into asset-backed tokens, tokenization standards, and regulatory frameworks for tokenized assets can enable efficient and transparent asset management on blockchain platforms.

Decentralized Governance: Investigating decentralized governance models for blockchain networks, including on-chain governance mechanisms and decentralized autonomous organizations (DAOs), can improve decision-making processes and promote community participation. Research into governance scalability, incentive alignment, and governance token design can enhance the sustainability and resilience of decentralized governance systems.

Blockchain Applications in Emerging Technologies: Exploring the integration of blockchain with emerging technologies such as artificial intelligence (AI), Internet of Things (IoT), 5G networks, and quantum computing can unlock new synergies and use cases. Research into blockchain-enabled IoT data marketplaces, AI-powered smart contracts, and quantum-resistant blockchain protocols can drive innovation at the intersection of blockchain and other cutting-edge technologies.

Social and Ethical Implications: Investigating the social, ethical, and cultural implications of blockchain adoption, including issues related to privacy, identity, inequality, and digital rights, is essential for responsible technology development. Research into inclusive blockchain solutions, user-centric design principles, and ethical frameworks for blockchain governance can address societal challenges and promote equitable access to blockchain technology.

Hence, by focusing on these future research opportunities, academia, industry, and policymakers can contribute to advancing the state-of-the-art in blockchain technology and realizing its transformative potential in the smart era.

8. POTENTIAL INNOVATIONS AND IMPACT OF EMERGING TECHNOLOGIES ON BLOCKCHAIN’ USE IN NEAR FUTURE: FROM INDUSTRY AND SOCIETY PERSPECTIVE

Here few of the potential innovations and impact of emerging technologies on Blockchain (Tyagi, 2022; Nair & Tyagi, 2023; Tyagi, 2023; Deshmukh et al., 2022; Tyagi, Chandrasekaran, & Sreenath, 2022; Sheth, I. A. K & Tyagi, 2022; A. K. V, Tyagi, & Kumar, 2022; Tyagi & Abraham, 2021; Tyagi et al., 2023) in the near future can be:

- Scalability Solutions: Research into novel consensus mechanisms, sharding techniques, and layer 2 scaling solutions such as sidechains and state channels can significantly enhance blockchain scalability. These advancements would enable blockchain networks to handle a higher volume of transactions efficiently, making them more suitable for mass adoption in both industry and society.
- Interoperability Standards: Developing interoperability protocols and standards will provide seamless communication and data exchange between different blockchain networks. This interoperability would enable cross-chain transactions, interoperable decentralized applications (dApps), and interconnected blockchain ecosystems, fostering innovation and collaboration across industries.
- Privacy-Preserving Technologies: Advancements in privacy-preserving technologies such as zero-knowledge proofs (ZKPs), homomorphic encryption, and secure multi-party computation

(MPC) will enhance privacy and confidentiality in blockchain transactions. These innovations would enable enterprises and individuals to transact securely while protecting sensitive information, opening up new possibilities for blockchain adoption in sectors like finance, healthcare, and supply chain management.

- Integration with IoT and Edge Computing: Research into integrating blockchain with Internet of Things (IoT) devices and edge computing infrastructure will enable secure and decentralized data exchange at the edge of networks. Blockchain-enabled IoT and edge computing solutions would enhance data integrity, security, and automation, revolutionizing industries such as smart cities, healthcare, and manufacturing.
- AI and Machine Learning Integration: Using artificial intelligence (AI) and machine learning (ML) techniques to analyze blockchain data can provide valuable insights into transaction patterns, fraud detection, and risk assessment. By combining blockchain with AI/ML, organizations can enhance security, automate compliance processes, and optimize decision-making in various domains, including finance, cybersecurity, and supply chain management.
- Quantum-Safe Cryptography: Developing quantum-resistant cryptographic algorithms and protocols will ensure the long-term security of blockchain networks in the era of quantum computing. Quantum-safe cryptography research is essential to safeguarding blockchain systems against potential threats faced by quantum computers, protecting sensitive data and transactions.
- Energy-Efficient Consensus Mechanisms: Exploring energy-efficient consensus mechanisms, such as Proof of Stake (PoS), Proof of Authority (PoA), and Proof of Burn (PoB), will reduce the environmental impact of blockchain networks. Transitioning to energy-efficient consensus mechanisms will make blockchain technology more sustainable and eco-friendlier, addressing issues about its carbon footprint and energy consumption.

In the last, from an industry and society perspective, these potential innovations and advancements in blockchain technology will drive significant positive impacts:

- Enhanced Efficiency and Transparency: Streamlined processes, reduced costs, and improved transparency in various industries, leading to increased efficiency and trust among users.
- Greater Financial Inclusion: Access to decentralized financial services, including banking, lending, and remittances, for underserved populations, fostering financial inclusion and economic empowerment.
- Improved Supply Chain Traceability: Enhanced traceability and provenance of products, enabling consumers to make informed purchasing decisions and businesses to ensure product quality and safety.
- Enhanced Data Privacy and Security: Strengthened data privacy and security measures, protecting individuals' sensitive information and mitigating cybersecurity risks in an increasingly digital world.
- Democratization of Innovation: Democratized access to funding, investment opportunities, and innovation through tokenization, decentralized finance (DeFi), and crowdfunding platforms, enabling broader participation in the economy and innovation ecosystem.

In summary, these potential innovations hold the promise of unlocking the full potential of blockchain technology, driving positive societal impact, and ushering in a more inclusive, transparent, and efficient future for industries and society alike.

9. CONCLUSION

Today Blockchain-enabled microgrids allow peer-to-peer energy trading among consumers, promoting renewable energy adoption and optimizing energy distribution. Smart contracts automate energy transactions, ensuring transparency and efficiency in energy markets while reducing operational costs. Furthermore, blockchain is reshaping the digital advertising landscape. By using blockchain's transparency and data integrity, advertisers can verify ad impressions, combat ad fraud, and ensure fair compensation for content creators. This makes a more equitable and efficient advertising ecosystem while enhancing user privacy and security. In summary blockchain technology is enhancing innovation across various sectors in this smart era. Its decentralized, transparent, and secure nature empowers individuals and organizations to create new value propositions and redefine traditional business models. As blockchain continues to evolve, its potential to drive positive societal impact in the smart era remains profound and unparalleled. The emerging applications of blockchain technology in this smart era represent a paradigm shift in how industries operate and interact within interconnected digital ecosystems. With its decentralized, transparent, and secure architecture, blockchain is fostering innovation across diverse sectors, revolutionizing traditional business models, and driving positive societal impact. From decentralized finance (DeFi) to supply chain management, healthcare, smart energy, and digital advertising, blockchain is enabling greater efficiency, transparency, and trust. By eliminating intermediaries, automating processes through smart contracts, and ensuring data integrity and security, blockchain is empowering individuals and organizations to reimagine how value is created, exchanged, and managed. As blockchain technology continues to mature and evolve, its potential to address complex challenges and unlock new opportunities in the smart era is limitless.

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