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Blockchain technology and its pioneering applications: A comprehensive review

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Abstract-*Blockchain technology, initially conceived as the foundational framework for cryptocurrencies, has emerged as a transformative force with far-reaching implications across various industries. This research paper provides a comprehensive examination of the fundamentals, key components, and pioneering applications of blockchain technology. It explores the decentralized and distributed nature of blockchain, its cryptographic underpinnings, and the consensus mechanisms that ensure secure and transparent record-keeping. The paper delves into the diverse applications of blockchain beyond the realm of cryptocurrencies, highlighting its impact on SCM, smart contract, identity management, healthcare, voting systems, real estate, and cross-border payments. Through a meticulous analysis, it uncovers how blockchain enhances transparency, reduces fraud, and revolutionizes traditional processes in these sectors. Despite its transformative potential, blockchain faces challenges, including scalability issues and environmental concerns associated with certain consensus mechanisms. The research also outlines the regulatory landscape and explores the evolving trends and future directions of blockchain technology, such as efforts towards interoperability, integration with AI and IoT, and the development of Central Bank Digital Currencies (CBDCs). In conclusion, the paper underscores the profound impact of blockchain on reshaping the digital landscape and calls for ongoing research and development to address challenges and unlock the full potential of this revolutionary technology. This comprehensive overview serves as a valuable resource for scholars, industry practitioners, and policymakers seeking a deeper understanding BCT and its dynamic application across sectors.*

Key Words: *cryptocurrency, decentralized, distributed, cryptographic, transparency.*

1.INTRODUCTION

Blockchain is not only associated with cryptocurrencies but has so many wide applications. It consists of distributed database of transaction records which are handled by group of interconnected computers across the globe. Blockchain operates decentralized, allowing network-wide access to all participants in a software application. It operates on a decentralized basis, with each transaction broadcasted to the network and verified using computer algorithms. This decentralized nature prevents a single centralized entity from controlling the entire network. A new transaction is connected with a previous one forming a blockchain [1].

1.1 Background

Satoshi Nakamoto is known to be the first to implement modern blockchain technology, as he published a paper in 2008, Bitcoin: A Peer-to-Peer Electronic Cash System, proposing a direct online payment system without a third-party intermediary. This system relies on cryptographic proof instead of trust, giving the way for modern blockchain technology. The Nakamoto's paper solved the problem of double spending by linking every transaction to the preceding transaction. In this way blockchain technology (BCT) evolved [2].

1.2 Working of blockchain

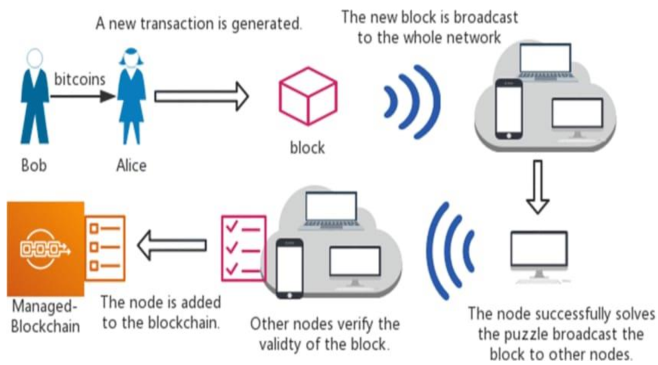

Fig 1. Working procedure of blockchain [3].

Bitcoin transactions require a four-transaction process, broadcasted to the Bitcoin Network, and verified by miners using a cryptographic puzzle. The network of nodes validates the transaction, ensuring accuracy in each block. This process is crucial due to the large number of users with the same records, making it difficult to confirm the same transactions. Once a new block is created, the transaction is completed, adding a new block to the existing blockchain. This process is crucial in ensuring the security and integrity of the Bitcoin network [4].

1.3 Types of blockchain

- Public Blockchain:-This type of Blockchain allows anyone to read and submit transactions.
- Private blockchain:- In this only one organization or all subsidiary organization with in same group have access to read and submit transactions.
- Consortium Blockchain:-Here, multiple group of organizations form a consortium and are allowed to submit transactions and read transactional data.
- Hybrid Blockchain:-This is new category which combines of Public, Private or Consortium Blockchain [5].

2.APPLICATIONS

2.1 Supply chain management

Supply chain management involves the strategic management of interconnected relationships within a company and across interdependent organizations and business units. It encompasses aspects such as sourcing from material suppliers, production, logistics, marketing, and related systems. These activities are designed to facilitate the seamless flow of materials, services, finances, and information from the original producer to the end customer. The primary objectives of supply chain management are to enhance value, optimize profitability through operational efficiencies, and achieve high levels of customer satisfaction [6].

In agriculture food supply chain, the main drawbacks of traditional Supply Chain are: Food safety cannot be assured at any stages, the detailed information about the origin of the product will not be available, failed to provide transparency and traceability. The solution for this can be utilizing blockchain to enhance supply chain management by increasing transparency, reducing errors, preventing delays, and eliminating unethical activities. It involves RFID tagging for product tracking, QR codes for information, and smart contracts for transactions. This results in improved accountability and efficiency throughout the supply chain. Customers can access product details through QR codes, providing information about the product's origin, age, duration, and expiry [7].

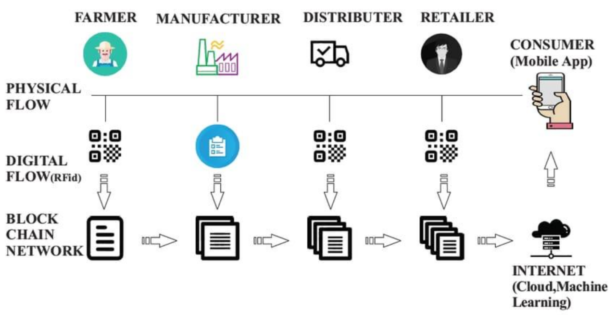

Fig 2. Agriculture food supply chain management [8].

In general, BCT improves end-to-end transparency, reducing inefficiencies and the bullwhip effect. Real-time information sharing enhances collaborative planning and risk management. Blockchain's transparent and immutable ledger allows tracing assets, certifying authenticity, preventing fraud and easing paperwork in global trade. Smart contracts enable highly automated supply chains based on pre-specified rules, increasing speed, easing coordination and ensuring ex-post enforceability of contracts. Tokenization of physical SC assets (equipment, inventories) allows for improved capacity utilization, increased contract flexibility and reallocation of risks in supply chains. BCT supports financial SCM through eased settlement of multi-party transactions and simplified financing of working capital using transparent records, automated transactions and tokenized financial claims [9].

2.2 Cross border payments

Cross-border payment generally refers to two or more countries or regions due to international claims on international trade, international investment, etc., with the help of certain settlement tools and payment systems to achieve cross-border or cross-regional capital transfers. Traditional system involves numerous intermediaries, leading to slower transaction speeds. Blockchain makes direct transactions between parties eliminating intermediary delays, significantly speeding up the process. In traditional system there are great prize associated with various intermediary settlements. Blockchain technology is transparent and decentralized, reducing indirect costs and enhancing cost efficiency traditional system architecture is centralized with potential single points of failure. Blockchain has distributed architecture ensures greater stability, fault tolerance and business continuity.

In traditional system funds move slower, impacting efficiency. Blockchain ensures real-time transaction processing enhances fund liquidity. Traditional system has limited visibility and traceability of transactions. Blockchain's distributed accounting ensures traceability, reducing trust risks and enhancing monitoring. Traditional system relies on centralized credit reporting. Blockchain offers a decentralized and tamper-proof credit system, improving reliability and reducing costs [10].

SWIFT, an acronym for the Society for Worldwide Interbank Financial Telecommunication, has been a stalwart in the realm of secure cross-border financial transactions and money remittance for over 45 years. SWIFT operates through a hierarchical network structure of banks, introducing potential liquidity and credit risks. On the other hand, rripple leverages blockchain technology to streamline cross-border transactions, resulting in reduced costs and accelerated processing times, facilitated by its cryptocurrency, XRP. Ripple's mechanisms for direct confirmation and synchronization play a pivotal role in expediting delivery and fortifying transaction security [11].

2.3 Intellectual property and royalities

Leveraging blockchain technology for the registration of intellectual property (IP) can greatly benefit the original owner by ensuring unambiguous copyright claims. Once the IP is registered on the blockchain, it becomes indisputable evidence and immune to tampering. This empowers the owner with complete authority over both ownership rights and the distribution of their intellectual property, bolstering security and protection for creators and their creative works [12].

IP and Blockchain have dual relationship, whereby IP system protects blockchain on one hand and Blockchain technology can be utilized to strengthen the IP regime on the other. Creation of IP using blockchain reduces litigations by establishing evidence of first inventorship, creatorship and initial use in trade. Transmission of Data on Blockchain during IP Filings ensures the integrity of filing data, eliminating the risk of tampering in "First-to-File" scenarios. Blockchain facilitates efficient patent examination by synchronizing internal and external search databases. It also maintains tamper-proof IP registers globally, ensuring correctness and real-time updates during rights transfers. Enhances collaboration with other IP offices such as WIPO, especially in schemes like the Patent Prosecution Highway, through immutable and traceable data. Blockchain enables Counterfeiting Detection tracking and detection of IPR violations like fake goods, aiding customs in preventing entry into domestic markets and curbing counterfeit drugs. Smart contracts on blockchain streamline IP rights licensing, contractual agreements and management, ensuring real-time execution and verifiable information .Provides MSMEs with crucial data on enforced and expired IP rights, allowing resource investment without infringement and access to technologies post-expiry. Enhances enforcement agencies capabilities by offering genuine IP data on blockchain, expediting dispute resolution and settling IP-related issues swiftly [13].

2.4 Energy Trading

Traditional energy markets face challenges like centralized management causing single points of failure and high operating costs. Privacy concerns arise as third parties may disclose user data and communication security is challenging. The lack of competition between renewable and traditional energy pricing hampers investment and the power grid is vulnerable to cyber-attacks. Moreover, relying on large energy plants and long- distance power transmission hinders efficiently meeting dynamic energy demands. In modern systems, adopting bidirectional energy management is seen as crucial for enhancing efficiency and stability [14].

Energy trading is the process of buying and selling electricity. In the case of Peer-to-Peer (P2P) energy trading, it involves direct exchanges between prosumers (electricity generators and consumers) and consumers. Prosumers can sell their surplus electricity directly to consumers, creating a more decentralized electrical network. The exchange includes both energy and monetary transactions, facilitated through a platform functioning as an energy exchange coordinator. This model encourages multi-directional trading within a local geographic area, contrasting with traditional one-way energy transmission from large-scale generators to consumers [15].

Blockchain ensures secure P2P energy trading by preventing double-spending attacks through consensus algorithms like PoW. Its immutable ledger safeguards against data-diddling attacks, maintaining data integrity. In communication, blockchain protects against DOS attacks, as users must pay gas fees for transactions, acting as a deterrent. Security concerns are addressed through cryptographic public keys, providing anonymity to users. Despite operational costs, blockchain proves cost-effective in comparison to traditional intermediaries. Smart meters, integrated with blockchain-enabled smart contracts, enable transparent and efficient energy trading. These meters transmit data at regular intervals, forming the foundation for decentralized P2P energy markets. Understanding smart contracts is crucial for successful blockchain implementation in energy trading [16].

2.5 Notary services

A messaging service provider (SP) notarizes content like chat history upon user requests. It creates a snapshot, signs it digitally, and sends the evidence to users. A client app (NC) sends notarization requests to SP and inserts the evidence into a blockchain network (BN). Users can verify and retrieve snapshots from BN. The blockchain ensures secure recording and validation of transactions [17].

One of the features envisioned for BCT is that it has notary function for digital encoding of important documents such as identity card, passport, insurance. In health sector, there are some documents which are required to be confirmed such as test results, proof of insurance, treatment, prescription. These documents are verified in seconds in an encrypted manner in the proposed system instead of hours or days by using traditional technology [18].

2.6 Voting System

For verification, most present E-voting applications rely on government issued information, which is not the most effective means of authentication as it is difficult to keep secure and there is possibility of casting multiple ballots. To address these issues, the suggested solution includes a decentralized database and a smart contract, which allow voters avoid casting duplicate ballots. This strategy also increases the efficiency of the validation and voting assignment phases.

Future trends in transparent voting system with ML: - Integration of the Machine Learning concept by adding a facial recognition system is one of the project's planned developments. Face recognition would be a great addition because it improves security and prevents duplicate and forged votes. The use of two-factor authentication will prevent proxy votes from being casted [19].

E– Voting or electronic voting is a means for the election process to be conducted without the use of traditional paper ballots [20].

2.7 Cryptocurrency

Cryptocurrencies, led by Bitcoin, have revolutionized the financial landscape globally. Cryptocurrencies operate independently of government control and use cryptographic security measures. Transactions are secured through blockchain technology, providing a distributed ledger system. Miners validate and timestamp transactions, earning incentives for their efforts in maintaining the cryptocurrency network. Governments, like the UK, have explored the role and potential regulations for cryptocurrencies. The decentralized nature of cryptocurrencies poses challenges for governments and law enforcement. Bitcoin ATMs have become widespread, allowing users to buy and sell cryptocurrencies with relative ease. Despite debates, cryptocurrencies, especially Bitcoin, have gained immense popularity, attracting investors globally. Cryptocurrencies have dramatically changed individuals' lives, with some making significant financial gains through investments.

- Ethereum: Decentralized platform since 2015 by Vitalik Buterin of value €28.6 billion which utilizes blockchain like Bitcoin but designed for broader business use. Known for smart contracts. Aims to decentralize the Internet.
- Ripple: Introduced in 2012 by Britto, Fugger, Schwartz. Utilizes Ripple Transaction Protocol (RTXP) and XRP (ripples). Focus on secure global financial transactions for banks. Market value €10.3 billion.
- Litecoin: Created in 2011 by Charles Lee. P2P internet currency for quick and almost free global payments. Similar to Bitcoin but with improvements. Currently serves as a backup to Bitcoin.
- Monero: Created in 2014 with a focus on privacy. Uses Crypto Note protocol, difficult to trace. Ring-signatures to enhance privacy. Popular in 2016 for darknet market transactions.
- Ethereum Classic: Similar to Ethereum but focuses only on smart contracts. Preserves history without external interference. Market value €1.7 billion.
- NEM: Peer-to-peer cryptocurrency with blockchain platform. Started in 2015, features proof-of-importance algorithm. Value almost €1.6 billion.
- Dash: Presented in 2014, initially known as Dark coin and Xcoin. Market value €1.2 billion.
- IOTA: First cryptocurrency without blockchain, uses Tangle technology. Transactions without fees, scalable system. Market value more than €1 billion.
- Waves: Enables custom token creation. Used for trading and crowdfunding. Integrates fiat currency gateways in wallets.
- Augur: Decentralized market platform built on Ethereum. Created in 2014, utilizes smart contracts on the Ethereum blockchain [21].

Cryptocurrencies use blockchain for transparency and security, eliminating the need for third-party intermediaries. Cryptocurrencies are not controlled by governments or banks, giving users ownership and control over their assets. Transactions are recorded in a secure ledger and user identities are encrypted, ensuring the validity of records and protecting against fraud. The blockchain verifies transactions between digital wallets, preventing identity theft and ensuring accurate balance calculations. Blockchain enables quick and secure transactions, making cryptocurrencies valuable and in high demand for payments and money transfers. Cryptocurrencies provide financial access to over two billion people without traditional banking services. Unlike other electronic money systems, cryptocurrency users truly own their accounts, enhancing control and autonomy [22].

2.8 Food safety

Issues in existing system :These serious imperfections of the existing system often lead to problems with the lack of trust of individual participants in the chain, or such prosaic irregularities as surprising as: falsifying certificates of origin of animals intended for further breeding or sent to a slaughterhouse; manipulation of information on the use of sensitive means of production. e.g. in animal production antibiotics and other drugs and in plant production pesticides, in food processing preservatives, etc.

First of all, attention is paid to preventive measures consisting in eliminating the symptoms of problem situations in the link in the chain in which they were detected. In this way, it limits the development of problem situations in the entire food market chain. The presented system is decentralized and is based on sharing data from all partners of the food value chain, collected in the digital book (ledger). In the case of animal production, this knowledge may relate to such parameters as accepting the animal to blockchain records along with the opening balance; installation of responders on animals, enabling monitoring of their activity; body temperature anomaly or behavioural changes; treatment ordered; stages of the food cycle; readiness to receive by the meat processing plant after obtaining appropriate technological maturity; scope of preventive measures and substances used throughout the entire animal husbandry period; drawing up a description of the animal's silhouette and coding it in the form of a QR code [23].

The use of blockchain can be done among the other categories in food delivery or food leftover sharing, even though they can benefit from blockchain to create a hedging mechanism against supply chain risk associated with online platforms (Choi2019). The benefits include, for example, ensuring grocery and food quality, recognising counterfeit or manipulative orders, certifying the identity of shoppers and delivery drivers and reducing commission [24].

2.9 Smart contracts

Smart contracts serve as mutual agreements among multiple parties, capable of storing information, processing inputs and generating outputs through predefined functions. To tackle the challenges associated with their immutability and the irreversible nature of blockchain, emerging trends in smart contract development focus on two key areas: Layer 2 protocols and innovative contract management solutions. Contract management solutions offer the potential to overcome the limitations of technology by managing the entire life cycle of a contract, including deployment, updates and termination. This holistic approach enhances the adaptability and usability of smart contracts for diverse applications, making blockchain technology even more versatile and user-friendly [25].

Nick Szabo introduced smart contracts in 1994 as computerized transaction protocols executing contract terms. Smart contracts minimize reliance on intermediaries, automate contract execution, and reduce the risk of exceptions. Stored on the blockchain, smart contracts have a unique address and are triggered by transactions. Own state and account on the blockchain. Express business logic in code. Describe all possible outcomes. Triggered by messages/transactions and deterministic. Transparent and inspectable code. Cryptographically verifiable Enable data-driven interactions. Eliminate disputes by ensuring verifiable outcomes. Operate autonomously based on predictable behaviour. Decentralized Autonomous Organizations (DAOs): Smart contracts give rise to DAOs, entities whose behaviour can be modified through encoded processes and member voting [26].

2.10 Healthcare

Blockchain technology holds substantial promise in the healthcare sector. It can revolutionize the management of healthcare data by bridging gaps between disparate systems and enhancing the accuracy of Electronic Health Records (EHRs). Blockchain finds applications in various healthcare domains, including drug prescriptions, supply chain oversight, pregnancy and risk data administration, access control, secure data sharing and the establishment of a transparent audit trail for medical activities. Additionally, other areas within healthcare, such as verifying provider credentials, streamlining medical billing, facilitating the exchange of medical records, supporting clinical trials, and combating drug counterfeiting, stand to benefit from blockchain technology. Implementing blockchain-based healthcare systems promotes a patient-centric approach, bolstering the security and reliability of patient's data while empowering individuals with greater control over their healthcare records. Safeguarding medical data is paramount, given its susceptibility to cyberattacks and blockchain's robustness against security breaches and system failures makes it a fitting framework for safeguarding healthcare data. Blockchain technology offers diverse methods of controlling access, thereby strengthening data security and privacy in the healthcare realm [27].

Healthcare providers generate enormous amounts of data in various formats, including reports, financial documents, laboratory test results, imaging studies, such as x-rays and CAD scans and measurements of vital signs etc. Healthcare providers establish a direct connection to the blockchain network. All clinical data is tracked and stored in existing health IT systems. Various patient-related data, using Patient IDs, is transmitted to the blockchain network through Application Programming Interfaces (APIs). Smart contracts are used to execute transactions within the blockchain system. Transactions are committed in the blockchain network using patient public IDs that don't contain personal information. Data transactions are recorded in blocks, which are chained together in an immutable ledger. Each transaction is uniquely identifiable. Clinical data is analysed to derive insights. The blockchain stores only non-identifiable patient data, such as gender, age and illnesses, while preserving patient anonymity. If a patient wishes to share their identity with a healthcare provider, they can share their private key. This allows the provider to access the patient's data and provide personalized care while maintaining confidentiality for those without access [28].

2.11 Real Estate

Blockchain can be used for property and land transactions to enhance security and speed. Developing a private blockchain for land transactions allows control and security. Only registered users can participate in land transactions via the blockchain. Smart contracts automate and facilitate the land transaction process. Smart contracts generate contracts between buyer and seller. Blockchain enables direct, secure money transactions without intermediaries. Blockchain technology can also be used for renting out properties, with smart contracts automating lease agreements and payments [29].

Real estate transactions often involve intermediaries, lawyers and government entities, leading to time-consuming and costly processes. In early April 2021, the total market cap of real estate was $2.08 trillion, which increased to $2.87 trillion by November 2021.There was approximate $40 trillion in physical money representatives, banks and cadastres by December 31st 2021, indicating a significant amount of paperwork and bureaucracy. Blockchain technology can address these challenges by allowing users to record their property on a blockchain, which is generally recognized. Smart contracts can be used to automate the buying and selling process, with the contract activating automatically when the buyer pays the agreed price. Smart contracts can also incorporate security deposits and reduce costs associated with traditional transactions. Blockchain and smart contracts have applications beyond real estate, extending to any domain where paper contracts are currently used [30].

2.12 Insurance

- Vehicle Insurance: Blockchain can streamline the claims process and enable usage-based insurance (UBI) by capturing real-time data. Smart contracts can automate claim settlements, reducing the administrative burden.
- Home Insurance: Blockchain can automate claim applications and processing, particularly in the case of natural disasters. Smart contracts triggered by predefined criteria can expedite payments to affected communities.
- Life Insurance: Blockchain can ensure the accuracy and transparency of information, making policy details accessible to beneficiaries, insured individuals and insurers. Smart contracts can automate policy-related processes.
- Disability Insurance: Blockchain can maintain a database of individuals with disabilities and smart contracts can automate the disbursement of payments based on predefined parameters.
- Health Insurance: Blockchain can address issues related to medical billing, privacy and information sharing in the healthcare sector. It can make the process more transparent and efficient.
- Long-Term Care Insurance: Blockchain can be used to raise funds for long-term care through Initial Coin Offerings (ICOs), supporting small businesses and start-ups in the sector.
- Marine Insurance: Blockchain can improve transparency, streamline processes, and provide an accurate audit trail in marine insurance. It eliminates the need for financial intermediaries and expedites premium payments and claim settlements [31].

Blockchain can streamline the insurance value chain, from product management to customer service, reducing manual processes and administrative overhead. The decentralized nature of blockchain ensures the security of policyholder data and transactions, reducing the risk of data breaches and fraud. Smart contracts enable automated execution of agreements, simplifying claims processing and reducing the need for intermediaries. This can lead to faster claim settlements and cost savings for both insurance companies and customers. The transparency of blockchain can reduce the likelihood of false claims by customers, as all transactions are recorded and verifiable. Blockchain helps maintain data integrity, which is crucial in the insurance sector, especially for medical claims and fraud prevention. Blockchain builds trust in the system by eliminating the need for intermediaries like brokers. Clients have more control over their data and interactions within the business system [32].

2.13 Government services

When using blockchain technology any material objects, property and personal records and even public records, individual certificates, can be recorded on the same platform, providing each object a permanent digital identity. This system will provide each citizen with individual credit and a verifiable digital identity, stored immutably in the blockchain platform. In this situation, government will rely on individual credit records rather than other conditions to provide public services, which will simplify bureaucratic processes and improve the speed and authority of government approval. It can also help to reduce administrative bias, ensuring everyone is able to access public services equally [33].

One of the most important benefits of blockchain technology is the ability to promote direct interactions between government agencies, citizens and businesses. As a result, blockchain technology has the potential to redefine how governments engage with individuals and each other, forcing public administrations to reconsider their roles in providing public services. Adoption of blockchain technology by different governments in the world :

- China: The Chinese government declared that it would begin employing blockchains in invoice issuance and tax collection.
- Japan: The Japanese government announced that it will be experimenting with a blockchain-based system for handling government tenders. The technology consists of allowing users to obtain information electronically, such as tax payment documents.
- USA: The US government was looking for contractors to evaluate how blockchain technology may be incorporated into its contract bidding mechanism.
- Britain: The incorporation of blockchain technology into governmental operations in the United Kingdom was offered as an interesting case study. The main concept behind blockchain use is to automate the registration and payment of government grants and perks.
- Estonia: Blockchain technology has been integrated by the Estonian government in official announcements, digital court files, property registries, succession registries, business registries, etc.
- Sweden: The Swedish government has begun to explore the use of blockchain technology to support real estate transactions [34].

2.14 Tokenization of assets

Tokenization provides secure ownership through blockchain .Ownership is secured by cryptographic links and private key signatures. Tokenization allows assets to be governed by smart contracts. Smart contracts enable automation of various asset-related tasks. Tokenization enhances asset divisibility, allowing assets to be divided into small fractions. This facilitates financial inclusion and more precise portfolio management. Tokenization can ease the formation of a liquid secondary market .It reduces counterparty risk and may lead to more accessible and liquid markets. Tokenization can lead to standardized and interoperable systems. It enables assets to be traded across different platforms and blockchains. Tokenization reduces counterparty risk by enabling atomic transactions. Multi sig wallets can be used to manage and secure tokenized assets [35].

2.15 Identity verification

The problems identified in the current traditional system of verifying identities are as such: Firstly, paper-based personal records are bulky to store while also posing a safety risk. Secondly, a person has no control over their personal information kept in a distributed database which may lead to identity theft and misuse of data. An identity verification system that is entirely owned by the individual will increase trust that the data is genuine and reliable. It will also help that this system is open and transparent. An identity verification system that is entirely owned by the individual will increase trust that the data is genuine and reliable [36].

Traditional identity authentication solutions mostly rely on a trusted central entity, so they cannot handle single points of failure well.it can realize the protection of real identity information and also it can avoid the storage overhead caused by the need to store a large number of certificates or key pairs. Due to the use of blockchain, there is no single point of failure in the authentication process, and it can be applied to distributed scenarios [37].

3.FUTURE TRENDS

3.1 Integration of blockchain with AI and IoT

Integration of Blockchain and AI supports to address the accuracy, latency, centralization, and security and privacy. However, the convergence of AI and blockchain for IoT resolves all issues such as accuracy, latency and security and privacy, but computational power and latency issues are not completely mitigated with the proposed architecture. Block IoT Intelligence architecture can be enhanced with machine intelligence concepts such as feature extraction and scaling and classification in a decentralized way to address these issues [38].

The Blockchain can solve privacy and trustworthiness issues. While AI has the power of building an advanced analytical algorithm on the Blockchain to defence against cybersecurity attacks.AI and Blockchain can complete each other and mitigate their challenges. Therefore, taking advantage of each technology can protect IoT from cybersecurity attacks. Integrating them will build an explainable AI, decentralized and distributed IoT structure, digitally signed transactions, secure data sharing, and immutable IoT [39].

It provides new way for distributed application development and also use in trusted third party scenario for IOT system. The automatic payment is a huge advantage [40].

3.2 Interoperability

A technical report from NIST defines blockchain interoperability as “a composition of distinguishable blockchain systems, each representing a unique distributed data ledger, where atomic transaction execution may span multiple heterogeneous blockchain systems, and where data recorded in one blockchain are reachable, verifiable, and referable by another possibly foreign transaction in a semantically compatible manner” [41].

Interoperability of Multiple Blockchains: Given the highly distributed and heterogeneous nature of the Internet, we can envisage there will be several private and public blockchains co-existing in the ecosystem. To maintain a global state of the information, these different blockchains should be able to communicate in a secure and transparent manner without affecting security. For example, to know the exact identity of a user, several blockchains may be queried before a blockchain validates the transaction of that user [42].

3.3 CBDC’s (Central Bank Digital Currencies)

The adoption of a digital rupee using blockchain technology by the Institute for Development and Research in Banking Technology (IDRBT) presents several advantages for India: Blockchain ensures transparency and immutability, reducing fraud and corruption while enhancing the security of transactions. The cryptocurrency industry's expansion could lead to significant job opportunities, leveraging India's pool of finance and IT professionals. Collaboration between IT and finance can open business avenues, attract foreign investments, and improve tax compliance, especially with regulatory measures like GST. Digital rupee implementation can streamline transactions, making them quicker and more cost-effective by eliminating third-party intermediaries. A government-backed digital rupee would reduce dependence on foreign cryptocurrencies, aligning with the goal of a self-reliant India in the crypto space. The digital rupee, based on blockchain, offers a solution to counterfeit currency problems, enhancing economic security. Introducing a digital rupee could save significant costs related to printing and distributing physical currency notes [43].

The disruptive potential of Blockchain or DLT has sparked interest among central banks. CBDCs can provide financial services to the unbanked, especially in regions where digital penetration through smartphones surpasses traditional banking access. CBDCs allow users to access digital payment tools at lower or zero costs without requiring a traditional bank account, potentially reducing financial barriers. The programmable money features of CBDCs encourage financial institutions and fintech companies to experiment with Distributed Ledger Technology (DLT), fostering competition and innovation in the financial sector. Central banks issuing CBDCs retain sovereignty over monetary policy, allowing for more direct influence over economic factors. CBDCs contribute to the resilience of domestic payment systems, especially as cash usage decreases, providing an alternative in the digital landscape. CBDCs can help mitigate or prevent the widespread adoption of privately issued currencies, ensuring that central banks maintain control over the monetary landscape. Some argue that CBDCs, especially those paying interest, enhance the economy's responsiveness to changes in policy rates, offering greater flexibility in monetary policy. CBDCs with negative interest rates can address the 'zero lower bound' constraint during crises by making holding cash costly, providing additional policy tools [44].

4.CONCLUSION

The versatility of blockchain unfolds across a spectrum of 15 impactful applications, weaving through vital sectors such as healthcare, supply chain management, voting systems, smart contracts, intellectual property, insurance, real estate, identity verification, and energy trading, cross border payments, food safety, cryptocurrency etc. Beyond its foundational role in secure transactions, blockchain emerges as a catalyst for innovation, introducing transparency and efficiency into diverse industries.

Looking forward, the convergence of blockchain with IoT and AI heralds a new era of interconnected technologies, promising solutions to complex challenges in accuracy, security, and decentralization. Simultaneously, the ascent of Central Bank Digital Currencies (CBDCs) signifies blockchain's pivotal role in reshaping traditional financial frameworks.

This journey from foundational applications to emerging trends underscores blockchain's transformative influence, elegantly shaping the landscape of decentralized technologies and inspiring optimism for a future marked by collaborative innovation and secure, transparent digital ecosystems.

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