Blockchain–Cloud Integration

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Blockchain is a new and emergent technology that is expected to change the way current markets work. It is a distributed digital ledger and is decentralized. With the current working capacity of blockchain, it has the potential to be the operating system of smart cities. Blockchain is technology that is open source and distributed and is used to record transactions between parties. It provides a way to develop a system that is both verifiable and secured. Blockchain is open source, so different versions of blockchain are available on the market. Each version is developed depending upon the different needs of the various industries. Blockchain is neither owned nor singly controlled by any one authority. Blockchain technology is evolving at a swift pace. It started with Bitcoin, and now there are many types of blockchain. Organizations are developing different versions of blockchain depending upon their need and benefits.

blockchain cloud computing decentralization Blockchain-as-a-Service

1. Benefits of Blockchain–Cloud Integration

Blockchain innovation is a vital innovation in the world that will allure businesses and other sector areas to utilize that innovation to work on various services. Blockchain is a progressive innovation that may innovate current market trading exchanges. The forthcoming Industry 4.0 interfaces the most recent advancements, for example, blockchain, AI, distributed computing, and IoT for improving the usefulness and productivity of their frameworks [1][2][3][4]. There are several benefits of blockchain and cloud integration; here, the researchers are discussing the popular advantages of blockchain and cloud integration.

1.1. Decentralization

In cloud computing, information is kept in a centralized server, which is one of the major issues from the perspective of security; this can be overcome by accepting blockchain in cloud computing. In IoT and cloud computing, a significant issue is a reliance on a brought-together server to oversee information and for making choices. The blockchain can give an answer to these issue as in the decentralized framework different duplicates of similar information are put away on numerous hubs which eliminates the chance of failure of the whole system. Additionally, the deficiency of information cannot be an issue, as numerous duplicates of the information are available on different hubs. Blockchain with integration with cloud computing is a possible good solution for decentralization and could provide total privacy to users.

1.2. Data Security

Blockchain systems by default inherit data security features. Loads of data are transacted and loaded into the cloud, so security of data is one of the main concerns in cloud computing that is provided by blockchain–cloud integration in different sectors. Even the storage of information on the cloud in the field of the Internet of Things (IoT) is a major test. IoT devices put away information, such as the individual data of the house proprietor including their voice accounts, video films, their family things, their property, and their own propensities in cloud, and the destruction of this information can hurt the individual security including assaults, theft, and illicit selling of the individual's information for cash. These conditions represent a danger to the IoT and cloud foundation. The answer to this issue is the utilization of blockchain in cloud computing, which has the capability of providing upgraded security to the entire engineering.

1.3. Adaptability

In blockchain applications, the quantity of exchanges in blockchain organizations can be tremendous. Blockchain has amazing information handling techniques to have large-scale exchanges for empowering adaptable blockchain services. Therefore, in this regard, cloud computing can provide on-demand services for blockchain activities, because of its scalability abilities. In this way, the blend of blockchain and cloud computing can provide an exceptionally versatile coordinated system.

1.4. More Efficient Supply Chain Management

Blockchain is the technology that will help to develop cost effective and more efficient ways of supply chain management. Blockchain enables better end-to-end tracking of goods and services, and it can be incorporated into cloud computing for much better results for the supply chain industry. A significant challenge of the supply chain management industry is to consistently monitor all vehicles in its organization, their present areas, time for which a vehicle remained in one spot, to set up correspondence between different vehicles. In a similar way, tracing different services such as products, parcels, etc., deal with issues because of the centralized methodology of their design. Blockchain has sufficient potential for tracing these goods and services.

1.5. Tolerance of Faults and Errors

Blockchain requires replicating information over the network over different servers, and this can be achieved by using Cloud. This will also limit the single point of risks from the point of view of the disturbance of any cloud hub, so that blockchain can provide uninterrupted services.

2. Impact Areas of Blockchain in Cloud Computing

Cloud computing is one of the key complementing technologies that support the creation and functioning of blockchains. Some of the prominent advantages of Blockchain–Cloud integration have been discussed in the previous section. In this section, the researchers explore the key areas of Cloud computing which have undergone

significant transformations as a result of integration with Blockchain technology. “Security”, “Privacy”, and “Storage” are areas of Cloud computing wherein numerous advancements have been observed since its integration with Cloud. Moreover, it has been realized that, to facilitate the growth of Cloud computing, it is essential to overcome the roadblocks of data security and privacy for which blockchain seems a perfect match. **Table 1** summarizes some of the prominent works for the mentioned areas.

Table 1. Blockchain impact areas in Cloud Computing.

	Theme	Publications
Cloud Impact Areas	Security	[5][6][7][8]
	Privacy	[9][10][11][12][13]
	Storage	[14][15][16][17][18][19][20]

Data security and user privacy are major concerns for Cloud adoption. Blockchain integration with Cloud has the potential to mitigate the challenges of security and privacy [6]. The distribution of vast volumes of data over a Blockchain–Cloud environment improves accuracy and minimizes cost [18]. Furthermore, improved access control mechanisms can be implemented in a Cloud environment through means of blockchain integration. As most Cloud organizations follow a centralized access control mechanism, integration with blockchain will infuse decentralization, preventing tampering or leakage of data via internal cloud managers [11]. Blockchain-enabled cloud solutions will ensure an efficient framework for identity access control, thereby supporting privacy protection [21][22][23][24]. Cloud auditing is another such area wherein privacy is of the utmost importance, as it involves the tracking and logging of all operations and their relevant data. Blockchain integration with Cloud will ensure preserving the provenance of data from being violated within the cloud ecosystem. The decentralized nature of blockchain will facilitate securing the origin of data and information on data owners, thereby solving one of the major concerns of cloud storage applications.

Blockchain-data-based cloud data entry protection mechanism. Over the years, cloud computing developed a lot, but data security and trusted computing remains a challenge in many cloud applications. Though scholars have conducted many kinds of research, and many models have been proposed by them, including the data integrity test and multiparity calculation; they still face problems such as excessive computational complexity and the lack of scalability. Blockchain technology has emerged as a new dynamic computing paradigm in which data blocks present in the database are generated through a crypto-graphic algorithm. The key features of blockchain, such as decentralization, anonymity, auditability, and persistence have made it possible to use blockchain technology in many fields. The topic discussed in this entry is how Blockchain technology can be applied to cloud computing using the security mechanism to improve the performance in secure storage and secure computing. The entry analyzes the requirements of security in cloud storage data and also examines cypher text access control technology and integrity verification technology.

Ref. [25] discusses the distributed virtual machine agent model deployed in the cloud using mobile agent technology. The multi-tenants cooperate with each other ensuring data trust verification through the virtual machine

agent. The virtual machine agent can complete the monitoring and verification tasks, which are essential for building the blockchain-based integrity protection mechanism. This integrity-protection mechanism based on blockchain is built utilizing the virtual machine proxy model and the unique hash value generated by the Merkel hash tree. It is used in monitoring the data change utilizing the smart contract in the blockchain database and the data that is used in the current time. Here, users can issue a message for the data tempering and the creation of blockchain-based cloud data integrity verification scheme is completed by "block-and-response" mode [26]. Ref. [27] examines the decentralized virtual machine specialist model deployed in the cloud utilizing the mobile agent innovation. The multi-tenants cooperate with one another, guaranteeing the information trust check through the virtual machine specialist. The virtual machine specialist can observe and check jobs, which is essential for building the blockchain-based trustworthiness insurance instrument. Here, users of the system can signal information tampering and the construction of a blockchain-based cloud information-verification system [28]. Ref. [29] constructs a technology application scheme of blockchain-based cloud computing by combining the plus points of blockchain and cloud computing. This scheme provides the protection and integrity check of the data. Moreover, the multi-parity scheme that is based on the blockchain has been projected. The security mechanisms and algorithms in blockchain and the general schemes of scalable multiparity computing have been discussed and studied.

3. Application Areas of Blockchain–Cloud Integration

The concept of Cloud computing has had a prevalent computing model for almost a decade. The last couple of years have seen a surge in the number of organizations migrating their businesses to the Cloud. The ubiquitous availability of resources, attractive pricing models, customized solutions, and numerous market players are some of the factors that contribute to the success of Cloud computing. In recent years, Cloud has emerged as a synonym for computing and storage capabilities that can be accessed over the internet. Cloud has transformed itself into a generic computing paradigm that supports and compliments the functions of other new-age technologies. Containerization, AI, Internet of Things, and Big data analytics are some of the services to have become a part of the larger pool of services being offered by leading Cloud Service Providers (CSPs). Researchers are truly of the belief that the integration of Cloud with other technologies can result in the creation of more robust, scalable, and secure applications. Blockchain technology is the newest entrant to the list of technologies looking forward to Cloud integration. Blockchain has merged as a new-age technology and has been exciting researchers and industry professionals for the last couple of years. The distributed ledger technology allows individuals to conduct transactions in a secure and automated manner. **Figure 1** represents a reference architecture for Blockchain–Cloud integration. In this section, the researchers discuss the integration of Blockchain technology with Cloud computing. During the course of the research, the researchers carried out a comprehensive literature review and identified five key application areas of Blockchain–Cloud integration: (1) Healthcare, (2) Supply Chain, (3) Finance, (4) Smart Cities, and (5) Agriculture. **Table 2** summarizes some of the prominent works for the above application areas.

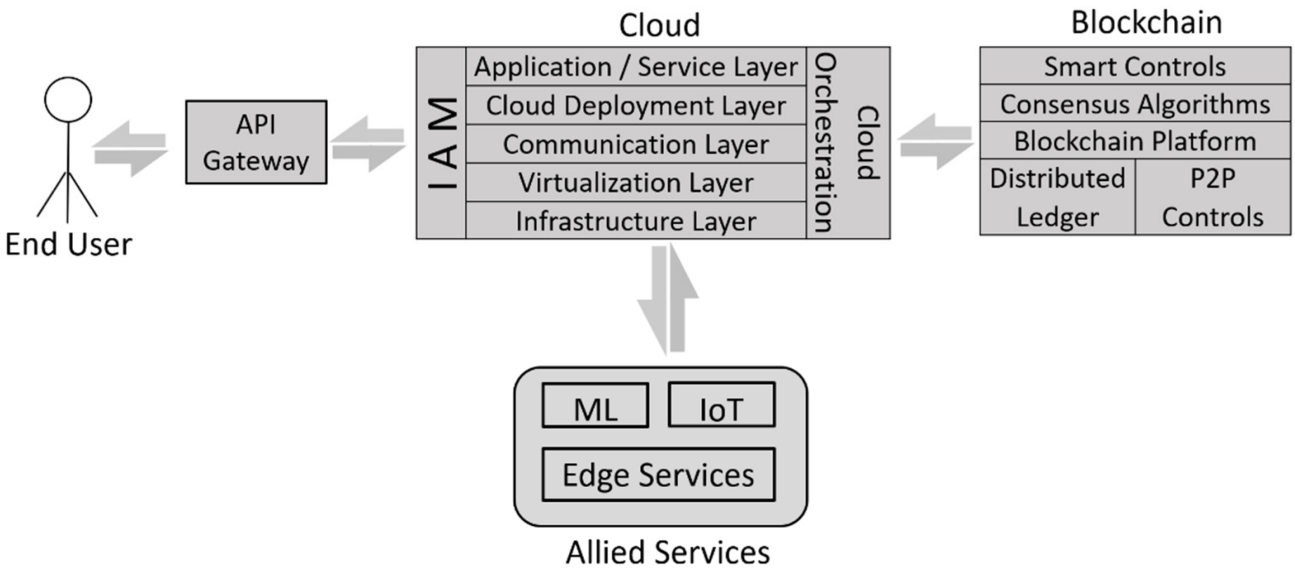

Figure 1. Blockchain–Cloud Reference Architecture.

Table 2. Blockchain–Cloud Application Areas.

	Theme	Publications
Blockchain and Cloud	Healthcare	[30][31][32][33][34][35][36][37]
	Supply Chain	[38][39][40][41][42][43]
	Finance	[44][45][46][47]
	Smart Cities	[48][49][50][51][52][53][54][55]
	Agriculture	[56][57][58][59][60][61]

3.1. Smart City

In the recent past, the concept of “smart cities” has attracted considerable curiosity among researchers across the world. The rise of Cloud computing and the Internet of Things has provided immense infrastructure support for the creation of smart cities. Blockchain being the new member of the bandwagon of technologies, aims to facilitate the creation of citizen-centric applications for a smart city environment. Blockchain has the ability to operate an entire smart city in an autonomous fashion when combined with IoT, AI, and Cloud computing. Blockchain-enabled IoT solutions are becoming more and more popular among industry players as they support ubiquitous sensing capabilities and intelligent information communication and processing. Blockchain enables the trusted and transparent exchange of information between IoT devices through the use of smart contracts and consensus algorithms. Energy trading and distribution platforms, traffic management systems, smart homes, and IoT applications are some of the many application areas of blockchain integration in smart cities. Moreover, blockchain has the potential to enhance the extent of e-governance, thereby improving citizen participation and formulation of government schemes in a smart city.

3.2. Smart Healthcare

Blockchain has revolutionized the healthcare sector by providing applications for health record management, medical insurance claims, and pharmaceutical supply chains. The technology has enabled health professionals to manage patient data in a secure manner without third-party intervention. Blockchain has enabled government authorities to roll out better healthcare schemes on the basis of the health records of its citizens. Diagnostic reports of patients can now easily be communicated to doctors and insurance firms for the purpose of faster claim settlements. The immutable nature of blockchain allows it to ensure trust and accountability and facilitate the creation of a patient-centric healthcare system. Complementary technologies of the likes of AI, Cloud, and IoT are a great success when combined with blockchain in creating modern day healthcare systems. The Internet of Medical Things, Edge-based healthcare systems, and AI-enabled medical imaging systems are some of the many areas of blockchain integration. Post pandemic, numerous works have been published discussing the applicability of Blockchain technology, IoT, and AI for the purpose of contact tracing and vaccination certificate distribution and validation.

3.3. Supply Chain

The recent studies in the area of blockchain technology depict its popularity beyond the realm of cryptocurrencies. Supply Chain Management (SCM) is one of the many leading areas discussing the applicability of blockchain technology. Numerous works in the past have been published stating the use of blockchain technology for managing food, agriculture, retail, hospitality, and pharmaceutical supply chains. SCM has always been a challenging task for organizations, and, specifically post pandemic, the complexity and challenges have increased manyfold. SCM holds the key to numerous economic activities of a country, and any disruption may lead to large fiscal deficits and job losses. Companies need to modernize SCM practices in order to stay relevant and possess a competitive advantage. Blockchain integration with SCM serves this purpose by providing viable methods of asset tracking while ensuring security and data integrity. Data being generated at every stage of the supply chain are recorded in the form of transactions. Blockchain-enabled systems are transparent in nature and support the real-time data collection of a product across the entire supply chain. The entire lifecycle of a product can be managed using blockchain technology while ensuring quality control. Blockchain technology has the potential to contribute to various aspects of SCM such as physical and digital asset tracking; tracking orders and payments; and managing invoices, licenses, and copyrights. The decentralized nature of blockchain enables a continuous information flow and facilitates the seamless sharing of this information between suppliers, vendors, manufactures, and end-user customers across the entire supply chain. The absence of a central authority, the presence of a distributed ledger, and a trust-based ecosystems enable blockchain to weave a network of complex assembly lines.

3.4. Agriculture

Blockchain technology can be seen as an enabler for the agriculture sector. Removal of numerous intermediatory entities and direct communication between farmer and the end user are the biggest advantages that blockchain technology provides to the agriculture sector. Smart-contract-enabled trading platforms are enabling farmers to sell

their produce at favorable rates directly to the end customers. Blockchain is a great supporter of the concept of information-intensive farming that involves Agri data assimilation and intelligent decision making. Smart agriculture that involves the use of new-age technologies is inevitable for the farmers to adopt as it is the only means of rural development and revitalization of the farmer economy. A Blockchain-enabled token-based economy can provide a secure and efficient trading platforms for assisting farmers in trading their crop produce.

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