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RESEARCH ARTICLE

Holochain: An Agent-Centric Distributed Hash Table Security in Smart IoT Applications

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ABSTRACT The accomplishment of blockchain has increased the focus on the various applications for simplifying the confidentiality and transaction sanctuary using the decentralized architecture via consensus mechanisms between different internet of things (IoT) nodes in daily increasing societal areas. The growth of blockchain lasted to grow and used to do compare technologies. The major shortcomings of blockchain is the lack of scalability in modern application settings. Holochain technology vends itself as a ''thinking'' exterior to blocks, and it is a peer-to-peer disseminated ledger technology. It works contrarily compared to the blockchain, and it offers an exclusive value in the existing market. IoT devices are continuously used in distributed environments, in various smart applications. The peer-to-peer IoT networks, connected to smart agricultural systems are exposed to the security issues. Specifically, the personal data of agricultural land records need protection against unauthorized access and eradicate corruption in land transactions. The Blockchain offers a possible solution based on distributed ledger, but it has scalability issues due to high storage and processing requirements with growing network size. Also data is not locally stored in a Blockchain. This paper studies the conventions of holochain technology, its architecture and challenges, and critical mechanisms of holochain applications. We also analyze the numerous models utilized for the implementation of protected transactions. We discuss an agent centric framework with distributed hash table for secured applications.

INDEX TERMS Holochain, communication infrastructure, holo, ledger, process models, distributed ledger technology, agent centric technology, blockchain.

I. INTRODUCTION

Holochain is the one of the developing technology which provides an infrastructure of open source distributed network for secure communication without including large storage and the requirements of exchanging data as in blockchain. For systems that need global consensus with secured mechanisms and high degree of privacy, blockchain is the appropriate technology. The environment that don't need global consensus, on the other hand, can use Holochain technology that is widely used nowadays. In addition to increased scalability, flexibility, efficiency, and extensibility, the absence of a worldwide consensus has several other advantages. As an alternative to Ethereum, which is also a decentralized application platform (dApp), Holochain technology has a wide range of potential applications. Aside than Distributed Ledger Technology (DLT), there are many more options available. The way these two technologies are put to use

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in the actual world is where the major distinction lies [1]. It is possible to build a wide range of distributed applications using Holochain. A decentralized network can already be provided by blockchain technology. As a whole, Holochain consists of a variety of technologies, and the term is derived from this reality. It provides a fundamentally holographic substrate as well as empowering holistic patterns on top of it. There are three types of distributed hash tables: hash chains, cryptographic singing, and Distributed Hash Tables (DHT). It may be regarded as a peer-to-peer network framework that is open source. It enables the creation of stunning apps based on a distributed philosophical framework. In some ways, this could sound like a close of blockchain, but their fundamental workings are rather distinct.

Holochain is the establishment for Holo, a cloud facilitating a marketplace for decentralized applications and the eventual fate of the web. Holo as a term is not extracted via cap. It is having ancestries. Previously, in the first aggregate knowledge of ancestral networks, holopticism was there where everybody takes an interest as a component of a criticism circle of the entirety. Holomidal isn't simply casting a poll or even direction; this is about an exemplified necessary encounter of detecting together. There is co-creation and connectedness in the first aggregate knowledge, even in an evolving climate.

Holochain technology presents a new paradigm for data transit and storage that is more efficient in assorted dimensions and real time use cases. Edge devices, including as smartphones, can join the network with the use of this technology. The method allows the network to grow enormously Holochain is a specific instance of another innovation made by societal development militants to accomplish reformative worth accountability, which is called holoptical information accountancy. An extremely rich multi-faceted consideration is done, and loads of criticism circles past the single element of cost is required. The originators made Holochain of the Meta-Currency Venture for understanding a piece of their socio-specialized imagination [1] and allows any device or peer to join it [2].

Holochain is a Distributed Ledger Technology (DLT) platform-based environment within affordances encouraging co-creation, unformed substance, and co-possession [3]. Holochain targets work with interconnectivity among immediate and backhanded members, for example, the people who introduce Holochain on their equipment gadgets to give facilitating space and the individuals who contact Holochain via an internet browser. One of the upsides of this plan is that it dodges the blockchain prerequisite for worldwide agreement amongst sustainers and hence manages the cost of more superior versatility and influence the client controls their information and personality data. The plan of holochain is very appropriate for Distributed Ledger Technology (DLT). Holochain activists call this plan 'specialist driven' rather than corporate 'information driven' representations. Holochain doesn't take underlying cash or token. Notwithstanding, the dispersed web engineering Holo utilizes a cryptographic money HoloToken(HOT) Fuel, and Holochain was intended to make it simple to offer elective digital currencies as conveyed decentralized applications (dApps). Holo Fuel, a standard credit framework [4], will cover the expenses for information capacity and Holochain advancement and support [5]. Table 3 shows the supply information of HoT Token that how the information can be supplied.

Holochain begins at the furthest edge that matters, the individual, and then facilitates emergent consensus from the bottom-up. Ethereum forces a one-size-fits-all, top-down consensus onto the global population. While international consensus is helpful for some use-cases, it's unnecessary for 90% of the users that first excited those who joined the crypto scene. However, blockchain architecture is fundamentally incompatible with the internet structure itself. The internet is a peer-to-peer (P2P) network of self-sovereign computational devices communicating via free tokenless protocols. Like Facebook, Ethereum is a monolithic centralized data and computational silo with vast economic resources attempting to infect the internet to steer her toward a narrowly defined future. Holochain is a protocol, not a platform. It will coexist alongside the communication protocols that power today's internet and, in doing so, provide a new toolkit for developers and creators to evolve the internet as a collective organism in symbiosis with humans and nature [6].

The major component of today's blockchain systems is energy. To solve cryptographic challenges, the Proof-of-Work consensus technique necessitates a large amount of computing power. It is a low-energy ledger system that is focused on the needs of the agents. Because each agent has a copy of the safe ledger, they are free to work on their own schedules. As a fully scalable distributed ledger system, it can also interface with other network devices.

Smart IoT applications in holochain give an adaptable stage to creating and running decentralized applications (dApps) that can communicate with IoT devices.

With regards to incorporating smart IoT applications with Holochain, engineers can plan and carry out dApps that interface with IoT devices through different means, including:

1) Integration through Oracles: Oracles are mediators between the Holochain organization and outer frameworks, like IoT devices. They give an extension to dApps to cooperate with IoT devices and get data from sensors or send orders to actuators. Oracles can total data from numerous sources, perform data changes, and give a normalized point of interaction to the dApp.
2) Secure Data Trade: Holochain empowers secure and shared data trade, which can be utilized for correspondence between IoT devices and dApps. IoT devices can distribute data to the Holochain organization, guaranteeing the uprightness and realness of the data. The dApp can then buy into the critical data streams and perform investigation, visualization, or trigger activities in light of the got data.

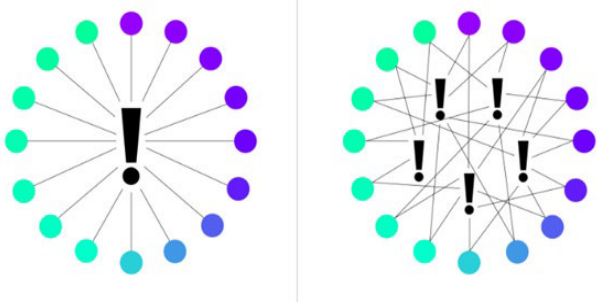

FIGURE 1. Blockchain Vs holochain.

3) Distributed IoT Device Management: Holochain's representative-driven approach considers decentralized and disseminated administration of IoT devices. Each IoT gadget can have its character and partake as an independent specialist in the Holochain organization. Device enrollment, confirmation, and access control can be overseen through dApp, empowering a decentralized and secure climate for IoT device executives.
4) Data Ownership and Protection: Holochain underscores client control and data ownership. This aligns with the standards of numerous IoT applications where clients must hold a data license. Holochain's engineering empowers clients to have complete command over their data, permitting them to impart data to explicit applications or clients, guaranteeing security and assent specifically.

Overall, Holochain provides a platform for building decentralized applications that can integrate with and leverage the capabilities of smart IoT applications. By combining the strengths of Holochain's decentralized architecture and the features of smart IoT applications, developers can create innovative solutions that empower users and enable secure, scalable, and autonomous interactions between IoT devices and dApps.

In figure 1 every transaction needs to be recorded in each of the node's ledger even if that transaction has nothing to do with the holder of the ledger. This is like a supercomputer that can only act on one perspective about the authenticity of transactions. Updating the system also requires the consensus of the majority in blockchain.

In Holochain, individualized and asynchronous validation of transactions which enables massive scalability as shown in figure 1. All data is held across the shared space by random nodes. Network updates in parallel instead of in unison and trust is generated on an individual basis

A. RELATED WORK

A number of authors and practitioners analyzed the Blockchain and holochain technologies. The authors [2] have worked on the distributed security and how the integrity of blockchain works. The authors [3] have worked on the how mining can be done with simulation panel. The contribution done by authors [4] is that how the artificial intelligence can be integrated with internet of things and with healthcare applications. The distributed ledger technologies and advanced integrations are proposed by authors [5]. The authors of this paper [7] have worked on the internet of things security with various distributed technologies. How the secure, trustable and transparent communications in blockchain is discussed by authors [8]. The few of the following are the excerpts from the related technology which are described in Table 1.

TABLE 1. Related work and existing integrations.

Ref.	Author(s)	Contribution in Work	Year
[1]	Zaman et al.	Distributed Security and Integrity with Blockchain	2022
[2]	Mardiansyah et al.	Simulation Panel with Mining	2022
[3]	Yang et al.,	Integration of A.I in IoT and Holochain	2022
[4]	Esteban et al.	Distributed Ledger Technologies and Advanced Integrations	2022
[5]	Diallo	IoT Security with Distributed Technologies	2022
[6]	Tezel et al.	Transparency, Trust and Cybersecurity	2022
[7]	MM, N. et al.	Trusted and Secured Holochain Technologies in Distributed Environment	2022
[8]	Yellasiri, R. et al.	Integration of Distributed Technologies in Wireless Networks	2022

To introduce the recent works in IoT and other security techniques, few authors have analyzed the following works:

The authors [9] addresses the challenges of supporting IoT devices in satellite and aerial-integrated networks. It proposes the use of rate-splitting multiple access techniques to improve IoT communications. To highlight the state-of-the-art in this field, the following recent works and security techniques can be introduced.

The authors [10] proposes a collaborative beamforming design for secure IoT networks assisted by reconfigurable intelligent surfaces (RIS). It focuses on enhancing the security of IoT communications by optimizing the beamforming vectors and RIS reflection coefficients.

The authors [11] presents a hybrid beamforming approach for satellite-terrestrial integrated networks. It aims to improve secrecy and energy efficiency by jointly optimizing the beamforming vectors at the satellite and terrestrial base station to ensure secure communications.

The authors [12] introduces a secure and energy-efficient beamforming technique for multibeam satellite systems. It utilizes the Signal-to-Leakage-plus-Noise Ratio (SLNR) criterion to optimize the beamforming vectors, ensuring security and energy efficiency in satellite communications.

These recent works highlight advancements in secure IoT communications and physical layer security techniques in various network scenarios, including satellite and aerial-integrated networks. They contribute to state-of-the-art

solutions for improving security, energy efficiency, and performance in IoT deployments.

By referring to these works, the paper can demonstrate the novelty and relevance of its proposed rate-splitting multiple access approach for supporting IoT in satellite and aerial-integrated networks. It shows the broader context of research in secure beamforming, reconfigurable intelligent surfaces, and energy-efficient communication techniques for IoT systems.

B. MOTIVATION

On the basis of above literature survey, it has been observed that Holochain has the truly decentralized, post-blockchain architecture to deliver hype that Ethereum could not. That's a straightforward claim to make when you spend some deep-dive and compare the two on first principles. The mining of Bitcoin in early 2010 started the 7th largest Ethereum meetup in the world in mid-2014. We've seen tremendous work in the past decade, but the macro-outcome has mainly produced new financial instruments, artificial speculative scarcities, and gambling schemes to help the rich get richer.

One global state, one global consensus, private enterprise consortium blockchains, central bank minted cryptocurrencies; this is what Ethereum powers. Sharding, sidechains, and other blockchain scaling solutions (if ever realized) are simply pushing data and computation closer to the edges and as blockchain is secure but it is slow and not sustainable so this is also main motivation behind holochain.

The motivation driving Holochain's representative-driven distributed hash table (DHT) security in smart IoT applications is to address the difficulties and prerequisites of decentralized and secure data trade, device management, and privacy concerning IoT.

1) Decentralization: Holochain means to give a decentralized framework to smart IoT applications, eliminating the requirement for a concentrated power or middle person. By utilizing a DHT architecture, Holochain permits IoT devices and applications to connect straightforwardly with one another, empowering distributed correspondence and eliminating single points of failure or control.
2) Security: Holochain focuses on security concerning IoT applications. Using cryptographic strategies, every specialist in Holochain has a cryptographic character and can sign and confirm data. This guarantees the respectability and genuineness of data traded between IoT devices and applications, moderating the gamble of altering or unapproved access.
3) Agent Centric Approach: Holochain's representative-driven model gives every member in the network, including IoT devices, their personality and command over their data. This enables people or associations to keep up with ownership of their data and specifically share it with others on a case-by-case basis, lining up with privacy standards and data sway.
4) Adaptability: Holochain's engineering is intended to scale on a level plane by permitting every specialist to keep up with its data and perform nearby handling. This makes it reasonable for huge-scope IoT arrangements where various devices produce immense measures of data. The specialist-driven approach guarantees that the organization's ability and execution can develop as the number of members and devices increment.
5) Privacy: Holochain underlines client control and privacy. In smart IoT applications, client data is often delicate and ought to be open to approved parties. Holochain's engineering permits clients to decide how their data is shared and with whom it is met to guarantee that privacy is necessary.

Holochain gives a system for creating secure, versatile, and decentralized smart IoT applications by tending to these motivations. It empowers proficient data trade, active device management, and client-driven command over data, advancing trust, privacy, and independence in the quickly growing world of IoT.

C. CONTRIBUTION

This paper makes several significant contributions to the field. The main contributions of this paper are as follows:

- The paper introduces an agent-centric architecture for IoT applications in the context of Holochain. This architecture allows each participant, or agent, in the network to have their own independent chain, providing scalability, efficiency, and data sovereignty. This contribution addresses the limitations of traditional blockchain architectures by enabling a more decentralized and customizable approach to IoT application development.
- The comparitive analysis of holochain with other architectures is also discussed in this paper.
- The holo roadmap followed by infrastructure roadmap, application roadmap, evolution of holochain and deveopment timeline, holochain core roadmap is discussed in this paper.
- Use case for holochain and holchain for scalable agriculture land records as a use case is also dicussed in this paper.

The contributions of "Holochain: An Agent-Centric Distributed Hash Table Security in Smart IoT Applications" advance the state-of-the-art in IoT application development, security, and scalability. By introducing an agent-centric architecture, leveraging DHT for data storage, enhancing security mechanisms, and emphasizing customization, this research paper provides valuable insights and solutions for building secure and efficient IoT applications in the context of Holochain.

D. ORGANIZATION

The Paper organization is as follows: Section II describes the holochain technology:background and architecture. Section III illustrates the roadmap of holochain technology. Section IV describes about consensus and blockchain

TABLE 2. Comparitive analysis of holochain vs other.

Parameters	Holochain [13]	Hashgraph [14]	Hyperledger Fabric [1]	Ethereum [3]	Tezos [15]	IOTA [16]
Decentralized Architecture	Yes	Yes	Yes	Yes	Yes	Yes
dApp Environment	Yes	Yes	Yes	Yes	Yes	Yes
Secure Hash Chains	Yes	Yes	Yes	Yes	Yes	Yes
Application Level Data Integrity	Yes	Yes	No	Yes	Yes	Yes
Smart Contrats	Yes	Yes	No	Yes	Yes	Yes
Custom Data Validations	Yes	Yes	No	No	No	Yes
Is Full Open Source?	Yes	No	Yes	Yes	No	No
DHT-Distributed Hash table	Yes	Yes	No	No	No	No
Machine-to-Machine Compatibility	Yes	No	No	No	No	Yes
Supports a Wide range of Programming Language	Yes	No	No	No	No	Yes
Scaling without Centralized	Yes	No	No	No	No	No
Full Cross and Complex Chain Compatibility	Yes	No	No	No	No	No
Every dApp Have it's own Chain	Yes	No	No	No	No	No
Customisable Security	Yes	No	No	No	No	No
Non-Priority Parallel Transactions	Yes	No	No	No	No	No
User Centric Data	Yes	No	No	No	No	No
dApps Compatibility for Portable Devices	Yes	No	No	No	No	No

technology. The holochain and embodied local states: comparitive analysis is discussed in section V. The key application areas and use cases of holochain are discussed in section VI and section VII. Finally, section VIII states the conclusion of paper.

II. HOLOCHAIN TECHNOLOGY: BACKGROUND AND ARCHITECTURE

Holochain architecture could be summated as a shared Distributed Hash Table (DHT). It overwhelms the bottlenecks of blockchain by possession of the main characteristics of blockchain integral. However, blockchain can be treated as a trusted network where the nodes are anonymous, and every node has a ledger for storing the transaction's history [17]. But blockchain faces bottlenecks, and the blockchain deprived of bottleneck can be considered as holochain:

- This can be achieved with the help of shared Integrity of Data. It is a process to handle the data in peer-to-peer systems organizations somewhere this is more demanding for securing data than central data.
- The shared integrity of data suggests robust data security besides fetching limitations like high demand in computations.
- The main component in holochain is DHT, which delivers excessive weightage to the environment. It proposes subsequent steadiness while confirming that the information is circulated securely by the network. This is the way that every peer is responsible for their actions.
- The architecture is also competent as it confirms that the overhead is achievable as possible. Even mobile devices and other devices could join the network and progress the computation power.

The distributed hash table (or "shared DHT") is a unique feature of the holochain architecture. It keeps important blockchain functionality intact, overcoming the blockchain constraints. Using Shared Data Integrity, it does this. A method of processing data in peer-to-peer networks, where data security is significantly more difficult than in centralised systems, where it is [18], [19], and [20]. Because of the shared data integrity, it's possible to maintain high levels of data security without sacrificing performance. Key to this system's success lies in its use of distributed hash tables (DHTs). Eventually, the data is consistent while also assuring its secure transmission over the network. Each peer is held responsible for his or her conduct in this manner. An efficient architecture ensures that overhead is kept to a minimum. Mobile phones and other gadgets can really join the network and increase processing capacity.

The Key components and taxonomy with the Holochain Architecture are:

- Application (Nucleus)
- Shared storage (DHT)
- Source Hash Chain

A. HOLOCHAIN APPLICATION

The heart of the concept revolves around the concept of application. It serves as the glue that holds the rest of the network together. A browser may be used to access an application, and the UI is determined by the developer [21]. This app can access and save data from the DHT as shown in figure 2 and 3. Additionally, it may make use of its own in-house hashing system. No data may be tampered with, edited, or lost because the application provides the validation rules. Lisp and JavaScript are the programming languages of choice for the majority of the apps as the new version of Holochain the primary "Ribosome", where there

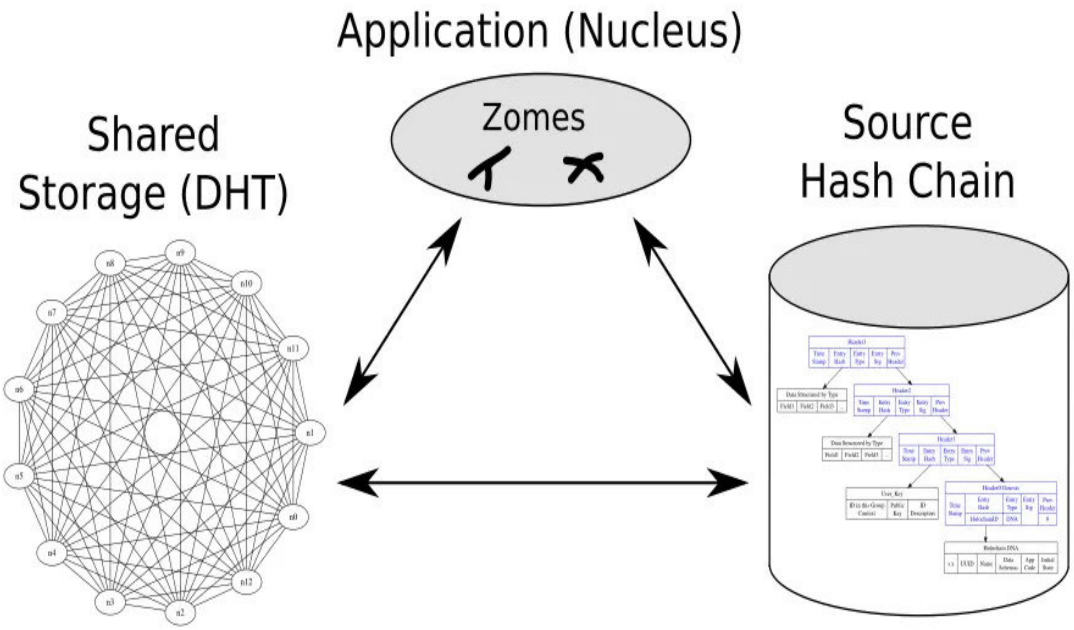

FIGURE 2. Architecture of holochain.

was a JS one and Lisp one before, interprets WebAssembly code.

B. SOURCE HASH CHAIN FOR THE ORIGINAL DATA

In order for the programme to function without an internet connection, the source hash chain must be used. Peer-to-peer or person-to-person ledgers can be owned by each user. Before it can be integrated with the global shared DHT, the data in the local chain must be signed [22], [23], [24].

Both parties must first validate the transaction to their own source chain before integrating it into a common distributed hash table (DHT) [25], [26]. This is a ground-breaking concept, given that not everything necessitates agreement. Using a social media Holochain app eliminates the requirement to confirm every single validation with the whole peer group. In most cases, local validation suffices, which may subsequently be shared with the global DHT [27].

Holochain would not be viable without the last component, DHT. DHT is already widely utilised in BitTorrent and other file-sharing apps. Peers use a cryptographic hash to verify their own data in a distributed hash table (DHT). A digital signature is used to verify that each piece of data has been successfully added to the local chain.

DHT also enables multi-party transactions. As a result, a chain crossing is created, which aids in the verification of the entire set of transactions. The transactions are now genuine since they can be seen by others. The network invalidates transactions if the hash value does not match during chain crossings. Meta-data is widely utilised to increase speed. For constructing peer-to-peer applications, Holochain is a free open source framework.

The applications built on holochains may be used in a variety of ways and are more efficient than blockchains (no token or mining required) [28]. Because of Holochain, humans will be able to engage with each other without depending on any authority to define or unilaterally modify the rules that govern their interactions with each other. In a peer-to-to-peer environment, the developers can retain ownership and control of data since no third party (such as a Google or Facebook employee) collects, sells, or otherwise disposes of it [29], [30].

The ownership of the data also allows to go farther in terms of user control, allowing to do more with data. Composable and adaptable apps may be created when users are at the centre of the design process. Holochain, on the other hand, does not need the use of currency, although it works best when issuance is facilitated by the acts of peers (like ratings) or when double-entry bookkeeping is used.

Holochain may also be used for the following purposes: noitemsep

- Facebook, Twitter, and other social networks like media sharing networks, review networks and many more.
- Logistics networks
- Cooperatively owned versions of Uber and Airbnb, as well as rating systems and reputational currencies
- The power of a unified systems (governance, feed-back systems, workflow, discussion boards, wikis, scheduling)

C. DECENTRALIZED DATA INTEGRITY

There are a number of misapprehensions regarding blockchain technology that would need to be dispelled in

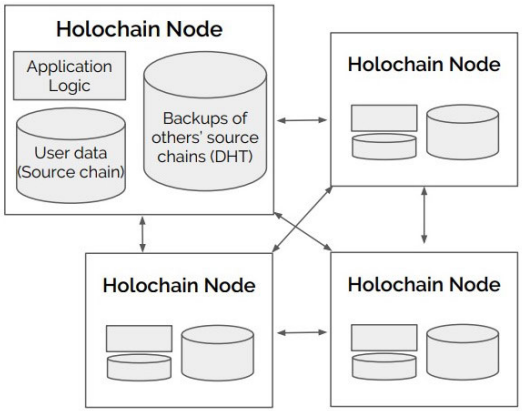

FIGURE 3. Flow of data in holochain nodes.

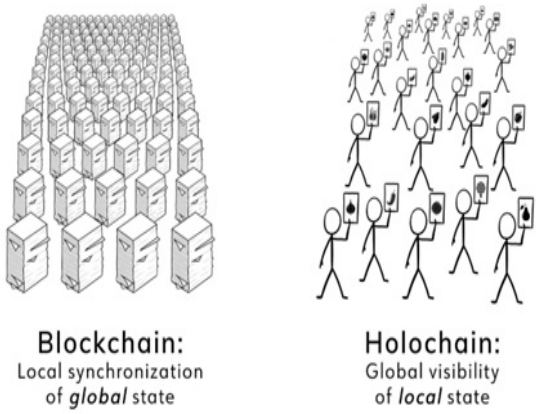

FIGURE 4. Global and local state in technologies.

order to provide a comprehensive introduction to Holochain as well as blockchain technology in general [31], [32]. When it comes to decentralized computing, ensuring that data is correct and free of tampering is a crucial problem, and this paper focuses on how each system addresses this problem as shown in figure 2.

The various properties are compared with respect to holochain and other technology and is shown in Table 2 [13], [15], [16]. The analysis shows us that the holochain follows all kinds of environment and architectures when it is compared with other technologies such as holochain, hashgraph, blockchain, ethereum, Tezos and IOTA. Table 2 shows that the properties such as decentrailized architecture, dApp environment, secure hash chains, Application level Data Integrity, Smart Contrats, Custom data Validations and so on are enabled in holochain technology, whereas these properties are somewhere enabled in other technologies like hashgraph, blockchain. Ethereum, tezos, IOTA and somewhere it is not. Few of the advantages of holochain are as under which offers few benefits that recognize it from conventional blockchain innovations:

- Scalability: Holochain is intended to be profoundly adaptable. Unlike blockchain, where each member cycles and stores each exchange, Holochain empowers disseminated applications to scale on a level plane by permitting every member to keep up with their free chain. This design lessens the generally computational and stockpiling necessities, empowering effective scaling as the organization develops [33], [34].
- Performance: Because of its appropriate and specialist-driven engineering, Holochain offers further developed performance contrasted with customary blockchains. By killing the requirement for worldwide agreement and empowering nearby approval of exchanges, Holochain can handle interactions quicker, prompting decreased inactivity and higher throughput.
- Efficiency: Holochain is asset productive concerning figuring power, stockpiling, and energy utilization. Every member just cycles and stores the data pertinent to their connections, diminishing the overt repetitiveness and above related with customary blockchain frameworks. This efficiency makes Holochain reasonable for asset-compelled conditions and devices.
- Data Ownership and Privacy: Holochain stresses individual data ownership and privacy. Members in a Holochain network have complete command over their data and can figure out who can get to and communicate with it. This approach aligns with self-sovereign character standards and enables clients to keep up with command over their data [35], [36].
- Flexibility and Customization: Holochain gives a flexible structure that permits designers to construct decentralized applications (dApps) custom-made to their particular use cases [37], [38]. It offers many instruments and libraries for application improvement, empowering customization and flexibility to various businesses and necessities.
- Interoperability: Holochain can work with interoperability between various applications and organizations [39]. Holochain considers consistent joining and correspondence between dApps by utilizing open principles and conventions, empowering the trading of data and administrations across different stages [40].
- Sustainability: Holochain advances sustainability by diminishing the ecological effect related to customary blockchain frameworks. Its proficient asset usage and energy-saving plan add a more eco-accommodating way to deal with decentralized innovation [41].

These benefits cause Holochain an appealing choice for building decentralized applications and frameworks that focus on scalability, performance, efficiency, data ownership, privacy, flexibility, and sustainability.

III. HOLO ROADMAP

The Holo Roadmap Milestone's types are described in two ways:

A. INFRASTRUCTURE ROADMAP

The Beta release of Holo will not be possible without achieving both the Infrastructure and the Application milestones.

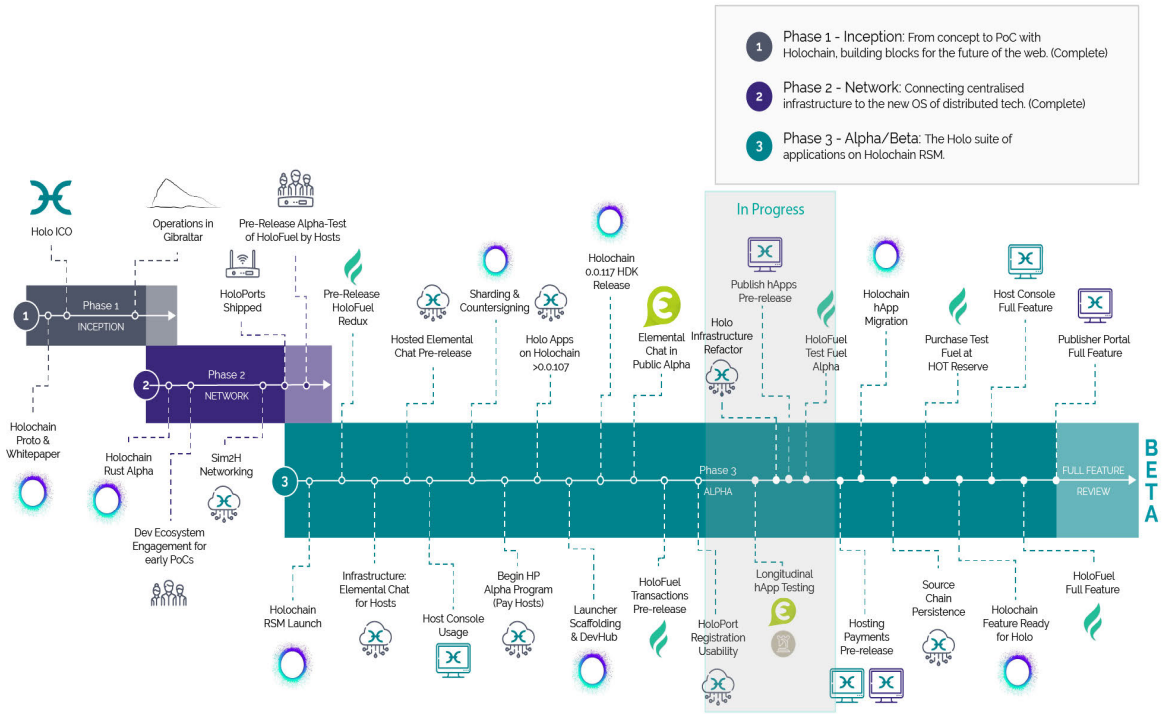

FIGURE 5. Holo's roadmap [20].

Those deliverables that affect the Holo network end-to-end functionality are referred to as ''Infrastructure Milestones.'' It was an infrastructure milestone to get the first hosted Holochain application to function on the Holo network because it was more about testing the layers of networking required to make it work than about the application itself [42], [43]. This was true for both hosts operating Elemental Chat as well as regular web users. Additionally, the Holochain features that are still under development are going to be supported by additional infrastructure milestones in the Holo roadmap. Our recent effort includes updating all Holo applications to function with the most recent ''sharding ready'' version of Holochain. This major change necessitated extensive testing before it could be released to the public. It expands the number of people who can utilise hosted Holochain applications from the hundreds that were previously supported to thousands [44], [45].

B. APPLICATION ROADMAP

Application Milestones are a second class of milestone. HoloFuel hosts, publishers, and consumers need these features and services of the Holo suite of applications. Holochain backend software (DNAs) and a number of linked business services are both reliant on these front-end user experiences.

The Roadmap of holo is shown in figure 5. The figure 5 is catagorised into three phases: noitemsep

- Phase 1- Inception: From Concept to Proof of Concept(PoC) with Holochain building blocks for the future of the web.
- Phase 2- Network: Connecting centralized infrastructure to the new operating system of distributed technology.
- Pahse 3- Alpha/Beta: The Holo suit of applications on Holochain Refactored State Model(RSM)

Since the initial coin offerings (ICO) in April 2018, phase 1 of inception has been successfully completed. Phase 2 of infrastructure advanced to the extent that another 500 HoloPorts will be delivered to expand the network and perform pretests in further phases. All Holoports are sold out at the moment and you have to get on a waiting list to buy the next batch [46], [47]. Recently, in phase 3, they hosted Elemental Chat where users can create channels and join group discussions was brought into alpha testing where we are now on the roadmap. A further step will now be that more HoloPorts will be delivered and it will be possible to participate in testing and future hosting even without specific hardware like the HoloPort. After that, the HoloFuel registration will be carried out, where the ERC-20 HOT tokens will be exchanged for HoloFuel. Once HoloFuel works and an application for it is available, demand may increase [48], [49].

C. EVOLUTION OF HOLOCHAIN AND DEVELOPMENT TIMELINE

This project is launched in 2016 by Coders Arthur Brock and Eric Harris-Braun launched the project in 2016. In today's

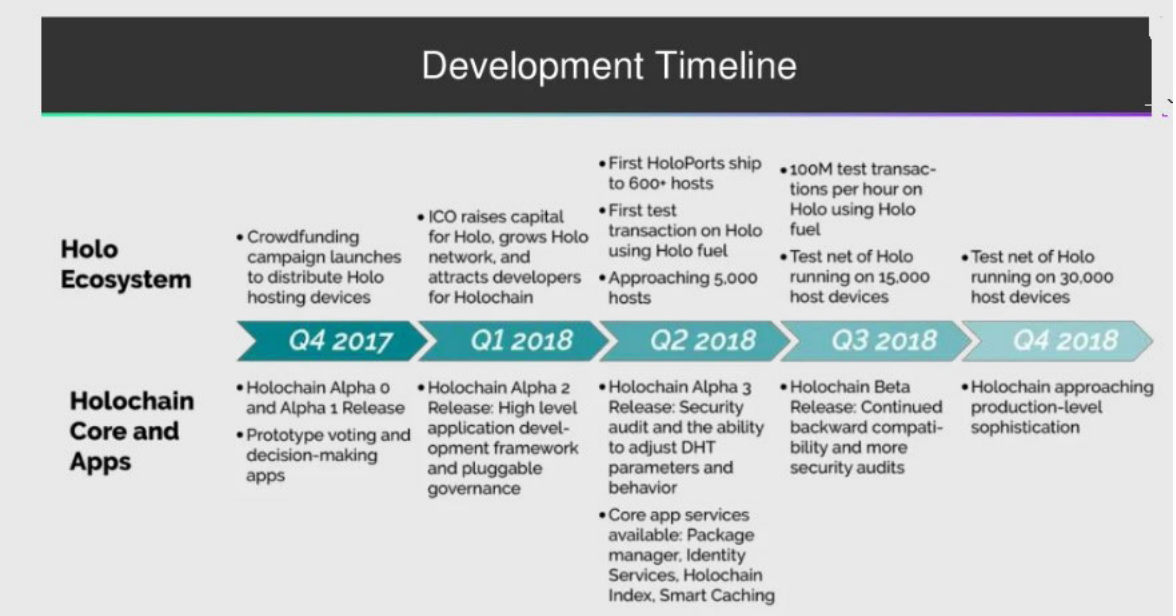

FIGURE 6. Development timeline.

TABLE 3. Holochain price predictions by experts.

Year	Holo Price Prediction
2022	HOT Forecast up to $0.00856
2023	HOT Forecast up to $0.00972
2024	HOT Forecast up to $0.01218
2025	HOT Forecast up to $0.0142

world, Holo is considered as the internal credit unit which permits agents to share the spaces for hosting with another agents which are involved in the same area. This was not considered as competitive technology till the validation of hash tables is done by US Patent and Trademark Office which are known as Distributed Graph Database. This lead to the commencement in the rise of holochain targeting to achieve a novel standard peer to peer economy [50].

With period of time the number of contributors and stakeholders constantly increases as most of people have understood that Holo is that kind of technology which converts their computers into source of income. Therefore, tokens are now available on most of plateform like Hotbit, Binance, Bitrue, and others [51].

The popularity of Holo is not a short term rise in world. On the other hand Holochain is expanded the various amount of projects which are possible to make. The holochain predictions of holochain by experts are shown in Table 3 and the deveopment timeline is also shown in figure 6.

D. HOLOCHAIN CORE ROADMAP

Until now, Holochain has never had a publicly defined roadmap; we instead simply highlighted a few key milestones on Holo's roadmap. That said, we have completed a lot of amazing work on the latest rust version of Holochain. The highlights are the Holochain RSM Launch and the subsequent 0.0.100-alpha.1 release incorporating developer feedback, countersigning for multi-party coordination, a sharded Gossip MVP implementation, the user-friendly launcher, a graphical Scaffolding Tool for rapid application development, and an Expanded HDK feature set including countersigning and many others [52]. The new Holochain roadmap milestones, descriptions of the milestones, and why each matter in the bigger picture framework are mentioned below:

1) SHARDED GOSSIP

It is performant, resilient and that works well at any scale. This will allow all peers to quickly come to consistency regardless of the number of peers in a DHT.

2) IMMUNE SYSTEM / WARRANTING

Its peers on the DHT which could generate warrants for inacceptable data or behavior of bad network, and it broadcast them, and give reply to them by taking protective action against unfair peers. It is required because Holochain does not have a consensus mechanism that incentivises good behavior through threat of economic loss. Instead, we've opted for a more nimble, adaptive approach — warrants are a low-level mechanism in Holochain that use peers in the network to validate the integrity of entries. It's why we call Holochain an integrity engine. When an entry is warranted, it means that another peer in the app has identified that a user's source chain has broken the rules of the application and that the data on the chain is invalid. We call it an immune system because

it is always on the ready and working in the background to protect everyone in the application network. It automatically empowers peers to recognize and neutralize threats in a distributed way.

3) HOLOCHAIN RESOURCE LOCATORS

There is a clear and universal format for storing references between distributed hash tables(DHTs), to and from private data on user chains, any type of DHT hash (including headers), and external resources.

4) HDK 0.1.0 - STABLE FOR CODING & VALIDATION

A developed version of the Holochain Developer Kit (HDK) is free, measured stable and is well-formulated. It is required because The release of the first stable Holochain Developer Kit (HDK) 0.1.0 will essentially be two distinct HDKs— a minimal, frozen ''Integrity HDK'' and a ''Coordination HDK.'' This is an important milestone for production-ready hApps. It means that developers can split their hApp's code into two pieces — 'integrity' code that defines the 'rules of the game' and remains stable over long periods of time, and 'coordination' code that reads, writes, and transfers that data and can be iteratively changed without forcing a migration on users. As core developer David Meister says, this ''should make it much easier for teams to keep their code running for long periods while still performing maintenance and feature upgrades.''

5) SECURITY HARDENING

A more protected type of Holochain that includes progressive protocols of network security and known as Holochain security vulnerabilities. It is required because Security matters, obviously. By making sure Holochain is secure, it will make the framework adoptable by a wider range of projects because it will give risk-conscious developers and organizations the confidence they need to move their apps to Holochain.

6) OPENING & CLOSING CHAINS FOR APP UPDATES

The HDK (Holochain Developer Kit) provisions create both inaugural and concluding source chain entries that mark the start and end of an agent's participation in a network and point to their novel presence in other network. It is required because In a typical web application or platform, changes to code happen all the time and these changes are easily deployed to all users. It works because the data and the code are segregated. With Holochain, data and most of the critical business rules are combined. The combination is what makes Holochain a data integrity engine, one that works peer-to-peer and with validity. It's also what makes updates to applications challenging. This milestone is the first step towards robust migration support—where the user source chains can be marked as closed in an old version of the app and they can point to a new source chain that is compatible with the newer version of the application.

7) LARGE SCALE TESTING FRAMEWORK

It is required because this was widely seen by the dev team as one of the most important milestones. Our current testing tools, Tryorama and TryCP, won't work for large-scale testing due to single-machine bottleneck. The developer community is excited too: as application and tool developer Guillem Cordoba says: ''It would allow unify to actually see the problems that their app has. Then, when the problems are identified, they can ask for help from the community, figure out which libraries have already been written to address their use-case. So it enables a much richer feedback-loop and learning patterns.''

8) HOLOCHAIN BETA RELEASE (v0.1.0)

A version of Holochain is stable, secure, and usable by all (devs, hApp end-users, etc.) It is required because This release is less about introducing new features and more about putting an official stamp of maturity on Holochain. As with the Security Hardening milestone, this will signal to mainstream devs and organizations that Holochain is capable and ready for them to build production applications that they can trust will work.

9) EPHEMERAL STORE

The data that is not intended for permanent addition to a chain or DHT has a temporary home. Why it matters: Holochain is meant for recording permanent data, but a lot of data that makes an application feel 'alive' — status indicators, notifications, 'most recently used' lists, typing indicators, and real-time document edits — isn't worth keeping forever. This feature creates a separate data store on top of the DHT for data with finite lifetimes

10) MERKLE TREE ENTRIES

It has ability to structure private entries as Merkle trees and purposely expose various fields using Merkle proofs. It is required because Often, when a third party is asking for a little bit of your personal information, it's not necessary for them to actually see it all (although they might want to). Your driver's license is a good example: you might want to use it as proof that you're old enough to enter a night club, but the night club doesn't need to know where you live. A Merkle tree would let the driver's licensing office create a digital signature for all your license data in a way that lets you reveal and prove your age without revealing your street address.

11) CLONABLE DNAs IN hApps

The capability to spawn a novel isolated network from a template DNA packaged in a hApp at any point after installation. It is required because In many applications, you're able to create separate spaces and assign different memberships and privileges to each of them. Clonable DNAs will allow applications to create a private chat among four teammates, a subscribers-only blog, a document with restricted access, or a temporary throwaway upload folder.

12) PUBLIC/SUBSCRIBE SYSTEM

Here the event listener hierarchy subscribe to notifications of particular DHT changes. It is upstream dependent on the Ephemeral Store for subscriptions tracking. It is required because Developers can already use signals to send ephemeral messages between peers. This is often used for events that update users on the status of a process, such as a new message notification or a request to acknowledge a transaction. But a lot of these messages mimic DHT gossip that's already happening. Pub/sub allows an agent to subscribe directly to these 'subconscious' messages and take action or update the user's UI immediately. This saves work for the developer.

13) ATTACK FACTORY

It is the compilation of known attacks or vulnerabilities. We can run our hApp through the Attack Factory for identifying vulnerabilities in the hApp. It is required because Security is always a combo of the framework/language/infrastructure being used and the way the application is built. The Attack Factory will clearly indicate the kinds of risks to watch for using Holochain and Holo and allow apps to test for these. It might also indicate the kind of things that are typically issues for blockchains but are less problematic using Holochain and Holo.

IV. CONSENSUS AND THE BLOCKCHAIN

Decentralized, cryptographically secure data ledgers are known as blockchains. It's possible to imagine a blockchain as a record of events: the things people said, who agreed to what, who paid money to whom, and so on, and so on. These kinds of documents were often kept in centralized databases, such as those owned by government agencies or private enterprises, prior to the invention of blockchain. Blockchain was designed to allow individuals to communicate and do business without having to rely on third parties, such as banks and credit card companies [53].

In other words, the integrity of the data is ensured by the fact that the data is not only cryptographically secured but also duplicated to many distinct computers (referred to as nodes). Only when a large number of nodes agree that a piece of data is factual can it be added to the record. For someone to edit the record, they would have to not only defeat cryptographic barriers but also alter most of the copies that are floating about - a very difficult operation. Every blockchain has its own unique consensus mechanism for nodes to establish a 'consensus' on what data should be committed to the record, although there is usually some sort of rivalry among nodes to publish the next chunk of entries, or 'block,' to the chain. In the end, the victorious node is chosen at random, thus consensus isn't precisely what it is in the real world. In any event, the blockchain nodes agree on a global state of data, where each node has a copy of the same information [28].

TABLE 4. Supply information of HoT token.

Circulating supply	177.62 billion HOT
Total supply	177.62 billion HOT
Issuance Blockchain	Ethereum
Ethereum contract address	0x6c6ee5e31d828de241282b9606c8-e98ea48526e2

TABLE 5. Value statistics.

Market cap	$ 461.76 million
Price to BTC	0.000000086 BTC
Fully diluted market cap	$ 461.76 million
24h volume	$ 969,403
Price to USD	$ 0.00260

The supply information of HoT token is shown in table 4. As a result, the issue of scalability arises: writing and storing the same data on all nodes demands a significant amount of computer power. While the Bitcoin network processes just only few transactions per second, the Ethereum network is already capable of processing hundreds of transactions per second. Some transactions might take as long as an hour before they are verified by the system [54]. Even Nevertheless, the accomplishments of blockchain are not to be taken for granted. Unlike any previous ledgering or value-storage system, this one is impervious to tampering, and as a result, it is revolutionizing world banking.

The statistics of values are shown in Table 5 w.r.t to its market cap $461.76million, price to BTC is 0.000000086 BTC, fully diluted market cap is $461.76 million, 24th volume is $969,403 and the price to USD is $0.00260.

The evaluation metrics of technologies are shown in Table 6. The Table is catagorised into some parameters such as Metrics(such as Blockchain-PoS,Blockchain-PPoS,Blockchain-PoW, DLT – Hashgraph,DLT – Holochain, DLT – Tangle, DLT – Tempo), Usage of Storage, Scalability, Energy Consumption, Throughput. The various statistics for the evaluated metrics of technologies are delibrated in table 6.

V. HOLOCHAIN AND EMBODIED LOCAL STATES: COMPARATIVE ANALYSIS

The users could save a lot of time and effort by not having to perform as much bulk replication. To maintain data integrity, we'd have to go about it in a certain way. In order for the network to be entirely secure, there is need to be absolutely sure that no one could falsify their data. Holochain does this in its simplest form. In a decentralized application, it is impossible to trust anybody but the users themselves to maintain the integrity of the data. Skeptics typically arise at this stage in the discussion among those who are knowledgeable with blockchain technology [55].

TABLE 6. Evaluation metrics of technologies.

Parameters	Usage of Storage	Scalability (number of nodes)	Energy Consumption (J per transaction)	Throughput (transactions per second)
Blockchain – PoS	High	∼10.000 nodes	1000 J/transaction	∼25 tps
Blockchain – PPoS	High	500.000 nodes	∼30 J/transaction	∼10000 tps
Blockchain – PoW	High	∼10.000 nodes	∼1 billion J/transaction	∼7 tps
DLT – Hashgraph	Moderate	Theoretically Unlimited	3600 J/transaction	∼250.000 tps (Theoretically) ∼10.000 tps (recent practical result)
DLT -Holochain	Low	Theoretically Unlimited	325 J/transaction	Theoretically Unlimited
DLT -Tangle	Moderate	Theoretically Unlimited	3.6 J/transaction	∼500 tps
DLT -Tempo	Low	Theoretically Unlimited	N/A (Considered very low)	∼1.400.000 tps

TABLE 7. Performance scoring levels of blockchain (PoW, PoS, PPoS) and DLTs.

Parameters	Throughput (transactions per second)	Level of Storage Requirement	Scalability (number of nodes)	Energy Efficiency (J p/tx)
DeFi	Low	DC	Moderate	Moderate
NFT	Low	DC	Low	DC
Supply Chain	Moderate	High	Moderate	DC
Land Registry	Low	Moderate	Low	DC
Crypto Currency	Low	DC	Low	DC
Health Records	Moderate	High	Low	DC
Digital ID	Moderate	Moderate/High	DC	DC
Insurance	Moderate	Low	Low	DC
Electronic Voting	High	Moderate	High	High
Energy Trade	Moderate	Moderate	High	High
DFS	High	High	Moderate	DC
Digital Notary	Low	High	Low	DC
AI/FL	Moderate	High	Moderate	DC

When it comes to decentralized applications, Holochain believes that it is equally superfluous for all nodes to retain a record of everyone's state or for nodes to come to agreement before a user commits to changing their own record. As long as the data structure remains impenetrable, the local representation of state can function as its own authority. All data that is exchanged must be traceable back to the source in order to ensure that it is only used for larger-scale coordination. Because the users (agents) essentially are the main reference in Holochain, it is an operator system for decentralized computing.

A distributed hash table or DHT is used to store data that has to be accessible to the network. A collaborative document editor, an Uber-like service, or a Twitter-like app's tweets and comments are all stored on the DHT. In addition to holding their own data, each Holochain app user retains a little slice of the DHT.

Despite the fact that some of these entries may or may not have been published to the DHT, the headers, which include the hashes, are shared to the DHT in all circumstances. That is to say, even if the contents of a particular diary page have not been made public, the fact that I wrote on it and the unique fingerprint that it contains have both been made public. The majority of blockchain's scalability issues stem from a lack of global consensus. Because Holochain does not require consensus to ensure data integrity, it does not have the same problems [56].

There's no need for everyone to agree on everything. All nodes would have to come to terms with each other and retain a record of our transaction forever if this were a blockchain. After that, we post the data to the DHT and store it in randomised groups of nodes so that others can verify our state representations properly in the future if necessary. Every atom in the cosmos, like every cell in our body, relies on party-to-party data confirmation. In order to achieve global consensus, no more compute is necessary beyond this one feature [13]. The DHT, in contrast to a blockchain, replicates each set of data only as many times as necessary to ensure that the data needed is always available, even if the creator is offline. Holochain has a maximum of a few hundred replications, whereas blockchain might have hundreds or even tens of thousands. The performance scoring levels of Blockchain (PoW,PoS,PPoS) and DLTs are illustrated in Table 6. Here various financial services/ unique tokens/ other parameters are catagorised on the basis of throughput, level of storage requirement, scalability and energy efficiency. All these are catagorised on the basis of Low, High, Moderate or DC. As a result, each user contributes a modest amount

TABLE 8. Prominent applications and use cases based evaluation.

Parameters	Holochain	PoW	PPoS	Tempo	Hashgraph	Tangle	PoS
Crypto Currency	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
DeFi	Enabled		Enabled	Enabled	Enabled	Enabled	
NFT	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Digital ID	Enabled		Enabled	Enabled	Enabled		
Supply Chain	Enabled		Enabled	Enabled	Enabled		
Digital Notary	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Land Registry	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled	Enabled
Health Records	Enabled		Enabled	Enabled	Enabled		
Insurance	Enabled		Enabled	Enabled	Enabled		
Electronic Voting	Enabled			Enabled			
Energy Trade	Enabled		Enabled	Enabled			
DFS	Enabled			Enabled			
AI/FL	Enabled		Enabled	Enabled	Enabled		

of extra effort to hold a small section of the DHT, which is carefully spread between all participants in the app [57]. Each script in Holochain has its own DHT, which serves as a common storage area.

Storage and processing power are added to a programme with each additional user. It's not possible to expand network capacity in blockchain applications, since miners and stakers create and store data, therefore increased user interactions increases processing resources. A Holochain app's computational power rises as demand for the service develops, because the software is hosted by its users. Let's take a look at a social networking app like Facebook or Instagram as an illustration of how Holochain and blockchain handle data integrity [54].

Consider the centralised social networks of today as an additional point of comparison. The users can do everything you're used to on this social network, including uploading text, photographs, and videos, as well as leaving comments on others' postings and conversing privately with pals. It's usual today for all of the data to be stored by the platform's owner, including the images, comments, and messages. Because of its centralization, the social network is said to be safe and scalable: the firm accepts responsibility for preserving the network and gets compensated in one or more ways to do so. Despite what these firms would have us believe, our data has been breached far more frequently than we'd like to think, and our personal information is frequently sold to advertising or exposed to unintended third party companies [55].

The mining or stakers administering the blockchain nodes might conceivably host a blockchain variant of a social network. After all nodes agree that the data is authentic, it will be added to the blockchain and copied across all of them, and preserved there for eternity. However, in this case, the data access would be extraordinarily enormous, posing a significant scalability issue [45]. In order to address this issue, several blockchain technologies and blockchain apps attempt to reduce the number of nodes that must come to agreement, or to do much of the processing or administrative work off-chain on centrally-approved servers. The prominent applications and evaluation on the basis of use case is shown in Table 7 with respect to holochain, PoW, PPoS, Tempo, Hashgraph, Tangle, PoS and this table shows that holochain is enabled in all of the promienent applications.

For developers and consumers, Holochain's method for data consistency is enough of a difference from blockchain's to take a few years to grasp its potential, comparable to how it took many years for Ethereum's capabilities to become generally known [56]. Holochain's popularity is expected to rise as additional applications are launched in the months to come [57]. A post-blockchain application sector may seem unusual at a time when blockchain has so much promise for growth. Even if Holochain is prepared to leapfrog over these obstacles, it's possible that it's time to stop thinking in terms of blocks.

VI. KEY APPLICATION CHARACTERISTICS OF HOLOCHAIN

As we require holochains for a variety of reasons, including their use in applications. As a result, the open-source framework approach is unusual in that it aims to bridge the gap between a public and private network. Distributed Holochain applications take advantage of the best of both worlds and can establish own interoperable network for any dApp build on top of the chain [19]. The key application areas of holochain can be considered as secured platform-related apps, Relationship management apps, Social media apps, Collaborative apps, Supply chain-oriented apps, Resource management apps, Reputation systems and moreover few of the importance of holochain in addition to applications are described below: noitemsep

- **Energy Efficiency**: Many resources are required to run today's blockchain platforms. As global warming becomes more of a worry, this might be a serious problem for our world in the long term.
- **Fully Customizable**: Holochain's strategy is to provide each app its own private network. As a result, each network has the opportunity to tailor its configuration to meet its own needs. As a result of the unique methodology, each app has the ability to choose its own protocols, standards, and consensus process. As a result, any program might have an impact on the

network's performance, such as its scalability, latency, or throughput, Resilience, governance, and privacy are a few more important features that may be tailored. There are several advantages of Holochain technology instead of Ethereum, NEO, or any other decentralized software platform.

- **Real Time Secured Connections**: To achieve this, the native Application Programming Interface (API) helps the apps communicate with other API. Secure and interconnected ecosystems may be provided through the API. In addition, the applications can function even if they are disconnected or partitioned.
- **Microservices and Holochain**: Microservices are critical to Holochain's success. To put it another way, this implies each service in an app is a separate microservice. Microservices may be utilized in other applications or ecosystems, which enhances the whole ecosystem. Embracing microservices is now more important than ever before since they are the way of the future [3].

  It's difficult to use or remain with a certain solution in a corporate setting. For the most part, businesses utilize a variety of solutions for each of their several divisions. As Holochain is an open-source framework that provides DLT solutions, it may be utilised for a variety of applications within the same company. The developers have the option to customize the app to meet the needs of the user.

  Holochain technology may be used to entirely replace the present systems. As a result, Holochain technology is a fantastic choice for service providers that want as much flexibility as possible. This will allow them to better provide clients with a wide range of wants and needs.
- **Evolvable**: It is more likely that the microservice method will help the platform grow in the future. It doesn't rely on smart contracts, according to David Atkinson, and that's a good thing. There are a variety of ways that smart contracts might be restrictive. The most significant constraint is the requirement for absolute precision. Initially, Holochain apps do not need to be that precise. A lot of pressure is put on developers who want to get their products out as quickly as possible.

  An appropriate solution for today's rapidly evolving economy is one that can adapt to changing technologies. As a result, it's well-suited to more demanding industries like energy, food, or supply chain management. In other words, a Holochain-built software may grow and change with the needs of the user over time.

  When compared to dApps, programmes built on the secure Holochain architecture are more dependable. For the sake of security, each app is limited to its own ecosystem or network. The limits can be specified by developers [4].

  As a result, data may be exchanged with other applications and networks utilising a more flexible security method. They can use the application development kit given by them to build such rules and get the benefits of their services. It is also capable of handling the required levels of security. Data integrity, tamper-resistance, and authorship evidence are all made possible by the use of cryptography.
- **Scalability**: There's a lot of room for growth with Holochain. The network's processing capacity can rise as additional apps join the network. It benefits from the distinct design it employs. There is computer power available from each node. Rust, a programming language for WebAssembly compilation, is used to make the apps scalable. The number of local peers has an impact on the system's scalability as well. As the number of local peers is expected to be minimal, it means that the network is more robust and tolerant than ever before.
- **Infinite Expansion and Consistency**: There are several circumstances where network capabilities restrict the scalability of digital applications (dApps). In general, Ethereum is a good option, although it's not the fastest. In addition, there is no way to avoid network scalability in the first place. Public DLTs are particularly vulnerable to this. New peers can be added to increase the network's scalability in private networks [5].

  On the other side, Holochain has an obvious advantage here. In the first place, the API allows several dApps to connect with each other, increasing computational capacity. Holochain apps, on the other hand, are likely to be more stable since they have their own local network with pre-defined network requirements.
- **Flexible & Open Source**: As compared to dApps, Holochain apps are better at adapting to changes. The Holochain app architecture is meant to provide developers more control over their local app network. As a result, they are able to configure various network functions, such as scalability and throughput [7].

  In addition, Holochain apps can grow and change over time. Most of the logic for dApps must be predetermined. Once a smart contract is in place, it's difficult to make changes. Since the current developer community supports agile development, this makes life difficult for developers.
- **Functioning Both Online and Offline**: In both online and offline situations, Holochain apps are intended to operate. However, dApps, both private and public, must be connected to the main network in order to function. Real-world activities such as supply chain necessitate working offline and a lack of internet access is not desired.
- **Confidentiality and Security**: In comparison to open dApps, holochain apps provide a higher level of privacy. It has comparable privacy features as private dApps. Additionally, both private dApps and Holochain appear to use the same kind of access restriction. When comparing public dApps with Holochain apps, the difference in access control may be seen.

- **Friendly to Mesh Networks**: It is possible to use Holochain networks in mesh networks. As a result, it can work with any type of wireless signal. In return, the apps are able to connect or disengage from any network signal. The network's genuine versatility comes from its capacity to do so. The only way to do this in dApps is if you're on the same network.
- **Capacity for Modularity**: Holochain apps benefit from modular design more than dApps. Modularity and microservices make it possible to reuse various pieces of the programme to create new solutions. Collaboration and openness are essential for success. Private dApps and Holochain apps benefit greatly from the open-source nature of the platform.

VII. KEY USE CASES FOR HOLOCHAIN

Holochain is a framework that may be used in a variety of ways. In addition, this implies that it may be put to use in a wide range of real-world scenarios. noitemsep

- **Social Networks**: Holochain's best use-case is in social networks. Because a social network may function without being connected and because the user can save a copy of it locally, this is a beneficial feature.
- **Logistics**: A look at Supply Chains Holochain can potentially be a boon to supply networks. Regardless of the organisation, firm, or geographic location, it can give a unique method of managing the supply chain.
- **P2P Systems**: Holochain may be properly utilised by P2P platforms. It may be customised to meet the needs of smaller communities. With the help of Holochain, the P2P platform may also interact with other networks. Building collaborative apps like chats, scheduling, debate, or even wikis is easy with Holochain.
  When it comes to securing the private or confidential data, Holochain isn't the best option. A lot of work is required, whether private or confidential or even anonymous. When used to sync data between numerous devices, however, it can be useful.
- **Enormous Files Handling**: The final use-case for which it is not recommended is for storing large files. Because each peer has a copy of the ledger, the system is more secure. If it is considerable, then the Holochain is rendered useless and the entire process is slowed down to a crawl.
  Holochain Open-source implies that anybody may contribute to the GitHub Holochain framework. Changes to their code must be approved by these nine individuals before they are finalized [8].
  Holochain's core repository, Holochain-rust, has 13,000+ commits and 41 additions. It is actively developed. The whole Holochain project is released under the terms of the GNU General Public License, version 3.0. This is the rust on the Holochain. The rust programming language is used in the basic Holochain framework. It also has a container API for those that need it [21]. A distributed web where users may keep their anonymity is what the future holds for it. Using their protocols and architecture, peers or communities may keep their shared data safe.

VIII. HOLOCHAIN FOR SCALABLE AGRICULTURE LAND RECORDS

Thus the Blockchain technology has its own limitations to scale the business further. It is expensive to implement the replication, checking, and achieve consensus on the transactions [2]. Blockchain also fails to implement a true democratic system, in which each peer wants to have ownership on its data, and processes, while sharing these with other peers completely on their own requirements. Ideally, we should be able to implement the computing paradigm where there is no server handling overhead, bottleneck, and security and privacy issues, rather each peer be able to focus on business application logic. Holochain defines data integrity rules amongst the peers, and peer accountability to isolate the rule-breakers.

A. CHALLENGES IN AGRICULTURE LAND RECORD KEEPING

Agriculture land record keeping is a mammoth transaction activity with mostly manual and non-digital processes. There are many challenges related to Krishi-land transactions such as digitalization of records, simplifying the sale-purchase process, keeping the Krishi-land ledger immutable and secure. The efficient solution of these challenges will help handling the increasing Krishi-land litigation cases, reducing the corruption, improving the quality of farm owner's life etc. The Krishi-land transactions are executed by multiple stakeholders like land, revenue, and forest departments, banks, landowners etc. The process of ownership assignment or ownership transfer gets delayed due to the involvement of multiple stakeholders, and traceability and transparency. These numerous stakeholders are involved in the transactions, so keeping track of deadlines and SLAs is difficult and complex, leading to delay in assigning ownership or transfer of ownership, etc. Any errors in the ledger can affect ownership rights. These manual ledgers and paperwork can be easily forged, affecting the ownership, and leading to boundary or land litigation disputes. In the absence of a will, the partition of property among successors of the deceased owner is again a complex process. Even the validation and verification of forged documents during the process is not an easy task, and it leads to delay due to complexity even it is not accurate.

B. EXISTING SYSTEM

In the traditional methods of land record maintenance, the property ownership is proved though a sequence of documents known as record-of-rights (RoRs) [58]. The RoR-chain is the proof of land transfer from current owner to the next owner. The process of land registration involves an agreement between both the parties involved in property

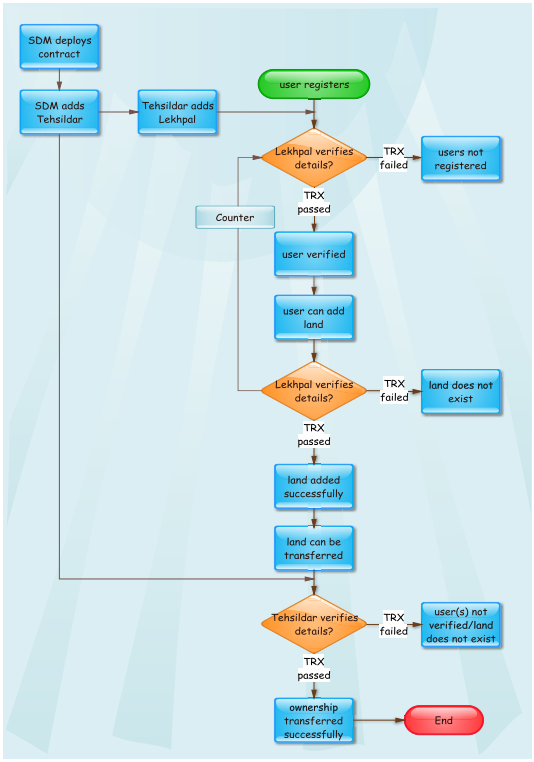

FIGURE 7. Agriculture land records use case.

RoR transfer. As per the Indian central land registration act 1908 [59], the registrar office undertakes the deed registration, and any one of these two parties can be challenged to prove the land ownership. Many types of frauds in property can also happen in the land records. The krishi land records are under the custody of Revenue and Panchayati Raj department. The revenue department approves the transactions initiated by other departments for ownership change due to rent/lease/sale/mortgage/crop update. RoR is also updated by revenue dept. State Laws are applied on Land records keeping. The complete existing land record system is facing the following challenges such as Complex land mutation process, taking benefits of government schemes, the existing system is completely paper based, the citizens at large are not technology-savvy, Bio-metric processing, sale deed preparation, and printing, Large number of land dispute litigation, Channel delay makes the process long, Time and money wastage of farmers, Security of the transactions, and Longer approval process from different stakeholders.

C. HOW HOLOCHAIN CAN HANDLE THESE CHALLENGES?

Multiple vital stakeholders can be on boarded on the chain to share the data through smart contracts over the private channel as and when required quickly. SLA of each stakeholder or department can be tracked easily and made available in a real-time dashboard. A golden record or ownership database can be maintained, accessible to authorized users over the chain to validate the transactions and records. This mechanism can identify fake documents by verifying them against the golden database. The use case and process diagram is as shown in the figure 7.

Dynamic parameters like ownership, mortgage information, litigation status, property tax details, etc., can be easily derived from a tamper-proof master source. Any land dispute associated with boundaries can be immediately flagged in real-time. The sanction of loans against land or property can be facilitated easily and quickly. The allocation process of new lands or property will be more transparent. Transfer of ownership can be done over an immutable platform that can quickly be backtracked and remain tamper-proof. Once land allocation or transfer of ownership is confirmed, it can be approved on distributed ledger where each transaction is signed off with a digital signature, timestamp, and digital key of the user.

D. RELATED WORK ON HOLOCHAIN FOR SCALABLE AGRICULTURE LAND RECORDS

The previous works/case study on holochain for scalable Agriculture Land Records are as under:

1) ''Decentralized Land Organization with Holochain'' by David Atkinson et al. (2019): This paper investigates the execution of a decentralized land organization framework utilizing Holochain. It examines the plan standards, information models, and agreement components utilized to oversee land records professionally and adaptively.
2) ''Holochain-Based Land Records The Board Framework for Smallholder Ranchers'' by Sarah Johnson et al. (2020): This study contextualizes executing Holochain-based land records in the executive's framework for smallholder ranchers. It examines the advantages of involving Holochain in further developing area record openness, straightforwardness, and security for ranchers in a particular district.
3) ''Towards a Blockchain-Based Land Library for Emerging Nations'' by John Smith et al. (2018): Albeit not explicitly centered around Holochain, this paper examines the difficulties of land vault frameworks in emerging nations and proposes a blockchain-based arrangement. It gives experiences into the potential advantages of decentralized advancements, for example, Holochain, in further developing area record the board.
4) ''Blockchain Innovation for Secure and Versatile Farming Area Records'' by Anna Brown et al. (2019): This exploration paper researches the utilization of blockchain innovation, including Holochain, for secure and adaptable horticulture land records on the board. It investigates the upsides of conveyed description innovation in guaranteeing information honesty, diminishing misrepresentation, and expanding straightforwardness in land exchanges.
5) ''Decentralized Land Administration: A Contextual Investigation of Holochain-Based Land Library

Framework'' by Imprint Wilson et al. (2021): This study presents a contextual analysis of executing a Holochain-based land library framework in a particular district. It examines the specialized viewpoints, client encounters, and difficulties experienced during the turn of events and organization of the framework.

These works give experiences into the execution, difficulties, and expected advantages of involving Holochain for versatile horticulture land records on the board. They address different aspects, like information integrity, security, and client encounters. Assessing these connected works can assist analysts with figuring out the current methodologies, recognizing holes, and forming research inquiries for additional examination in this domain.

IX. CONCLUSION

Hashgraph, Tangle, Holochain, and Tempo global ledger technologies are the latest and high performance alternatives to Blockchain. It is imperative that all Blockchain and Decentralized Consensus Technologies guarantee decentralized administration and participant data protection so that participants and peers can deal directly with one another without the need for a middleman. It is clear that the future of mankind will be shaped by a system that is distributed, flat and completely democratic with applications in areas such as financial markets and data storage as well as electronic voting systems and the trade of energy. If distributed ledger technologies are to be widely used, as well as many other essential uses, it is imperative that countries implement the required rules and technical research. As a result of the idea of confidence on peer transactions, Blockchain and Decentralized Consensus Technologies have the capacity to alter most structures that are now under the control of a central authority. In applications with large involvement and transaction volume, blockchain infrastructures are inefficient. These speed and scalability difficulties have prompted the development of brand-new distributed ledger technologies like holochain.

REFERENCES

[1] K. Wahlstrom, A. Ul-Haq, and O. Burmeister, ''Privacy by design,'' *Australas. J. Inf. Syst.*, vol. 24, pp. 1–12, Jan. 2020.

[2] S. Zaman, M. R. A. Khandaker, R. T. Khan, F. Tariq, and K.-K. Wong, ''Thinking out of the blocks: Holochain for distributed security in IoT healthcare,'' *IEEE Access*, vol. 10, pp. 37064–37081, 2022.

[3] V. Mardiansyah and R. F. Sari, ''BCSimMP: A blockchain simulator with mining pool,'' in *Proc. 7th Int. Conf. Big Data Anal. (ICBDA)*, Mar. 2022, pp. 109–114.

[4] G. Yang, ''An overview of current solutions for privacy in the Internet of Things,'' *Frontiers Artif. Intell.*, vol. 5, pp. 1–15, Mar. 2022.

[5] R.-F. Esteban, B.-M. F. Luis, P. Víctor, and M.-M. Valentín, ''Fundamentals of blockchain and new generations of distributed ledger technologies. circular economy case uses in Spain,'' in *Blockchain Technologies for Sustainability*. Cham, Switzerland: Springer, 2022, pp. 25–46.

[6] S. Manski, ''Distributed ledger technologies, value accounting, and the self sovereign identity,'' *Frontiers Blockchain*, vol. 3, p. 29, Jun. 2020.

[7] C. Diallo, ''Opportunities and challenges of IoT security using distributed ledger technology,'' *Sensors Transducers*, vol. 256, no. 2, pp. 27–35, 2022.

[8] A. Tezel, E. Papadonikolaki, I. Yitmen, and M. Bolpagni, ''Blockchain opportunities and issues in the built environment: Perspectives on trust, transparency and cybersecurity,'' in *Industry 4.0 for the Built Environment*. Cham, Switzerland: Springer, 2022, pp. 569–588.

[9] Z. Lin, M. Lin, T. de Cola, J.-B. Wang, W.-P. Zhu, and J. Cheng, ''Supporting IoT with rate-splitting multiple access in satellite and aerial-integrated networks,'' *IEEE Internet Things J.*, vol. 8, no. 14, pp. 11123–11134, Jul. 2021.

[10] H. Niu, Z. Lin, Z. Chu, Z. Zhu, P. Xiao, H. X. Nguyen, I. Lee, and N. Al-Dhahir, ''Joint beamforming design for secure RIS-assisted IoT networks,'' *IEEE Internet Things J.*, vol. 10, no. 2, pp. 1628–1641, Jan. 2023.

[11] Z. Lin, M. Lin, B. Champagne, W.-P. Zhu, and N. Al-Dhahir, ''Secrecy-energy efficient hybrid beamforming for satellite-terrestrial integrated networks,'' *IEEE Trans. Commun.*, vol. 69, no. 9, pp. 6345–6360, Sep. 2021.

[12] Z. Lin, K. An, H. Niu, Y. Hu, S. Chatzinotas, G. Zheng, and J. Wang, ''SLNR-based secure energy efficient beamforming in multibeam satellite systems,'' *IEEE Trans. Aerosp. Electron. Syst.*, vol. 59, no. 2, pp. 2085–2088, Apr. 2023.

[13] *Holo Product Roadmap*. Accessed: May 10, 2023. [Online]. Available: https://holo.host/roadmap/

[14] *Hashgraph Consensus*. Accessed: May 10, 2023. [Online]. Available: https://hedera.com/how-it-works/

[15] *Blockchain Vs Hashgraph Vs Dag Vs Holochain: Types Of DLTs*. Accessed: May 15, 2023. [Online]. Available: https://101blockchains.com/blockchain-vs-hashgraph-vs-dag-vs-holochain/

[16] *An Open, Feeless Data And Value Transfer Protocol*. Accessed: May 28, 2023. [Online]. Available: https://www.iota.org/

[17] E. Harris-Braun and A. Brock, ''Grammatic capacities and the evolution of complex adaptive systems,'' 2018. [Online]. Available: https://docs.google.com/document/d/12Jd7ZeUzT-k6h2Qxw9jmOhNVlkYD1RnO4t2_mp6g4kg/edit

[18] S. Gaba, I. Budhiraja, V. Kumar, S. Garg, G. Kaddoum, and M. M. Hassan, ''A federated calibration scheme for convolutional neural networks: Models, applications and challenges,'' *Comput. Commun.*, vol. 192, pp. 144–162, Aug. 2022.

[19] A. Aggarwal, S. Gaba, and M. Mittal, ''A comparative investigation of consensus algorithms in collaboration with IoT and blockchain,'' in *Transforming Cybersecurity Solutions using Blockchain*. Cham, Switzerland: Springer, 2021, pp. 115–140.

[20] S. Gaba, A. Aggarwal, and S. Nagpal, ''Role of machine learning for ad hoc networks,'' *Cloud IoT-Based Veh. Ad Hoc Netw.*, pp. 269–291, 2021.

[21] M. M. Niranjan, ''Trusted holochain networks,'' Tech. Discl. Commons, May 2022. [Online]. Available: https://www.tdcommons.org/dpubs_series/5138

[22] A. Sharma, S. Gaba, S. Singla, S. Kumar, C. Saxena, and R. Srivastava, ''A genetic improved quantum cryptography model to optimize network communication,'' in *Recent Trends in Communication and Intelligent Systems*. Cham, Switzerland: Springer, 2020, pp. 47–54.

[23] S. Nagpal, A. Aggarwal, and S. Gaba, ''Privacy and security issues in vehicular ad hoc networks with preventive mechanisms,'' in *Proc. Int. Conf. Intell. Cyber-Phys. Syst.* Cham, Switzerland: Springer, 2022, pp. 317–329.

[24] A. Aggarwal, S. Gaba, S. Nagpal, and B. Vig, ''Bio-inspired routing in VANET,'' in *Cloud and IoT-Based Vehicular Ad Hoc Networks*. 2021, pp. 199–220.

[25] A. Aggarwal, S. Gaba, S. Nagpal, and A. Arya, ''A deep analysis on the role of deep learning models using generative adversarial networks,'' in *Blockchain and Deep Learning: Future Trends and Enabling Technologies*. Cham, Switzerland: Springer, 2022, pp. 179–197.

[26] S. Gaba, A. Aggarwal, S. Nagpal, D. Kumar, and P. Singh, ''A forecast of coronary heart disease using proficient machine learning algorithms,'' in *Proc. 6th Int. Conf. Image Inf. Process. (ICIIP)*, vol. 6, Nov. 2021, pp. 517–522.

[27] R. Yellasiri, S. Tiruvayipati, S. Tumula, and K. K. Reddy, ''A peer-to-peer approach for extending wireless network base for managing IoT edge devices off-gateway range,'' in *Smart Intelligent Computing and Applications*, vol. 1. Cham, Switzerland: Springer, 2022, pp. 551–559.

[28] N. Ganesh, N. Venkatesh, and D. Prasad, ''A systematic literature review on forensics in cloud, IoT, AI & blockchain,'' in *Illumination of Artificial Intelligence in Cybersecurity and Forensics*, 2022, pp. 197–229.

[29] D. Aggarwal and S. Gaba, ''A comparative study: Reviewing performance of routing protocols in mobile ad-hoc network,'' *Vol*, vol. 4, pp. 528–532, Mar. 2018.

[30] A. Sharma, S. Gaba, S. Singla, S. Kumar, C. Saxena, and R. Srivastava, *Recent Trends in Communication and Intelligent Systems*. Cham, Switzerland: Springer, 2020.
[31] A. Yadav, S. Gaba, H. Khan, I. Budhiraja, A. Singh, and K. K. Singh, "ETMA: Efficient transformer-based multilevel attention framework for multimodal fake news detection," *IEEE Trans. Computat. Social Syst.*, early access, Mar. 20, 2023, doi: 10.1109/TCSS.2023.3255242.
[32] A. Aggarwal, S. Gaba, S. Nagpal, and A. Arya, "A comparative analysis among task scheduling for grouped and ungrouped grid application," 2021. [Online]. Available: https://ceur-ws.org
[33] M. S. Gaba and R. Kait, "A modified approach to improve security and congestion control in aodv routing protocol against blackhole attack," *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 5, no. 6, pp. 266–272, 2017.
[34] S. Gaba, S. Nagpal, A. Aggarwal, S. Kumar, and P. Singh, "A modified approach for accuracy enhancement in intruder detection with optimally certain features," in *Mobile Radio Communications and 5G Networks*. Cham, Switzerland: Springer, 2023, pp. 149–157.
[35] S. Gaba, I. Buddhiraja, V. Kumar, and A. Makkar, "Federated learning based secured computational offloading in cyber-physical IoST systems," in *Recent Trends in Image Processing and Pattern Recognition*. Cham, Switzerland: Springer, 2023, pp. 344–355.
[36] A. Aggarwal, S. Gaba, J. Kumar, and S. Nagpal, "Blockchain and autonomous vehicles: Architecture, security and challenges," in *Proc. 5th Int. Conf. Comput. Intell. Commun. Technol. (CCICT)*, Jul. 2022, pp. 332–338.
[37] A. Aggarwal, S. Gaba, S. Chawla, and A. Arya, "Recognition of alphanumeric patterns using backpropagation algorithm for design and implementation with ANN," *Int. J. Secur. Privacy Pervasive Comput.*, vol. 14, no. 1, pp. 1–11, Feb. 2022.
[38] V. Rishiwal, O. Singh, S. Tanwar, S. Tyagi, I. Budhiraja, N. Kumar, and M. S. Obaidat, "Base station oriented multi route diversity protocol for wireless sensor networks," in *Proc. IEEE Globecom Workshops*, Dec. 2018, pp. 1–6.
[39] I. Budhiraja, N. Kumar, and S. Tyagi, "Energy-delay tradeoff scheme for NOMA-based D2D groups with WPCNs," *IEEE Syst. J.*, vol. 15, no. 4, pp. 4768–4779, Dec. 2021.
[40] I. Budhiraja, N. Kumar, S. Tyagi, Q.-V. Pham, and S. Tanwar, "Energy efficient mode selection scheme for wireless powered D2D communications with NOMA underlaying UAV," in *Proc. IEEE Conf. Comput. Commun. Workshops*, Jul. 2020, pp. 877–882.
[41] I. Budhiraja, R. Gupta, N. Kumar, S. Tyagi, S. Tanwar, and J. J. P. C. Rodrigues, "Interference mitigation and secrecy ensured for NOMA-based D2D communications under imperfect CSI," in *Proc. IEEE Int. Conf. Commun.*, Jun. 2021, pp. 1–6.
[42] I. Budhiraja, A. Khan, M. Farooqui, and M. Pal, "Multiband stacked microstrip patch antenna for wireless applications," *J. Telecommun.*, vol. 16, no. 2, pp. 925–931, 2012.
[43] I. Budhiraja, N. Kumar, S. Tyagi, S. Tanwar, and Z. Han, "An energy efficient scheme for WPCN-NOMA based device-to-device communication," *IEEE Trans. Veh. Technol.*, vol. 70, no. 11, pp. 11935–11948, Nov. 2021.
[44] I. Budhiraja, R. Kumar, and M. Pal, "Slotted dual arrowhead multiband rectangular microstrip patch antenna," *Int. J. Sci. Eng. Res.*, vol. 3, pp. 758–762, Sep. 2012.
[45] S. Gaba, I. Budhiraja, A. Makkar, and D. Garg, "Machine learning for detecting security attacks on blockchain using software defined networking," in *Proc. IEEE Int. Conf. Commun. Workshops*, May 2022, pp. 260–264.
[46] H. Sharma, I. Budhiraja, N. Kumar, and R. K. Tekchandani, "Secrecy rate maximization for THz-enabled femto edge users using deep reinforcement learning in 6G," in *Proc. IEEE Conf. Comput. Commun. Workshops*, May 2022, pp. 1–6.
[47] H. Sharma, I. Budhiraja, P. Consul, N. Kumar, D. Garg, L. Zhao, and L. Liu, "Federated learning based energy efficient scheme for MEC with NOMA underlaying UAV," in *Proc. 5th Int. ACM Mobicom Workshop Drone Assist. Wireless Commun. 5G Beyond*, Oct. 2022, pp. 73–78.
[48] V. Vishnoi, P. Singh, I. Budhiraja, and P. K. Malik, "Multiband dual-layer microstrip patch antenna for 5G wireless applications," in *Proc. 3rd Int. Conf. Comput., Commun., Cyber-Secur.* Cham, Switzerland: Springer, 2022, pp. 85–93.
[49] I. Budhiraja, V. Vishnoi, N. Kumar, D. Garg, and S. Tyagi, "Energy-efficient optimization scheme for RIS-assisted communication underlaying UAV with NOMA," in *Proc. IEEE Int. Conf. Commun.*, May 2022, pp. 1–6.
[50] V. Vishnoi, P. K. Malik, I. Budhiraja, and A. Yadav, "Deep reinforcement learning based throughput maximization scheme for D2D users underlaying noma-enabled cellular network," in *Advanced Computing*. Cham, Switzerland: Springer, 2022, pp. 318–331.
[51] I. Budhiraja and D. Garg, "Alzheimer's disease classification using transfer learning," in *Advanced Computing*. Cham, Switzerland: Springer, 2022, pp. 73–81.
[52] M. A. Khan, M. Farooqui, and I. Budhiraja, "Performance analysis of SFBC-OFDM system with frequency domain equalization," *Int. J. Sci. Eng. Res.*, vol. 11, pp. 1–5, Nov. 2012.
[53] A. Banerjee, B. Dutta, T. Mandal, R. Chakraborty, and R. Mondal, "Blockchain in IoT and beyond: Case studies on interoperability and privacy," in *Blockchain based Internet of Things*. Cham, Switzerland: Springer, 2022, pp. 113–138.
[54] M. A. Al Mamun, "Real-time integration of IoT sensor and IOTA tangle for securing IoT infrastructure," M.S. thesis, 2022.
[55] N. Deepa, Q.-V. Pham, D. C. Nguyen, S. Bhattacharya, B. Prabadevi, T. R. Gadekallu, P. K. R. Maddikunta, F. Fang, and P. N. Pathirana, "A survey on blockchain for big data: Approaches, opportunities, and future directions," *Future Gener. Comput. Syst.*, vol. 131, pp. 209–226, Jun. 2022.
[56] N. M. Denter, F. Seeger, and M. G. Moehrle, "How can blockchain technology support patent management? A systematic literature review," *Int. J. Inf. Manage.*, vol. 68, Feb. 2023, Art. no. 102506.
[57] T.-M. Choi and T. Siqin, "Blockchain in logistics and production from blockchain 1.0 to blockchain 5.0: An intra-inter-organizational framework," *Transp. Res. E, Logistics Transp. Rev.*, vol. 160, Apr. 2022, Art. no. 102653.
[58] V. Thakur, M. N. Doja, Y. K. Dwivedi, T. Ahmad, and G. Khadanga, "Land records on blockchain for implementation of land titling in India," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101940.
[59] S. Goel, "The registration act, 1908: Critical analysis of the 1908 act," *SSRN Electron. J.*, vol. 10, pp. 1–19, Oct. 2016.

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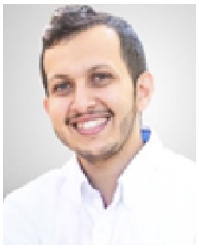

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