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Review Article

Security and QoS issues in blockchain enabled next-generation smart logistic networks: A tutorial

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A B S T R A C T

The blockchain-enabled smart logistics market is expected to grow worth USD 1620 billion and at a compound annual growth rate of 62.4%. Smart logistics ensures intelligence infrastructure, logistics automation, real-time analysis of supply chain data synchronization of the logistics process, cost transparency, unbroken shipment tracking all the way down to the transportation route, etc. In the smart logistics domain, significant advancement and growth of the Internet of Things (IoT) sensors are evident. However, the connectivity of IoT systems, including Tactile Internet, without proper safeguards creates vulnerabilities that can still be deliberately or inadvertently cause disruption. In view of this, we primarily notice two key issues. Firstly, the logistics domain can be compromised by a variety of natural or man-made activities, which eventually affect the overall network security. Secondly, there are thousands of entities in the supply chain network that use extensive machine-learning algorithms in many scenarios, and they require high-power computational resources. From these two challenges, we note that the first concern can be addressed by adding blockchain to IoT logistic networks. The second issue can be addressed using 6G. This will support 1-μs latency communications, support seamless computing at the edges of networks, and autonomously predict the best optimal location for edge computing. Motivated by this, we have highlighted motivational examples to show the necessity to integrate 6G and blockchain in smart logistic networks. Then, we have proposed a 6G and blockchain-enabled smart logistic high-level framework. We have presented the key intrinsic issues of this framework mainly from the security and resource management context. In this paper, recent state-of-the-art advances in blockchain enabled next-generation smart logistic networks are analyzed. We have also examined why 6G and not 5G would be compatible with the smart network. We have introduced five different use cases of blockchain technology in smart logistics. Later, this paper discusses some important concerns that blockchain in smart logistics might face. We have also provided potential solutions to tackle these concerns.

1. Introduction

It is evident that delivering essential services that are crucial to our way of life, such as electricity, communications, transport, banking, etc., we are now more reliant on smart sensor technology or Internet of Things (IoT) technology [1–3]. Critical infrastructure is becoming increasingly interconnected and interdependent, resulting in efficiency improvements and cost savings. Automation in transport and logistics is not a new phenomenon. With the rapid pace it is growing and with Industry 4.0, we call it smart transportation and logistics [4,5]. In particular, smart logistics makes supply chains more effective and efficient at each step. Smart logistics enhances the way organizations transport goods, handle inventory and mobility assets, restock stock, and manage the retail experience by bringing end-to-end visibility and using connected devices in the supply chain and intelligent asset tracking technologies. Sensor-driven asset tracking technologies, for example, can provide insight at each stage of shipment, tracking moisture, heat, and vibration to provide businesses with real-time visibility as a product moves through the supply chain [6].

As per the Australian Industry Standard report, *"the Transport and Logistics industry in Australia has an estimated annual revenue of $96.65 billion, adding $39.95 billion to the Australian economy in 2017"* [7]. The

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key driving force behind this is IoT-based smart network deployment in the supply chain (transportation and logistics sector). For the global logistics industry, it is forecasted that up to USD 2.5 trillion of additional value will be generated by the IoT by 2025. Although the significant growth of this sector has been seen, at the same time, this has pushed researchers to identify novel promising innovations across (a) IoT security environments and (b) effective resource utilization in order to enhance network security and transparency as well as to make resource utilization strategies effective for the supply chain systems.

Security perspectives. On the one hand, we have seen a tremendous growth in IoT sensor-based supply chain networks, but on the other hand, we have seen many adverse scenarios that urge us to rethink the design of sensor-enabled autonomous supply chain networks. Recent events, such as compromises of the Australian parliamentary network, university networks, and major business entities; natural disasters; and the effects of COVID-19, show that threats to the operation of Australia's critical infrastructure entities remain serious. Key supply chain businesses transporting groceries and medical supplies have also been targeted [8, 9]. Now, to strengthen the supply chain networks, it is expected that the future smart supply chain will consists of key features such as sustainability, traceability, and high levels of safety and effectiveness. To integrate these features into smart logistics, researchers note that blockchain technology is a promising approach. Using blockchain, the supply chain would get rid of the manual process and paperwork mandated by the authorities. Blockchain technology in the smart logistics industry would track the location of cargo, shipping containers, and trucks in any part of the world. It would further enable the sharing of data among businesses, governments, and other stakeholders in a secure environment. The blockchain-based platform will offer potential as well as add predictability and visibility to the supply chain process, creating a new business model.

Resource utilization perspectives. With the exponential growth of IoT-based smart logistic networks, the demand for wireless capacity will continue to be skyrocketed [10], and the emergence of the Internet of Everything (IoE) in smart systems, connecting millions of people and billions of IoT nodes, demands ultra-reliable low latency communication (URLLC) [11]. To this end, researchers argue that 6G will be a better platform to connect things to things [12] and machines to machines for ultra-low latency communications [13]. It is arguable that why not we could be using 5G. Towards the concern, we have highlighted key reasons for the integration of a smart supply chain with 6G in the following section. We have mentioned that there are certain limitations of 5G that have been reported, which would not fully make 5G compatible or suitable with future smart cities or smart networks.

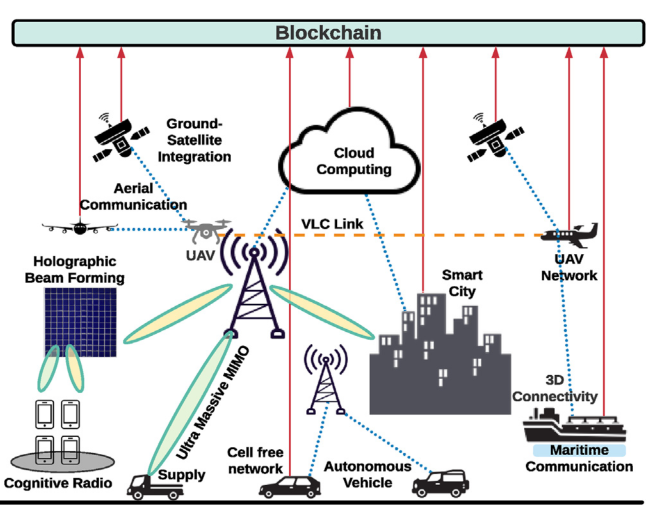


Fig. 1. A high-level view of blockchain-enabled IoT next-generation architecture.

Motivated by this, we observe that there is an urgent need to study the concepts of blockchain and 6G in this sector (as shown in Fig. 1). The key issues, such as security and resource utilization, need further investigation. In this chapter, we have comprehensively provided a synthesis of the existing literature and provided our opinions to address these key issues. Our contributions are as below.

1. We are among the early ones to critically evaluate the needs of the integration of blockchain and 6G in the smart logistics sector.
2. We have comprehensively discussed the security and resource utilization issues in this sector. Given this, we have mentioned a few open issues. A high-level view of addressing these issues is also presented.

In the following sections, Section 2 comprehensively discusses the need for integration of 6G and blockchain in the smart logistics domain. Section 3 highlights the closely related work in this area. A high-level view of the smart logistics sector with Blockchain is discussed in Section 4. Various novel use case scenarios of smart logistics are discussed in Section 5. Following this, the open issues are highlighted in Section 6, and finally, in Section 7, we have summarized this paper.

2. Motivational examples to integrate 6G and blockchain in smart logistics

Because of the above brief discussion of “security perspectives” and “resource utilization issues” of smart logistics, we now present the concepts of integrating blockchain and 6G in smart logistics in more detail.

Blockchain technology is an incorruptible, tamper-proof, democratized, and decentralized system that records an economic transaction. Transactions added to blockchain are time-stamped, so tracing the transactions and products becomes easy. The decentralized nature of blockchain provides high resilience to cyber attacks and vulnerabilities. Blockchain enables the sharing of information using a “distributed ledger” that can be accessed by members participating in blockchain but cannot be updated by individuals without approval from the group. This disruptive technology is being explored among different sectors from the government to intellectual property, financial transactions, transportation, healthcare, election security, energy, education, etc. However, the logistics industry is the biggest killer application. This is because the logistics and freight are highly sophisticated and involve multiple stakeholders and processes with different interests.

It is estimated that over the period of 2021–2028, the blockchain technology in the logistics market is expected to grow worth USD 1620 billion and at a compound annual growth rate of 62.4% [14]. Reasons for this rapid growth are that the world's logistics industry is becoming complex and needs interaction and exchange of information between various stakeholders, such as manufacturers, freight forwarders, warehouses, land transportation providers, government, retailers, ocean carriers, multiple ports, banks, and end-users. With many third-party intermediaries, multiple data exchange and complexity can potentially lead to unclear visibility, increased cyber attacks, and instability of the system. Blockchain has the potential to provide opportunities and benefits for every participant and process in the supply chain and logistics. It allows the organization to trace and track the product's transaction from origin to the destination of the goods along the whole supply chain. Information and data stored in the blockchain are permanent and unalterable, hence, the network becomes more trustful and secure. Therefore, blockchain has the potential to develop communities of trust, provenance, collaboration, and consensus across supply chains.

It is also estimated that by 2023, due to a lack of strong use cases, 90% of blockchain-based logistics initiatives will suffer “Blockchain fatigue” [15]. The reason for the “Blockchain fatigue” is that most of the blockchain projects have remained in the pilot stage due to the lack of standards, the convergence of technology immaturity, the issue of scalability and interoperability, the overly ambitious scope, and the misunderstanding of how technology could help the supply chain management and logistics industry. Stakeholders, organizations, and industries are trying to understand the capabilities of blockchain in logistics, how it can benefit their business, and what problems it can solve.

Tactile Internet for smart logistics. The Tactile Internet is an emerging technology that is described as a communication infrastructure that combines low latency and high reliability. It is considered a leap forward compared to the mobile Internet and the IoT and will revolutionize practically every aspect of society [16,17]. When the Tactile Internet is introduced into the smart logistics and supply chain, it will innovate the existing communication and interaction across diverse supply chain entities, promoting the intelligent process of smart logistics and end-user quality of experience (QoE) by taking advantage of haptic information and haptic-related applications [17].

Autonomous driving, vehicle platooning, remote driving, aerial drones, virtually connected railway systems, and Unmanned Aerial Vehicles (UAVs) are among the main applications of the Tactile Internet in intelligent mobility systems. Self-driving capabilities in future wireless networks will require vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems [18]. Future Tactile Internet systems must meet the stringent latency, reliability, and stability control restrictions imposed by those, as mentioned earlier, autonomous, intelligent, and cooperative mobility systems.

Any data processing phase, including data collection, information filtering, data fusion, representation, modeling, processing, and interpretation, might pose a security vulnerability in IoT systems, including the Tactile Internet. The main security concerns may include terminal security, data processing, data transmission, and management security. Compared to conventional scenarios, privacy loss in wireless IoT systems is more likely to occur because of many factors, including a higher level of interaction with smart devices and sensors, location-based services, and a low awareness level on the user-side, necessitating the development of novel privacy-preserving mechanisms [18]. Due to the huge scale and spread nature of IoT networks, safeguarding the privacy of IoT data flowing through the network and data fusion with privacy preservation are important concerns. To protect the underlying personal information in the future beyond 5G networks supporting Tactile Internet applications, it is critical to create appropriate access control and encryption mechanisms. Blockchain technology has the potential to achieve privacy-preserving capabilities in future wireless systems, as it consists of a number of blocks regarded as secure, public, and verified [19].

6G concept in the smart logistics sector. Researchers argue that 5G will be a better platform to connect things to things and machines to machines for ultra-low latency communications. However, there are certain limitations of 5G that have been reported that would not fully make 5G compatible or suitable with future smart cities or smart networks. A few of them are below.

1. The unprecedented proliferation of extended reality (XR) services such as: encompassing augmented, mixed, and virtual reality (AR/MR/VR), flying vehicles, brain-computer interfaces, connected autonomous systems, etc., will deteriorate the fundamental aim of 5G to support short-packet, sensing-based URLLC services. To successfully operate IoE services such as XR and connected autonomous systems, future generation wireless networks must be able to support high reliability, low latency, and high data rates for heterogeneous devices across uplink and downlink [11].
2. We have seen the involvement of Artificial Intelligence (AI) in almost every sector, including the wireless domain, driven by recent breakthroughs in reinforcement learning and deep learning. The automaton with AI support, big data, the growth of smart devices, etc. It is reported that 6G use cases for AI can autonomously sustain high Key Performance Indicators (KPIs) and manage resources, functions, and network control. AI-enabled 6G provides "collective network intelligence" where the network intelligence is brought down at the edge level [20]. This makes the 6G networks self-sustain rather than self-organized networks such as 5G.
3. Recently, a new network concept, i.e., 3D networking, is emerging. This is because of the integration of ground and airborne networks. 3D servers, 3D base stations, 3D network planning and design, etc., are very different from 2D networks. Therefore, 6G can promisingly provide new network optimizations for ultra-high mobility management, routing, and resource management in a 3D context [21].
4. A recent report by Smart Cities Press mentioned that by 2030, the IoT connections will cross approximately 125 billion. And to accommodate such a growing number of nodes, the network providers need the power of 6G [22]. The end of smartphone eras to smart wearable sensors, connecting robots to autonomous systems, the revolution of sensor-based smart environments, smart logistics, etc., have all fueled the fire to rethink the limitations of 5G and to start working towards 6G.

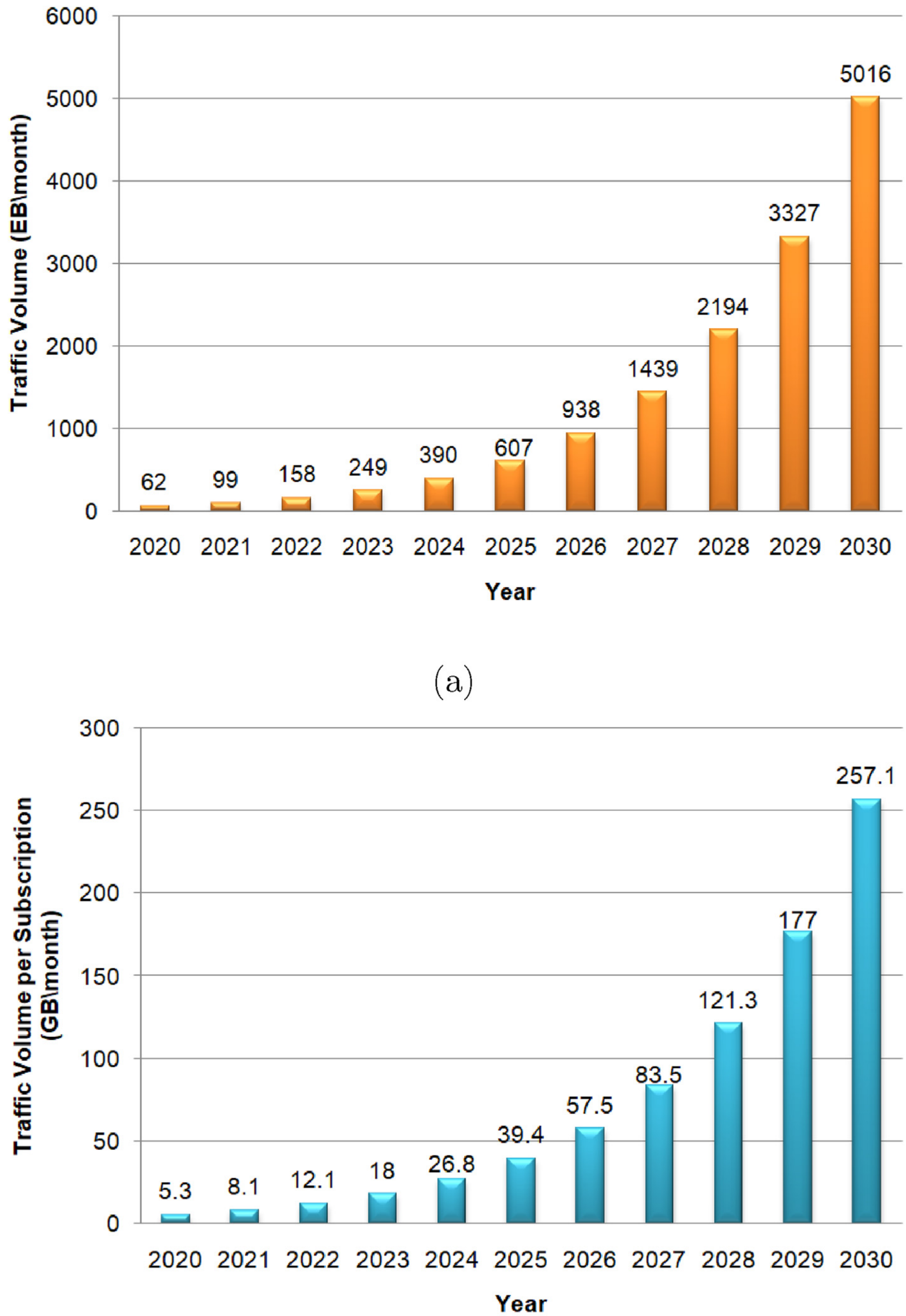
Comparative analysis between 5G and 6G. The International Telecommunication Union (ITU) has forecasted that by the end of 2030, the number of mobile subscriptions worldwide will reach 17.1 billion, which was previously 5.32 billion in 2010, and the global mobile traffic volume will increase by 670 times in 2030 compared to 2010. The global use of Machine-to-Machine (M2M) subscriptions will also increase exponentially. It is estimated that M2M subscriptions worldwide will increase 455 times in 2030 (which is 97 billion M2M subscriptions) compared to 2010 (0.213 billion M2M subscriptions) and smartphone subscriptions will increase by 7 times in 2030 compared to 2010 [23]. It is also expected that by the end of 2030, the global mobile traffic volume will increase 80 times and the traffic volume per subscription will increase 48 times compared to mobile traffic in 2020 (as shown in Fig. 2).

Owing to the limitation of service geographical area coverage, the exponential growth of mobile connectivity and M2M connectivity in the future, radio spectrum, and operation cost, the 5G network will reach its limit by the 2030 and cannot achieve anytime and anywhere high-reliability, ubiquitous wireless communication service globally, and high-quality services, particularly in coping with the upcoming trillion-level connections of IoE devices in remote areas [24,25]. It is expected that 6G will overcome the shortcomings and limitations of the current 5G technology by developing a space-air-ground-sea network, removing conventional cell structures, communicating at a higher frequency, higher performance networking, and improved Quality of Service (QoS), and will add capabilities of computing and Integrated AI for powerful analysis, optimizing, learning, and intelligent recognition abilities [25–27]. In Table 1 we have provided the comparison between 5G and 6G networks [24,28]. It is expected that 6G connectivity will support a speed of 1 Tbps and therefore extend the performance (increase capacity and latency) of the 5G network [29]. With zero latency, a data rate of 1 Tbps, and bandwidth up to 3 THz, 6G (or 6th generation) technology empowered by AI to re-shape the wireless evolution from "connecting things" to "connecting intelligence" will be characterized by a high degree of heterogeneity in multiple facets [30]. 6G will further provide high-energy performance, energy-efficient communications, environmental intelligence, human-centric networks, etc.

From the above literature, it is evident that the concept of automation is already embedded in our lives. Particularly in the smart logistics domain, IoTs are helping in different directions, such as: tracking and remote monitoring of manufacturing assets, video surveillance/streaming of manufacturing assets and processes, real-time remote control of robotics, remote site safety/security, etc. In the world of "smart", there are still many challenges due to the unprecedented growth of sensors. Thus, the need for 6G over 5G is evident [31].

3. Related works and other key reasons

In this section, we primarily focus on the literature related to the smart logistics sector. The aim is to encourage the reader in this direction to emphasize the significant importance, impact, and horizon of this sector in today's smart lives. We have provided a brief overview of



(b)

Fig. 2. The forecasted growth of global mobile connectivity (a) traffic volume and (b) traffic volume per subscription from 2020–2030 [23].

blockchain initiatives in the smart logistics industry. And we have also shed some light on 5G and 6G initiatives in this domain.

It is estimated that the global smart city technology revenue will reach USD 1.7 trillion by 2028, IoT will reach USD 1.1 trillion by 2022 and globally IoT connected devices will almost triple from 8.74 billion in 2020 to more than 25.4 billion in 2030 (as shown in Fig. 3), mobility (the largest segment of the global smart city) will reach more than USD 115 billion by 2019, and energy and smart building (second largest smart city segment) will reach the amount to USD 206 billion and 183 billion, respectively, by 2025 [32]. The reason for this rapid growth in global smart city technology is urbanization, and it is estimated that the number of people living in the city will increase from 54% to 66% (i.e., increase of 2.5 billion people) by 2050 [33,34]. People's living conditions have been impacted because of the complex systems to deal with an increase in the number of urban traffic management, food supplies, water supplies, local waste disposal, etc. [35]. The solution to this problem is the “smart city”, which comprises investment in human and social capital, ICT infrastructure, high-quality life, sustainable economic growth, and political efficiency powered by disruptive technologies with strategic management of natural resources through participatory government [35,36].

When smart city infrastructure is combined with the energy Internet, big data, and IoT, it provides effective intelligent solutions in government

Table 1
Comparison between 5G and 6G networks.

Standard/factor	5G	6G
Deployment	2020	Expected by 2030
Architecture	Massive MIMO	Intelligent surface
Spectrum	Sub-6 gigahertz (GHz) and above 24.25 GHz	95 GHz to 3 THz (THz)
Latency	10 ms	<1 ms
Maximum spectral efficiency	30 bps/Hz (bit/s/Hz)	100 bps/Hz
Mobility	500 km/h	>1000 km/h
Connection density	1 million/km^2	10 million/km^2
User experience data rate	1 Gb/s	>10 Gb/s
Peak data rate	Upto 20 Gb/s	>100 Gb/s
Traffic density	10 Tb/s/km^2	>100 Tb/s/km^2
Energy efficiency	1000× relative to 4G	10× relative to 5G
Coverage percentage	70%	99%
Receiver sensitivity	About -120 dBm	<-130 dBm
Reliability	About 99.9%	>99.999%
Positioning precision	Meter level	Centimeter level
Ultra-sensitive application	Not feasible	Feasible
Smart city components	Separate	Integrated
Satellite integration	No	Yes

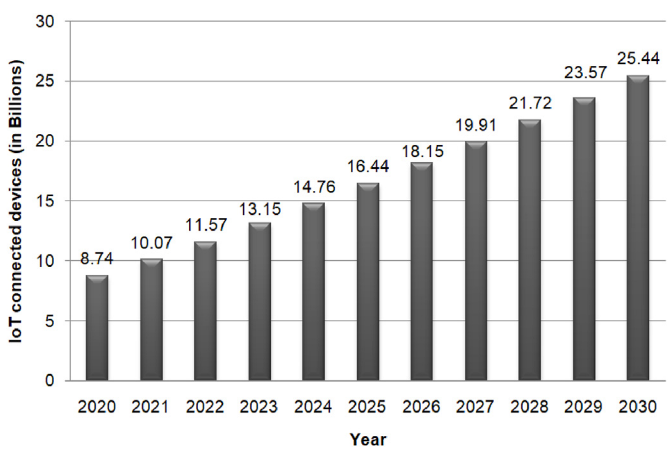


Fig. 3. The forecasted growth of global IoT connected devices over the decade [32].

affairs, the environment, logistics, etc. [37]. Wei et al. [16] proposed a QoE-driven Tactile Internet architecture for smart cities that consists of five layers: sensing layer, transmission layer, storage layer, computing layer, and application layer. Furthermore, the approaches supported at each tier of this architecture adhere to low latency, high user experience quality, and high-reliability requirements [16]. However, it may face many challenges, such as maintenance of equipment, high operating costs, user privacy, leakage of information, poor security of IoT, denial of services, upgrade difficulty, energy consumption, etc. [37].

Blockchain in the IoT smart city domain can help to alleviate privacy concerns. As a simple and secured infrastructure is provided by the blockchain to directly transfer (or communicate) the information (such as data, money, or a piece of property, etc.) between the two devices with a time-stamped contractual handshake (smart contract), this distributed ledger technology has many benefits for the distributed IoT [38]. The convergence of blockchain and IoT combined with other technologies, such as AI and SDN (hybrid architecture), will open unlimited possibilities for smart city initiatives, involving various aspects of life, businesses, and industries (security, fleet management, manufacturing technologies, electricity, precision agriculture, supply chain, autonomous decisions, energy industry, smart logistics, smart building, smart grid) [39,40]. Not only will companies and their customers will benefit from the transparency and fast track of transactions, but the entire ecosystem (smart city) will also be strengthened because of automated trusted services.

Some of the possible use cases of blockchain technology in smart cities are universal ID cards, green energy, interoperability for smart devices, smart retail and logistics, smart mobility and energy, urban planning, land property and housing management, pollution management, key-less signature interface, prioritizing local commerce, etc. [41]. Furthermore, the decentralized nature of blockchain technology will not only eliminate the single point of failure but also help to authenticate, authorize, and audit data generated by devices [40]. The technology can also be used for identification purposes (such as tax data, voting, proof of citizenship, etc.) in a smart city. Using the distributed ledger technology also ensures the elimination of paperwork, hence managing and reducing pollution and local waste [42].

Another challenge is that the current city infrastructure faces a limited amount of information/data sharing capabilities. 4G (or LTE) broadband communication does not have the bandwidth, capacity, or latency to carry out the transaction of information required to drive automation. This issue can be overcome by adapting the 5G and 6G technologies.

3.1. Theoretical analysis

Oughton and Frias [43] analyzed the potential cost, coverage, and rollout implications of 5G infrastructure in Britain, explored by extrapolating 4G network (4G LTE and LTE-Advanced) network from the duration of 2020–2030 for effective policy formulation. They investigated how poor connectivity has impacted certain locations in the UK for society and businesses and how much near-ubiquitous coverage is essential for economic development. To calculate the cost model for a non-virtualized 5G infrastructure, the Capital Expenditure (CAPEX) is defined as Eq. (1) for the rollout for each geotype of each year (i) of the study period of 2020–2030.

$$Capex_{5GNET_i} = C_{Macro\ cell_i} + C_{Small\ cell_i} + C_{Backhaul_i} + C_{Core_i} \quad (1)$$

where $Capex_{5GNET_i}$ represents the total CAPEX costs of all assets such as $C_{Macro\ cell_i}$ (upgrade of macrocell), $C_{Small\ cell_i}$ (deployment of greenfield small cell), $C_{Backhaul_i}$ (fiber backhaul), and C_{Core_i} (cost of the core upgrade). OPEX (Operational Expenditure) and the recurrent OPEX (e.g., the maintenance cost of investment assets, backhaul of small cells, etc) have been excluded from the above value. In Ref. [44], Wisely et al. estimated that the cost of dense urban (in central London) deployment of the eMBB scenario of 5G network for a 100 Mbps everywhere network will be approximately 4–5 times more than that of the cost of deploying LTE.

To evaluate network performance, networks were dimensional to calculate the minimum number of base stations for each exploratory plot. The probability distribution of the Signal to Noise and Interference Ratio (SINR) was calculated within each cell size and then converted into an average spectral efficiency (bps/Hz) for the cell based on the potential spectral efficiency for each SINR value (as shown in Eq. (2)).

$$\eta_{ISD} = \int \eta\ (SINR)\ f\ (SINR)\ dSINR \quad (2)$$

Here, ISD stands for “Inter-Site Distance” (using the existing sites), and η_{ISD} represents the average spectral efficiency in a cell. Then, the average cell throughput (in Mbps) was calculated as follows:

$$Throughput^{cell}_{ISD} = 3\sum_f \eta^f_{ISD} BW^f \quad (3)$$

where the $Throughput^{cell}_{ISD}$ is calculated according to the bandwidth (BW) in each carrier frequency and the factor 3 accounts for three-sector cells. Overall, in Ref. [43], it was found that by 2027, 90% of the population will be covered by the 5G network; however, due to the exponential increase in costs, it is unlikely to reach the final 10% coverage.

3.2. 6G deployment initiatives

The deployment of 5G technology has already commenced globally. To sustain the upcoming competition for the future demand of wireless networks, researchers have begun to conceptualize the 6G generation, aiming to lay the foundations for the stratification of the communications services for the 2030s [45]. China launched the world's first 6G satellite “Tianyan-5” into orbit on November 6, 2020. This remote sensing satellite was jointly developed by China University of Electronic Science and Technology, Beijing WeinaXingkong Technology, and Chengdu Guoxing Aerospace Technology with the aim of a 6G test for improved latency speed and signal strength with the purpose of monitoring real-time climatic change developments [46]. The sixth generation is envisioned as an ultra-dense heterogeneous automation network architecture comprising non-terrestrial (for example, drones, planes, and satellites) and terrestrial infrastructures (cellular networks) that would integrate ground, air, underwater, and space networks to provide ubiquitous wireless connectivity [5].

6G infrastructure will involve technologies such as very large-scale antenna arrays (MIMO and supermassive (SM) multiple-input), Orbital Angular Momentum (OAM) multiplexing, blockchain-based sharing, laser and visible-light communication (VLC), holographic beamforming (HBF), quantum computing, molecular communications, collective/pervasive AI, and the Internet of Bio-Nano-Things [5,24]. As 6G aims to provide large coverage of urban and remote areas, it is beneficial in the implementation of smart city infrastructure, providing real-time information and connecting all the sub-ecosystems (economy, living, governance, education, people, environment, mobility, businesses, buildings, etc.). This infrastructure will generate heaps of sensitive information, and hence, full security is needed to provide the trusted service. In Ref. [47], the authors investigated how 6G can provide holistic management of C4 (communication, computation, caching, and control) resources for a single system incorporating 3D coverage.

As the 6G network is still a concept and research work, upcoming security and privacy threats are unknown. In addition to the loss of control over devices, breach of information security, or loss of money can also cause the loss of property or even endanger physical safety [48]. Some other challenges in 6G are massive system connectivity, high data consumption in future tenants, security needs with scalability, and device resource restrictions [49]. There are some publications [49,50–52] that have presented the role of blockchain technology in 6G networks to overcome the above challenges, such as intelligent service, innovative air-interface design, authentication, accountability, elevated security and privacy, resource management, and autonomous networks. Some of the possible use cases of blockchain in 6G are smart health, smart logistics, agriculture, industry 4.0, vehicle-to-vehicle communication, pervasive connectivity, seamless environment monitoring, trustworthy and decentralized 6G communication infrastructure (spectrum sharing and extreme edge), UAV, etc. [49,53].

In some of the other existing literature on blockchain in logistics, the work mainly focuses on improving traceability, transaction trust, disintermediation, and visibility. Table 2 summarizes the existing literature review on blockchain-enabled logistics. In 2018, Maouchi et al. highlighted the importance of transparency, traceability, and decentralization features in the supply chain [54]. Hackius and Petersen [55] represented four use cases of blockchain application in logistics and supply chain management. The four use cases proposed by the authors are to ease paperwork processing in ocean freight, identify counterfeit products, facilitate origin tracking, and operate the IoT. Bocek et al. [56] proposed an idea of how blockchain technology is important in the pharmaceutical industry, from tracing and tracking the product to managing data. The authors presented the pharmaceutical supply chain and described how smart blockchain and IoT can be used to speed up logistics activities and

Table 2
Related literature review.

Year	Author	Purpose
2017	Hackius and Petersen [55]	Blockchain and logistics use cases.
2017	Bocek et al. [56]	Blockchain-based pharmaceutical supply chain.
2017	Polim et al. [57]	The authors proposed a decentralized retailer-logistics provider ledger.
2018	Zhang et al. [58]	CPS and industrial IoT integrate to create smart production-logistics systems.
2018	Maouchi et al. [54]	For the supply chain, a blockchain-based transparent and decentralized tracing solution.
2019	Wei et al. [16]	QoE-driven tactile Internet architecture for smart cities.
2019	Chang et al. [59]	Blockchain-based cross-border trade and global supply chain.
2019	Kamilaris et al. [60]	Review of blockchain in food supply chain and agriculture.
2019	Tijan et al. [61]	Review of blockchain in logistics and supply chain.
2019	Alladi et al. [62]	Review of blockchain for Industrial IoT and Industry 4.0.

Note: CPS: Cyber-physical systems, IoT: Internet of Things, QoE: quality of experience.

remove third-party interference while reducing operational costs. Polim et al. discussed the problem that occurs between grocery store retailers and logistics providers due to the information asymmetry in a grocery supply chain [57].

Chang et al. [59] discussed the challenges and opportunities of blockchain technology in cross-border trade and global supply chain with leading pilot initiatives by Walmart, the port of Antwerp, IBM, Accenture, the Blockchain in Transport Alliance (BiTA), etc. The trend of blockchain and 6G in smart logistics is rising [60]. In this work, Kamilaris et al. investigated the impact of blockchain, particularly in the agriculture and food supply chain. They have comprehensively presented the existing ongoing projects and initiatives. Following this, they have shed light on potential challenges.

Meanwhile, there are some experiments going on in blockchain-enabled smart logistics and cities (Table 3). For example, for smart IoT, Ali et al. [63] developed a blockchain-based behavioral verification system. For external devices that want to join the smart home network, the system demonstrated a level of confidence. To protect IoT devices from harmful attacks, blockchain was implemented in the IoT behavior controller system to store, track, and identify IoT devices. Again, Lee et al. [64] developed a blockchain-based smart home architecture to address the shortcomings of the present centralized smart home network and to protect the smart gateway from future threats. They used the Ethereum blockchain to ensure that the data from smart homes were validated and kept private. In another paper, Nadeem et al. [65] presented a blockchain-based vehicular distributed Ad-hoc system to keep vehicle drivers' personal lives private while providing on-demand and low-cost access. To overcome the challenges associated with the system's storage, processing, and broadband bandwidth limits, the three interconnected components are termed vehicle Cloud, roadside Cloud, and central Cloud which constitute a Cloud hierarchical architecture. The shared Cloud network connects cars and service providers securely via a blockchain-regulated peer-to-peer (P2P) network that can withstand cyberattacks and address bottlenecks in the automotive sector. Gao et al. [66] proposed a vehicular network that incorporated blockchain, Software Defined Networking (SDN), and fog computing. In the suggested method, the blockchain created a trust model by deciding which messages to send from the source vehicle based on information gathered from peers. For carpooling services, Li et al. [67] developed a blockchain-assisted vehicular fog computing system. The act of sharing a single vehicle with one or more passengers traveling in the same direction is known as carpooling. In such a system, malicious users or drivers can falsely report their locations. The authors used conditional privacy, one-to-many proximity matching, destination matching, and data

Table 3
List of blockchain-based smart logistics experiments.

Year	Author	Purpose	Tools
2018	Malik et al. [69]	Permissioned blockchain system that promotes food provenance for the food supply chain.	Hyperledger Composer, Caliper
2018	Figorilli et al. [70]	Blockchain prototype for open source traceability of wood using RFID sensors and open source technology for information tracing.	Azure blockchain Workbench, JSON, MySQL server, REST API
2018	Biswas et al. [34]	Blockchain-based scalable framework in the IoT for secure transactions.	Hyperledger Fabric, kafka-Zookeeper, Configtxgen
2018	Li et al. [67]	Blockchain-based vehicular fog computing, a privacy-preserving carpooling system.	Miracl cryptographic toolset
2019	Yao et al. [71]	Blockchain-based lightweight anonymous authentication technique for a distributed vehicular system.	Java Runtime Environment
2019	Rathore et al. [68]	Decentralized security architecture for IoT networks based on blockchain and SDN (software defined networking).	Mininet, Amazon EC2, Ethereum, Truffle development suite
2019	Gao et al. [66]	The 5G-enabled Fog vehicular network's integration of blockchain and SDN.	MATLAB, NS-3
2019	Nadeem et al. [65]	Blockchain-based distributed Cloud architecture to protect drivers' privacy.	Not implemented
2020	Hang et al. [72]	Blockchain-based system to preserve agriculture data from the fish farm in a tamper-proof manner.	Couch DB, Hyperledger Fabric, REST API, JSON Docker engine
2020	Ali et al. [63]	In a blockchain-based smart IoT system, behavior capture and verification procedures were established.	Tensorflow and Keras
2020	Lee et al. [64]	A blockchain-based smart home gateway network design was developed to address issues with the current centralised security network architecture.	Mininet, Amazon EC2, Ethereum Bridge, Truffle development suite

audibility in the carpooling system to protect passenger privacy and security. In their study, Rathore et al. [68] offered a decentralized security architecture based on SDN paired with blockchain technology for IoT networks in the smart city that relies on the three main technologies of SDN, blockchain, and Fog as well as mobile edge computing to detect attacks in the smart city.

From this comprehensive discussion, it is evident that we need Blockchain and 6G in future networking for smart cities or smart logistics domains. In the following section, we have comprehensively discussed the blockchain for smart logistics use cases.

4. Smart logistics with blockchain

Blockchain technology is a distributed ledger technology where the ledger of a transaction is distributed among all participating members in the network, over which successfully validated transactions are recorded chronologically, which takes the form of “blocks”. Transactions contained within blocks could be value transactions, e.g., transport data, details of events in logistics, or automated actions. Before adding any new information (block), members participating in the blockchain-based logistic network come to an agreement or consensus, and then validated information (block) is added to the chain and then broadcast across the blockchain network, as shown in Fig. 4. The block is rejected if no consensus on the validity of the block is reached. This “mutualization of data” is possible because of cryptographic techniques that make certain identical copies and permissions are established to access stored data in a blockchain-based system [61]. Authentication of transactions is achieved by a “consensus mechanism”, which allows members to collaborate with each other of no particular trust. Unlike the traditional method used by the supply chain, which is controlled by central authorities, a blockchain-based system relies on a P2P network that is controlled by no individual, group of people, or central authorities. Smart contracts are self-executable computer codes that can be used as legal contracts when certain conditions and logic are met, which can also be used to automate the process, which further reduces costs and time. Hence, the blockchain benefits for 6G networks for smart applications can be elevated security features, intelligent resource management, and scalability. In logistics, blockchain ensures immutability, over-the-board transparency, provenance, asset management, finality, and a single version of truth.

Another interesting feature blockchain can provide to the logistics is to efficiently administer the import and export licenses. Storing the licenses would save the organizations to avoid the trouble of losing them and would allow customs authorities to easily check the validity and authenticity of the permits. With the help of smart contracts, automatically invalid permits will be canceled upon expiration of their validity period, which could avoid a situation like when the Department of

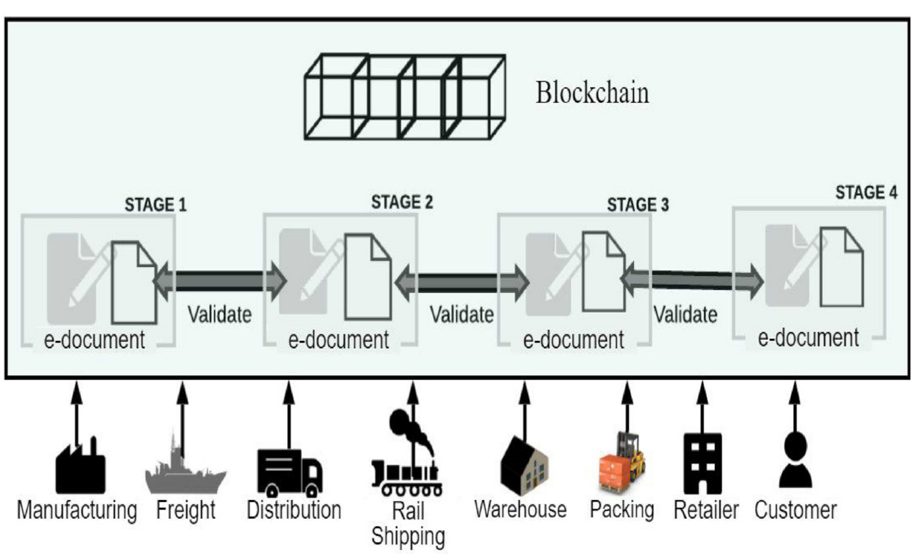


Fig. 4. The proposed high-level system model.

Agriculture in the Philippines canceled all permits of import on meat products in 2016, after having found that old permits were being recycled to smuggle imports. Therefore, blockchain can promisingly help to verify the license, fight fraud, and smuggling cases.

Furthermore, there have also been some government initiatives across the world in terms of logistics and supply chains; for example, the government of India has begun to embrace blockchain technology as a means of streamlining operations and services. Its most recent experiment was in the domain of domestic trade. The country's Finance Ministry's Central Board of Indirect Taxes and Customs (CBIC) began a trial electronic freight and cargo tracking system project based on blockchain technology on October 15, 2021. This aims to ensure secure container documentation and GPS-based tracking [73]. The experiment is being carried out at the Tughlakabad Import Commissionerate's Inland Container Depot (ICD), which accounts for around 20% of the overall tax receipts under Delhi Customs. After an assessment of costs, time savings, and compliance, the project may be expanded across India if this test run is successful [73]. Another example is the Australian Border Force (ABF), Singapore Customs, and the Infocomm Media Development Authority of Singapore (IMDA), as well as industry participants, which have conducted a blockchain trial to demonstrate that trade documentation may be issued and confirmed digitally across two independent systems [74]. The blockchain trial was launched as part of the Australia-Singapore Digital Economy Agreement, which aims to simplify cross-border trade and lower transaction costs between the two countries. This is one of the first cross-border document interoperability collaborations involving numerous government entities from two nations [74].

The European Blockchain Partnership (EBP) also aims to develop a trusted, secure, and resilient European Blockchain Services Infrastructure (EBSI) that meets the highest standards in terms of privacy, cyber security, interoperability, and policy implementation using blockchain and distributed ledger technologies [75]. In the USA, food and drug inspection employ blockchain to address the problem of lack of openness and security in health data processing [75]. The Food Standards Agency in the UK is utilizing blockchain to track the circulation of meat to improve food traceability [75].

In the following literature, some key and critical use case scenarios are discussed.

5. Smart logistics use cases

In this section, we have highlighted critical supply chain or smart logistic scenarios where blockchain and 6G can play a potential role.

5.1. Single digital window

Australia is currently planning to create a "single digital window" through which all Australia's international trade information and documents can be exchanged by multiple stakeholders and government agencies. A "single digital window", also known as a "single window system", is a facility that enables traders and businesses to submit the reports, documentation, and licenses for exportation, importation, or transit of products to the authorized agencies through a single entry point. Establishing such a system will accelerate and simplify border procedures, information flow, and formalities between government and trade, saving time and money. As a technology choice, blockchain has the potential to upgrade the existing "single digital" system. Blockchain would streamline trade finance, customs application, insurance, etc., reduce delays resulting from physical paperwork movement, reduce the documentation process, and reduce processing times and costs. Moving along the supply chain will also enhance the provenance, immutability, and visibility of sensitive documents and goods in a secure environment.

In May 2018, the Singapore International Chamber of Commerce (SICC) partnered with vCargo Cloud, a Singapore-based provider of cross-border trade facilitation solutions, and initiated the world's first blockchain-based platform for electronic certificates of origin (eCOs) to increase efficiency and prevent fraud [76]. The certificates of origin are the international trade documents authorized by the government or other empowered organizations in a specific country to certify that the goods and packages in a particular shipment have been successfully obtained, manufactured, and processed. This blockchain-enabled platform attempts to revolutionize the way trade-related documents are handled by storing information about trade transactions on a tamper-proof distributed ledger system that can be authenticated and accessible by the platform's many involved parties. QR codes are used on this platform, allowing eCOs to be scanned with smartphones and then printed. To avoid unauthorized duplicates, the number of printouts is limited. Hence, increasing the efficiency and lowering the cost of eCOs verification. This helps to establish self-certification through the ASEAN (Association of Southeast Asian Nations) single window for providing a robust legal framework, reducing manual paperwork, and accelerating freight clearance across all 10 member countries.

5.2. Cross-sector domain application

A cross-sector application involves parties from various other sectors, and cooperation is often not an obvious choice between these sectors. There are opportunities for innovative approaches that require business collaboration in one or more sectors. We are starting to see some cross-sector innovation from transport networks to connecting utilities to water companies working with energy providers and telecommunications partnerships with electricity providers. For any international trade, different processes are required and implemented in sequence. Blockchain can simultaneously implement these processes so that the involved parties do not have to wait for each other. Furthermore, blockchain could coordinate processes in decentralized networks of businesses and governments.

Logistics and energy are the two best examples of cross-sector applications, which can be efficiently improved with the help of blockchain. Logistics comprises small to large enterprises and organizations. On average, in transporting sea containers, 30 parties are involved, and to ensure that a container is reached its destined location, a total of 200 times data are exchanged between these parties. The efficiency can be improved in this process with the help of blockchain technology. Apart from improving the efficiency and speed of exchanging information between these parties, blockchain also has the potential to monitor the operation's progress in real-time, reduce the risk of fraud, easy data verification, and shorten the cash cycle [77]. The same applies to the energy sector, which involves producers and purchasers of energy. The problem for the energy sector is that it is challenging to make maximum use of sustainable energy resources, Because of that, wind farms and solar energy applications are being closed down because grid operators are not able to use all stored power. Because of these inefficiencies, North America and Europe are facing a loss of billions of dollars. With the help of blockchain, organizations would coordinate the supply and demand of energy.

The port of Rotterdam with the BlockLab team is currently piloting the "cross-sector domain" blockchain platform to facilitate the running of its electrical grid and logistics operations. Rotterdam is using blockchain technology to enhance its competitive position as a logistics hub, and SmartPort is also one of the main drivers behind it. Blockchain can securely track the location and ownership of cargo shipments, and with the help of "smart contract" it can also automate trade processes. Moreover, blockchain would facilitate smart and decentralized grids for the energy transition. The port of Rotterdam is also developing another blockchain application with the BlockLab and S&P Global Platts for trading price incentives to maximize sustainable energy consumption.

5.3. V2V communication

V2V communication is simply a wireless technology that lets vehicles within a few hundred meters broadcast their steering-wheel position, speed, brake status, and other data to other vehicles. In logistics, V2V communication allows multiple freight vehicles to form communication or platoons and also improves safety and fuel efficiency. Some organizations are now connecting freight vehicles, such as trucks, using direct V2V communications; this enables the rear vehicle to react to the front vehicle's actions immediately. These vehicles accelerate and brake together by electronically coupling the trucks, and are able to operate safely at a closer distance. This technology is inserted into a whole fleet of trucks that are taking part in shipping products where the front truck is in full control of the rear truck, which is known as truck platooning. Blockchain is ideally suited in this case, as it is decentralized in nature. For example, in a free-flow traffic situation, Chen et al. [29] suggested a platoon-driving approach for autonomous cars in their paper. This approach enables successful path-matching vehicles to be grouped into platoons and guided by the platoon head. In addition, a platoon head selection method is implemented to offer vehicles an incentive to serve as platoon heads and to keep platoons dynamically updated. Following that, a smart contract is used to enable blockchain-based payment between the platoon head and platoon members, preventing false and malicious payments.

Also, V2V communication enables logistics and freight companies to store and validate the data efficiently. The stored and validated data used on the blockchain can further help logistics companies and trade to streamline their operations across the world effectively. Blockchain makes the whole process more efficient, improves traffic situations and also reduces fuel usage. TNO, TKI Dinalog, Rotterdam Port Authority, logistics companies, truck companies, and the government are developing a prototype for truck platooning for better trading and shipping. Moreover, using blockchain as a technology will lead truck platooning towards autonomous shipping.

5.4. Ocean freight, air freight and road freight

The global shipping industry carries out about 90% of world trade. More than 50,000 merchant ships are involved globally, with world fleets registered across 150 countries, transporting every kind of cargo, and it is regulated by over a million seafarers [78]. Digitalizing ocean shipping will pave a way for the development of worldwide digital networks that will offer better visibility to all stakeholders and will help shippers track freight across carriers. Distributed ledger technology could potentially reduce the time and cost required for processing documentation for ocean freight shipments. To unveil the potential in ocean freight, the ZIM ocean carrier service has joined the TradeLens, which is the joint venture between IBM and Maersk for a blockchain-based digital shipping service. It uses a blockchain-based platform for the single version of truth between all stakeholders without compromising confidentiality and privacy to enable trust between multiple parties, from carriers to the freight forwarder, provides certainty through real-time access to shipping documents and information, and moreover improves the business model. Maersk also reported that by using the TradeLens platform, the transaction time was reduced by 40% and the cost was reduced by thousands of dollars. In LogChain, an Israeli-based blockchain start-up has successfully established its full cycle of international maritime shipment from Belgium to Israel, shipping beverages. LogChain handles the whole supply chain transition, including letters of credit and electronic bills of lading. Furthermore, it was reported that LogChain has reduced the time approximately by two weeks of documentation and shipment cost by 7% to 9%. In 2018, Maersk also collaborated with EY and Guardtime to launch the world's first distributed ledger technology platform for transferring marine insurance named “Insurwave” and now commercially used by AP Moller-Maersk, XL Catlin, Willis Towers Watson, and MS Amlin.

Air freight involves many stakeholders along the entire supply chain, such as air cargo costing, billing, etc., which use manpower-intensive, manual paperwork and are prone to error processes. In Singapore at the International Air Transport Association World Cargo Symposium, a blockchain-based air cargo billing, costing, and reconciliation system was launched by Cargo Community Network (CCN) partnered with Microsoft for promoting air cargo billing processes, real-time revenue recognition, and accelerating billing reconciliation to enhance the efficiency of cargo agents, airlines, and freight forwarders [79]. With Microsoft's Azure blockchain technology and built-in smart contract, freight forwarders and airlines can now update their compute charges and shipments in real-time, and stakeholders are able to retrieve real-time information like shipment details from the freight status update, flight manifest, and airway bill. These not only shorten the billing cycle from weeks to a few hours but also enable visibility and accountability and reduce discrepancies across the entire supply chain.

Internationally, 85% of road freight goods are carried over a distance of 150 km, and 8 billion tonnes of goods are transacted per year. To facilitate trade across Asia, Singapore's CrimsonLogic launched the region's first cross-border permissioned blockchain network named Global eTrade Services Open Trade Blockchain (GeTS′ OTB), which is aligned with the Southern Transport Corridor and China's Belt Road Initiative to improve security, efficiency, and transparency. GeTS′ OTB enhances the transparency and trust between shippers, customers, and freight-forwarders and the security of trust-related documents such as eCOs and invoices. GeTS′ OTB has already attracted partners like Suzhou Cross-E-commerce, China-ASEAN information Harbour, IBM, Korea Trade Network, TIFFA EDI services, PT-EDI Indonesia, commodities Intelligence Centre, and Trade-Van Information services (Taipei, China). GeTS' OTB has conducted more than 13 million transactions, increased productivity by 1.5 times, improved speed by 60%, and recorded more than USD 400 billion of Gross Merchandised Value (GMV) in the first half of 2018.

5.5. Traceable luxurious goods

With significant benefits in sight, it is estimated that blockchain technology in the global supply chain market is expected to grow by approximately USD 666.61 million by 2024. The global supply chain network is massive and complex. Keeping track of the transaction history along the entire supply chain from source to destination is a challenging process. If all these transactions and stakeholders are recorded on the blockchain, the information would be added only once through the consensus of other members in the network. This means data in the network become permanent and information can be easily shared among the actors participating in the network, which help them to keep track of products and goods. Businesses and organizations can use this recorded information and documents to provide evidence of the legitimacy and authenticity of products such as luxury goods like diamonds, fine arts, or pharmaceutical products. Hence, this emerging technology is a useful innovation for precious goods, as it provides a secure environment.

For example, established in 2015, Everledger is the blockchain platform for asset tracking companies and supply chains to store records of valuable assets like diamonds and art. It tracks diamonds from the mine to the gem cutter, through manufacturers and distributors to the retailer, and finally to the buyers or consumers. It has replaced the paper certification process with a blockchain ledger. The raw material is assigned a serial number, and every information and measurement of a diamond is entered into the digital ledger, throughout the material's transformation and every time the material changes its place. Data entered in a blockchain system for each step of the process are permanent and also extremely secure. Since 2015, Everledger has provided transparency and provenance to more than 2 million diamonds, and approximately recorded 100,000 diamonds a month.

As Everledger stores digital certificates of the diamond on the blockchain, network participants such as merchants, banks, and insurers can verify the legitimacy of an asset (well in this case, a diamond). Now, a legit person will buy a diamond, insure it, and register it on the Everledger. Next, this person loses the diamond that he/she reports as stolen. After that, the insurance company reimburses her for the loss. Finally, the thief who stole the asset will try to sell the stolen diamond to some jeweller. This jeweller will ask Everledger for confirmation and learn that it's a stolen diamond. The stolen diamond is reported to the insurance company, which takes control of it.

Although some key subdomains of smart logistics and supply chains are discussed where blockchain can potentially help, we identify critical issues that need to be addressed before blockchain's deployment in these areas.

6. Open issues

Blockchain has the potential to disrupt every area of logistics, creating new business models through improving operational efficiency, but there are three prime challenges to blockchain implementation in smart logistics has been identified. These challenges need to be overcome before blockchain can reach widespread adoption.

Interoperability: Processes in international and cross-border trade are not tightly synchronized as logistics will involve numerous blockchain-based platforms for different technical uses from finance to logistics with different algorithms. Currently, no standard exists to allow interaction between these platforms. The issue of interoperability raises two questions:

1. *how will various blockchain-based platforms in smart logistics interact with each other?* and
2. *how will information exchanged between involving parties be understood by them?*

These issues can be addressed by introducing gateways to the blockchain network connecting different areas of logistics. Now, a blockchain gateway refers to a computer system in a blockchain network that facilitates the flow of virtual assets into and out of the blockchain network [80]. A gateway, as a node in the blockchain network, has read/write access to the blockchain's shared ledger and can participate in the blockchain's consensus mechanism. When communicating with its blockchain, a gateway is said to be facing interiorly, and when dealing with a remote peer gateway belonging to a separate or different blockchain network, it is said to be facing exteriorly [81]. Two peer gateways execute a gateway protocol that implements the essential processes for moving a virtual asset from one blockchain to another through the mediation of the gateways. By definition, a gateway belongs to only one blockchain network, and it must be traceable and authenticable to entities in that blockchain network when looking inward. A gateway must have at least one blockchain transaction signing a public/private key pair for interior interactions. While interacting with external peer gateways, a gateway must have a gateway identity public/private key-pair when facing exteriorly. Peer gateways can identify and authenticate the gateway using this key pair. For example, Accenture introduces the “interoperability nodes” that connect the targeted blockchain system to enable synchronization. To all in-scope distributed ledger technology systems, an interoperability node is provided with the appropriate identity and access control capabilities [82]. Fig. 5 describes the interoperability node connecting the freight blockchain system and manufacturer blockchain system in logistics.

There are several prerequisites for a gateway protocol in terms of security, such as the gateway identification key-pair used to engage with other peer gateways externally must be distinct from the transaction signing key-pair used for its ledger internally. Secondly, all communications between gateways must take place via a secure channel, which must be established using standard secure channel establishment protocols like IPsec, SSL/TLS, and so on [81]. Furthermore, during the transportation of an asset, a crash of one gateway (or both) must not result in the loss or leaking of asset or entity information (e.g., originator and beneficiary identities). A gateway must always be placed in a safe state via the gateway recovery mechanism [81].

Scalability: Regardless of the current size of the blockchain, transaction rate, and trade's expanding demand, blockchain in logistics systems will undergo the problem of scalability. Across the supply chain, many transactions process simultaneously, and these transactions create numerous events, such as sensor reading, shipment tracking, route creation, invoice delivery, customs clearance, stock inbound, freight transition, order creation, payments, advance shipping notice, etc. Although some events that occurred are not relevant, they still need to be tackled so that the overall system can handle the throughput throughout the cycle, proportioning the resources among the stakeholders' involvement level in the supply chain. There is also a problem of high energy consumption and computing power in some large-scale logistics transactions, which further leads to high latency. This problem of scalability can be solved by an overlay network, which is a computer virtual network that is built on another physical network with the ability to self-organize [83]. Tunneling is the essential concept of overlay networks; for example, packets in the network are collected and encapsulated before being routed to their actual destination. An overlay network is a common type of network that is used to distribute key value stores and exchange topology between agents like Zookeeper, Etcd, and Consul. Extended virtual network IDs are also introduced by such protocols; for example, the VXLAN Network ID (VNI) is 24-bit long, and the Virtual eXtensible LAN (VXLAN) supports over 16 million virtual networks [84]. In Ref. [67], the authors proposed Intelligent Transportation Security (ITS) with a blockchain overlay network to solve the issue of security and scalability. This architecture consists of three layers: the ITS network infrastructure layer, the cloud computing and service provisioning layer, and the blockchain overlay layer [67]. First, RSUs (Road Side Units), 4G and 5G cellular network base stations, and Internet gateways and routers comprise the ITS network infrastructure layer. This layer also includes vehicles that interact with an ITS network. Second, the service provisioning layer is composed of servers from ITS operators and third-party service providers, such as those providing cloud computing and services. Now, this blockchain overlay layer (a virtual network) is made up of some vehicles that want to join blockchain and employ security-related services, as well as nodes from the ITS infrastructure and service provisioning layer.

In logistics, an overlay network can be used to distribute the key-value stores to exchange the data on blockchain topology between stakeholders such as manufacturers, freight, producers, etc. Fig. 6 describes an overlay virtual network for the manufacturer and freight

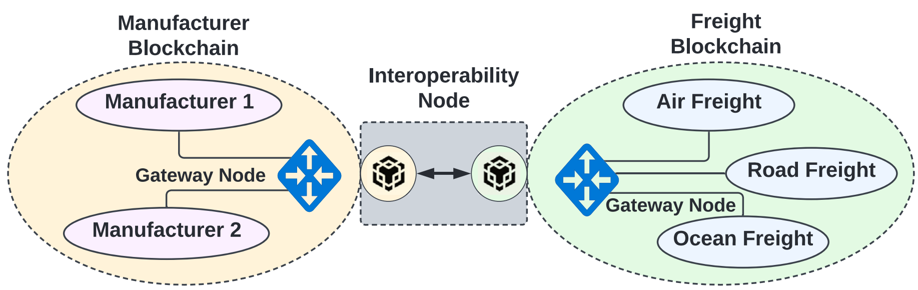


Fig. 5. The interoperability node connecting the freight blockchain system.

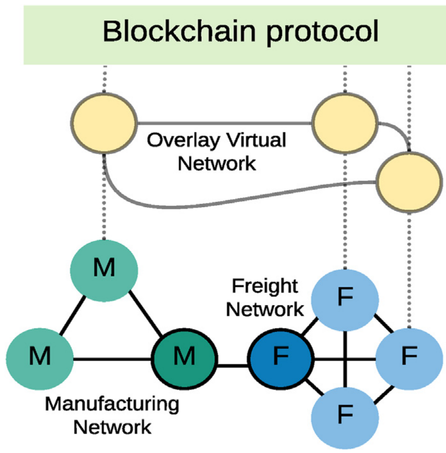


Fig. 6. Overlay network for blockchain.

network. An overlay network with a blockchain-based platform will provide the trade with a proper network and will carry out preventive action by recreating a proper network if a node in blockchain fails to form for any specific reason. One issue here is that the physical network and the virtual network are two separate entities with separate management policies, control points, and provisioning. We need a management system that adapts and controls overlay network behavior so that specific demands of users are met as well as those of service providers.

Another scalability issue for the blockchain-enabled 5G and 6G networks is that the 5G and 6G networks' targeted end-to-end latency for payload and carried data is 10 ms and sub 1 ms, respectively. This requirement implies that configuration and setup transactions at a very high throughput rate [85], while current public blockchain networks (such as Bitcoin and Ethereum) can handle only 10–14 Transactions per Second (TPS), and private blockchains can transact up to 3000 to 20,000 TPS [86]. Therefore, an upgrade of the blockchain architecture, an increase in block size, and sharding techniques are being researched to enhance the capacity to co-op with the future demand [85]. Nonetheless, blockchain is a better option for the complex transactions initiated by the next-generation wireless systems [87]. In the future, there will be demand for massive connectivity in 6G technology which will initiate network resource management, such as spectrum sharing, power distribution, and computational resource distribution, as the major issue [88]. This issue can be tackled by using blockchain technology in the 6G network by integrating smart contracts between operators and users, which will enable the network to manage resource utilization, energy trading, monitoring, and sharing efficiently [89,90]. In the same way, energy management and spectrum management problems can be solved by blockchain. However, scalability will remain an open challenge for researchers.

The convergence of technologies: To build trust and collaboration between businesses and stakeholders in logistics, blockchain technology is likely to be used with the IoT, and AI. Though the convergence of these technologies will speed up and improve time-consuming and sophisticated processes of shipping and freight, there is a chance that cyber attackers will find human or computer vulnerabilities in any of these layers of technology as an incentive for their own malicious benefits. To tackle the security issue in such a case, Software Defined Networking (SDN) technology can be handy (Fig. 7). Blockchain-enabled software defining networking will support real-time application performance, and all data can be analyzed with the SDN controller [91]. Hence, any kind of malicious data or file injected by cyber attackers can be filtered out and prevented from network crashes. The main role of using SDN with blockchain is to deploy protection for the entire network from security threats and mitigate network attacks such as DDoS/DoS attacks, cache poising/ARP spoofing, and other network attacks [92]. Additionally, to provide further protection to the blockchain system, it can utilize SDN functionalities by implementing a firewall for blockchain-based applications by filtering out network traffic [92]. The SDN can communicate with the nodes in the blockchain, which it guards to determine if the origin of the traffic is legitimate or not, and the packets from the illegitimate source are intercepted, protecting the blockchain from being harmed.

Real-time data acquisition, data processing and data analytics. The data collected by IoT sensors are processed locally or at the data center level to perform real-time tasks such as anomaly detection, detection of operational faults in sensors, etc. for the global monitoring and managing of the transportation system. Since smart devices are integrated and deployed in multi-technology environments such as IEEE 802.11, LTE-V, or 5G, the flow optimization for multi-RAT connections and context-aware resource allocation subject to high-rate, low-latency, and high-reliability requirements are critical challenges in smart network

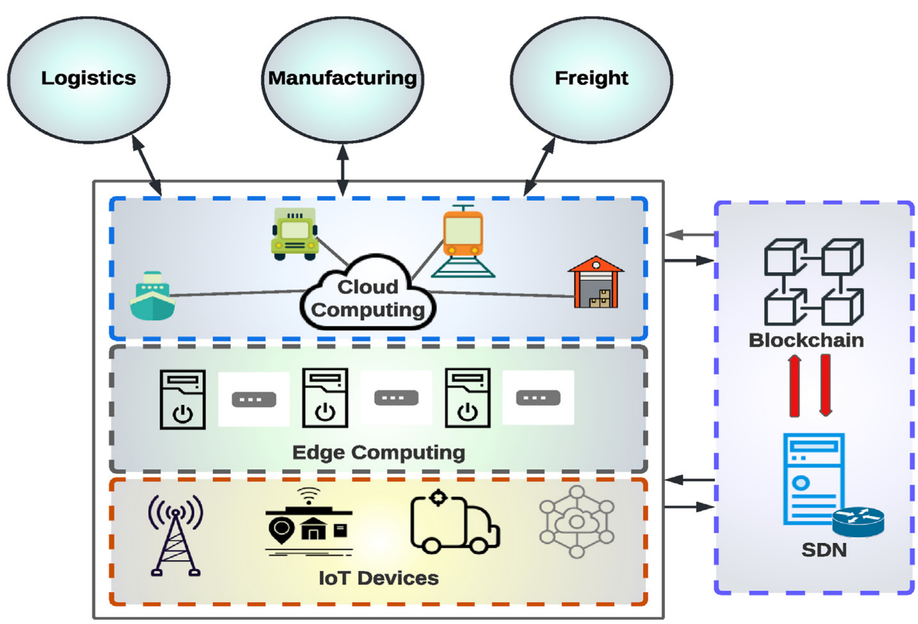


Fig. 7. The blockchain-SDN network in smart logistics. SDN: software defined networking.

performance. Thus, efficient resource allocation techniques have to be conceived to meet next-generation networking requirements.

Safety and security: Although blockchain offers numerous benefits to the logistics sector, it also poses a number of concerns for their safety, security, reliability, and privacy due to its heavy reliance on its characteristics. Furthermore, because blockchain applications will be connected with other stakeholders and supply chain entities, this connectivity must be secure [5]. Malicious attacks or illegal access to such networks could have negative repercussions for the sector's operations and infrastructure, as well as its stakeholders and customers [93]. Despite the fact that blockchain can withstand major security threats such as selfish mining, Distributed Denial of Service (DDoS), Sybil, ransomware attacks, etc., the existing blockchain has some security gaps. For example, if more than half of the blockchain systems have control over computing resources, they can change consensus mechanisms and prevent new transactions from being approved for illicit reasons, which is referred to as the 51% attack [94]. Message hijacking and DDoS attacks are still possible using blockchain technology, and these attacks are the most common on blockchain networks [62]. DDoS attackers try to take down the network's mining process, as well as e-wallets, cryptocurrency exchanges, and other financial services [93]. On a network of blockchains, DDoS attacks are impossible to carry out. A Sybil attack occurs when an attacker impersonates a significant number of people at the same time [95]. Selfish mining is a bitcoin mining approach in which a group of miners work together to boost their profits.

Another important issue highlighted in Ref. [62] regarding implementing a blockchain-based solution for the supply chain is the privacy of manufacturers and suppliers. Any supply chain participant or stakeholder with access to the shared blockchain could be a rival of the manufacturers and suppliers, gaining unauthorized information from the blockchain.

Furthermore, smart logistics components are vulnerable to cyber attacks due to the integration of 6G or 5G technologies into the smart logistics sector. Since the devices are cheap and easy to temper with, and their growing number in dense networks puts tremendous pressure on security applications. Therefore, we emphasize that the convention security application cannot be directly applicable in 6G; thus, we need to investigate more reliable secure platforms for secure and efficient communications. Hence, providing an adequate level of cyber security has become an issue of vital importance that must be addressed in smart logistics. If not addressed, the cyber-attack can compromise the whole operation of a smart logistic network, which eventually may inflict enormous damage that cannot be tolerated by the industry. In next-generation networks, we emphasize that autonomous methods to detect cyber-attacks in 6G-enabled smart logistic networks must be studied. And recent blockchain studies can promisingly help us to address this issue.

7. Conclusions

This paper explores the different aspects of blockchain-enabled next-generation smart logistic networks. Existing literature on blockchain technology in smart cities and smart logistics is analyzed. We have highlighted motivational examples to show the necessity of integrating 6G and blockchain in smart cities and smart logistic networks. Comparative analysis between 5G and 6G technology is highlighted to examine why the 6G network will be compatible with the smart network. We have presented the key intrinsic issues of this framework mainly from the security and resource management context. In this paper, we have also introduced five use cases with real-world initiatives where blockchain technology can be used in smart logistics. These use cases are single digital window, cross-sector domain application, vehicle-to-vehicle communication, freight, and traceable luxurious goods. Later, some key challenges of using blockchain in smart logistics were identified, such as interoperability, scalability, the convergence of technologies, real-time data acquisition, and security, and possible solutions for these concerns were explored.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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