Amalgamation of blockchain and 6G-envisioned responsive edge orchestration in future cellular V2X ecosystems: Opportunities and Challenges

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SURVEY ARTICLE

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Amalgamation of blockchain and sixth-generation-envisioned responsive edge orchestration in future cellular vehicle-to-anything ecosystems: Opportunities and challenges

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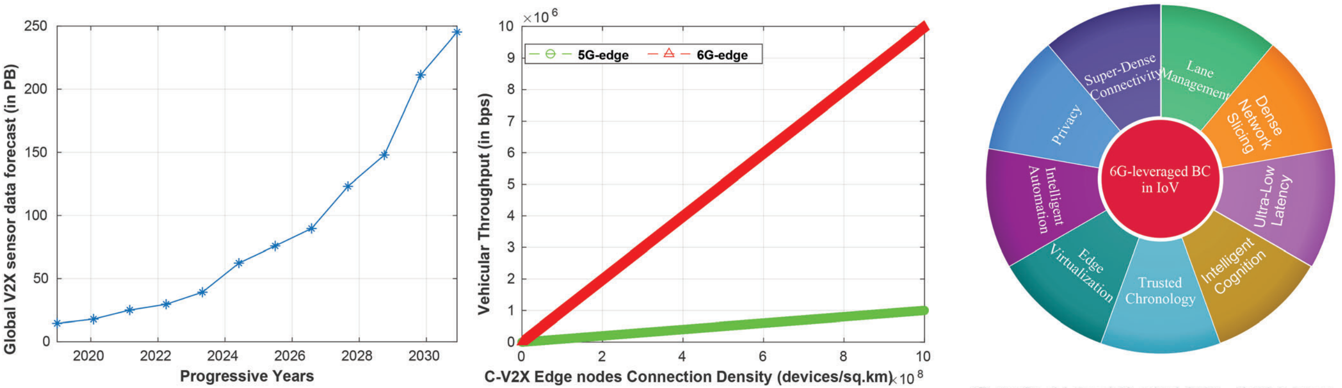
Abstract

In modern decentralized cellular-vehicle-to-anything (C-V2X) infrastructures, connected autonomous smart vehicles (CASVs) exchange vehicular information with peer CASVs. To leverage responsive communication, sensors deployed in CASVs communicate through responsive edge computing (REC) infrastructures to support device-to-device- (D2D) based communication. To support low-latency, high-bandwidth, dense mobility, and high availability, researchers worldwide have proposed efficient 5G REC infrastructures to end vehicular users (VU). However, with the growing number of sensor units, intelligent automation, dense sensor integration at massive ultra-low latency is required. To address the issue, the focus has shifted toward sixth-generation (6G)-based intelligent C-V2X orchestration. However, the sensor data is exchanged through open channels, and thus trust and privacy among C-V2X nodes is a prime concern. Thus, blockchain (BC) is a potential solution to allow immutable exchange ledgers among CASV sensor units for secure data exchange. With this motivation, the proposed survey integrates BC and 6G-leveraged REC in C-V2X to address the issues of fifth-generation (5G)-REC through immutable, verified, and chronological timestamped data exchanged through 6G-envisioned terahertz (THz) channels, at high mobility, extremely low latency, and high availability. The survey also presents the open issues and research challenges in the 6G-envisioned BC-enabled REC C-V2X ecosystems via a proposed framework. A case study *6Edge* is presented for smart 6G intelligent edge integration with BC-based ledgers. Finally, the concluding remarks and future direction of research are proposed. Thus, the proposed survey forms a guideline for automotive stakeholders, academicians, and researchers to explore the various opportunities of the possible integration in more significant detail.

1 | INTRODUCTION

Modern Smart Cities are driven through intelligent transportation that allows an integrated communication standard for vehicle-to-anything- (V2X) based ecosystems. Cellular vehicle-to-anything (C-V2X) ecosystems encompass smart interconnected vehicles, wireless protocol and internet-of-things (IoT) communication stacks to form an umbrella ecosystem for connected autonomous smart vehicles (CASVs).[1] In C-V2X, CASVs are embedded with smart sensors units that allow vehicular information exchange with peer CASVs and road-side units (RSUs) through wireless short-range vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-node (V2N) links, collectively termed as V2X links.[2] This allows co-operative communication and information exchange among CASVs for topology formation, tagged geo-locations, mobility information, weather services, traffic conditions, and energy trading with peer systems in the subnet.[3] However, with the rise of V2X networks, millions of sensors are currently deployed with CASVs to form dense sensor interactions that support advanced driving functionalities.[4] The sensors communicate through low-powered IoT-networked protocol stacks, and hence data exchange is computationally constrained.[5-7] Figure 1A presents the predicted forecast of the global V2X sensor data generation by 2030. By 2030, it is estimated that ≈ 245 PB of sensor data among CASVs would be exchanged. Thus, to handle the exponential increase in high-volume vehicular data in C-V2X, CASVs are faced with severe challenges of high mobility and adaptability for short-range communication links for V2V and V2I links. For the same, earlier, long-term evolution (LTE) coupled with orthogonal frequency division multiplexing (OFDM) was frequently deployed to support the bandwidth requirements in C-V2X.[8] However, to support the short-range communication requirements in C-V2X, FCC allocated 75 MHz spectrum in the 5.9 GHz frequency band, with a defined set of interfaces as IEEE 802.11*p* standard.[9]

As C-V2X evolved, requirements of device-to-device (D2D) communication motivated researchers to look beyond fourth generation (4G) LTE-based V2X solutions. To support low sensor computations at high bandwidth, third generation partnership project (3GPP) proposed C-V2X release 14 standards to support massive machine-type communications and multiple-in-multiple-out- (MIMO) based services. This allowed highly responsive vehicular infrastructures with sensor sharing to support low-powered direct spectrum ranges.[13] 3GPP allowed efficient resource sharing among CASVs through efficient multimedia broadcast multimedia services (MBMS) that allows massive dissemination through C-V2X links. However, to meet the mobility and latency requirements of CASVs, TE units at CASVs are not mature enough to deploy safety-critical automated driving applications. Moreover, the wide-band positioning of co-operative C-V2X links at low-latency is not addressed with 3GPP *release 14*. Thus, to cope up with increased vehicular communication footprint at reduced latency, researchers exploited the integration of 5G new radio (NR) with C-V2X to leverage ultra-low latency at high availability, and dense CASV sensor connectivity.[14] To support the same, 3GPP *release 15* was standardized to support modern C-V2X links, with end-to-end low latency ≈ 3 ms, at the reliability of 99.99999%. In protocol design, IEEE 802.11*bd* was formalized at low-latency and high throughput, with backward compatibility to legacy IEEE 802.11*p* standards. Also, with 5G-based C-V2X, enhanced mobile broadband (eMBB) services are deployed to allow high



(A) Global C-V2X sensor data generation forecast by 2030 [10]

(B) CASV throughput for C-V2X edge connection density [11]

(C) Benefits of fusion of 6G-assisted CASV with BC in internet-of-vehicles (IoV) [12]

FIGURE 1 Motivation behind amalgamation of blockchain (BC) and sixth generation (6G) for responsive edge computing in cellular-vehicle-to-anything (C-V2X): (A) Global C-V2X sensor data generation forecast by 2030;[10] (B) connected autonomous smart vehicle (CASV) throughput for C-V2X edge connection density;[11] (C) Benefits of fusion of 6G-assisted CASV with BC in internet-of-vehicles (IoV)[12] bandwidth to support CASVs sensor exchanges. Figure 2 shows the 6G-assisted REC in C-V2X-based ecosystems. It consists of the 6G radio access network (RAN) core, with optical photonic units (OPU) units to support high bandwidth at macrocell nodes. For the same, OPU employs photonic switching units and communicate as optical packets in core networks.[15] Macrocells also provide services to edge-controllers to communicate with RSUs units through different V2X links. In CASVs, there are different communicating devices like Bluetooth, sensor units, a global positioning system (GPS), and to communicate with external nodes through a wireless interface, we have the common arbitrator network (CAN) and local interconnect network (LIN) bus nodes.[16] CAN is a robust vehicle bus standard designed to allow devices and micro-controllers to communicate with each other in the absence of a host computer. LIN is also a standard used to interconnect various components within a car. LIN implementation requires a lesser cost as compared to the implementation cost of CAN. In V2X, there might be malicious CASV nodes that can form attacks through the propagation of incorrect updates in the network, and thus access and control policies need to be incorporated.[17] 6G also supports REC and allows dynamic provisioning in C-V2X links.

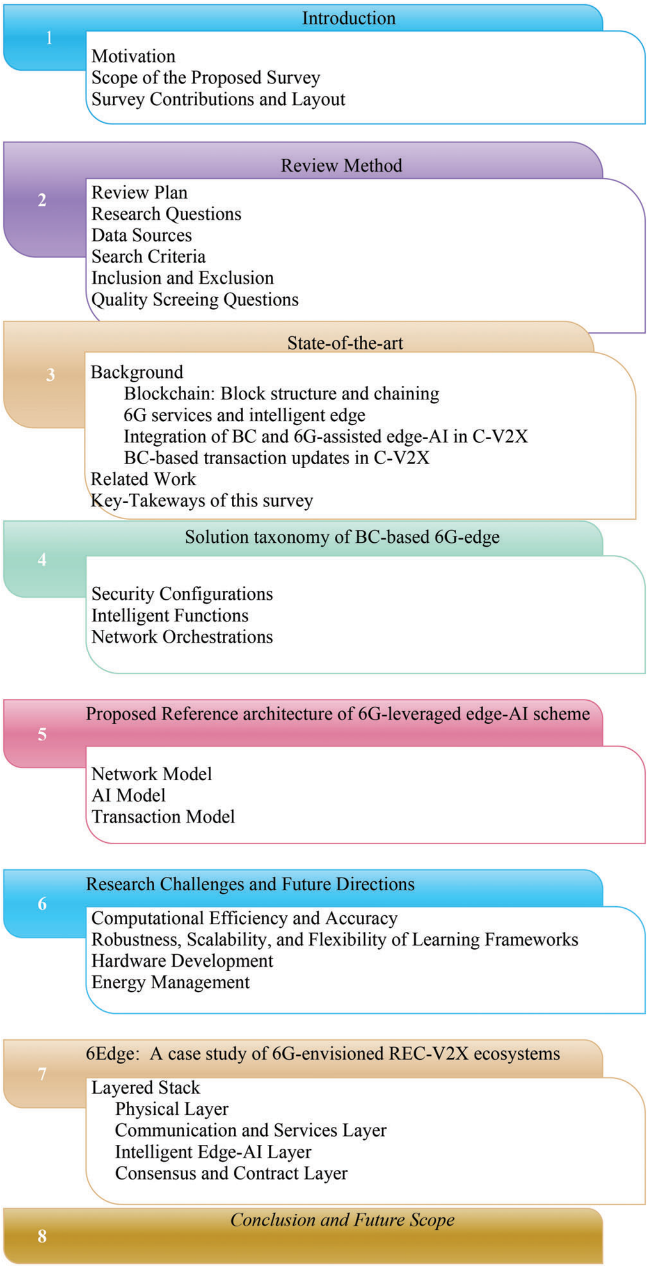


FIGURE 2 Sixth-generation services and responsive edge computing in cellular-vehicle-to-anything ecosystems

5G-NR-leveraged C-V2X supports various spectrum bands coupled with scalable OFDM that covers responsive time division duplex (TDD) subframes that allows a resilient radio interface at low-latency and high spectral efficiency. Also, the ecosystem supports consistent quality-of-service (QoS) across legacy networks with intelligent network slicing operations at the core level.[18] This allows the sharing of CASVs sensor exchanges through shared virtual resource pools supported through network function virtualization (NFV) control planes. This lowers the operational exchange (OPEX) costs with increased operational flexibility at network and switch fabrics, at increased granularity at flow operations. With NFV support, 5G cores support content caching and proximity services closer to the network edge or device terminal equipment (TE), defined as MEC. With MEC, C-V2X guarantees ultra-low latency, high mobility, and precise location awareness with real-time data access. MEC also supports content caching for D2D communication for 5G-C-V2X. Through virtualization via NFV in MEC, efficient and dynamic scaling of resources is achieved through service application programming interfaces (APIs).[19] However, with growing sensor integrations and expanding networks, 5G vehicular services would require intelligent on the edge orchestration and dense sensor connectivity in the near future. Also, NFV would require intelligent virtualization of the physical layer (PHY) and medium access control sublayer (MAC) layers with resource-slicing based on a defined set of vehicular functionalities. The resources allocated to slices would be based on diverse traffic conditions and would require efficient management at control layers.

The issues mentioned above related to responsive MEC integration and dense sensor connectivity require intelligent edge orchestration. Thus, 5G-REC deployments in C-V2X require high device density and service availability shortly to support mobility, and device density on the current 5G fronthaul networks.[20] The 6G flagship program is currently rolled out by the University of Oulu, Finland, for future adaption by 2030, which allowed researchers and automotive stakeholders to explore issues and challenges of current 5G-enabled REC C-V2X ecosystems. With high network connectivity, ultra-dense sensor integration, super-mobility and accurate real-time location precision 6G services can optimize the physical PHY and link-level MAC layers of 5G to allow dynamic REC to scale to super-dense large scale wireless C-V2X ecosystems. With more flexibility in network orchestration service through programmed reconfigurability of PHY and MAC channel access.[21] 6G offers unprecedented connectivity to MEC at tera-hertz frequency bands and very high availability of 99.9999999%. Figure 1B presents the comparative analysis available vehicular throughput for 5G and 6G REC, for several connected CASVs sensors (devices) in each km. It is envisioned that 6G offers 10*X* times more connected density than 5G, and hence can form ultra-dense sensor connectivity, with no bottlenecks and well available user throughput. Figure 1C presents the various benefits of fusion of 6G-assisted CASV with BC in IoV.[12]

Thus, the fusion of 6G-assisted CASV with BC in C-V2X would drive cutting-edge solutions for computing technologies for vehicle-to-cloud (V2C) environments, fog computing nodes, and distributed processing and management of cellular nodes. Via 6G, the possible limitations of 5G are handled perfectly, including the drawbacks of short and directed bursts in V2X communication scenarios, and ultra-high reliability, extremely low-latency, and processes ad offloads services as near-node through edge-AI. Thus, data-centric applications are serviced with less latency, with a ubiquitous communication boundary that involves space-air-ground-sea integrated networks. 6G allows perfect integration of AI services that are part of the management toolbox and orchestrates the requirements of intelligent networking, content, caching, and coding performance. The communicating antennas can set up strong precoded data from learning models that facilitate the communication parameters through AI models. At the security front, 6G combines BC, federated ML, and digital-twin technology (DTT), as part of an inherent service stack that can address potential security loopholes in C-V2X communication and allow services like virtual cloud reality, smart grids, distributed learning, and industry verticals to communicate effectively to C-V2X. This allows the realization of services to be integrated to CASVs, as and when needed, on the fly mechanism.

However, the fusion of 6G-assisted edge-AI with BC has some potential challenges to address. C-V2X networks are highly dynamic and suffer from limitations of path losses of wireless networks, dynamic node topology, and traffic flow information. Currently, the AI models are not mature enough to learn effectively from real-time dynamic data and are more focused on historical data sources. In real-time deployments, the collected data from sensors are passed through multiple heterogeneous nodes in different formats. 6G communication stacks have to design uniform protocols that can address the exchange interoperability. Moreover, 6G-enabled radio has to estimate the losses due to high-dimensional wireless fading channels and requires effective AI modulations scheme to track channel estimation schemes. Once data is collected, the interfacing of 6G-assisted edge nodes through BC is designed through service-oriented points that facilitate micro-payments and contract execution ecosystems. The design of service points that can facilitate communication is a challenging and complex task. Table 1 presents the list of abbreviations and the intended meanings used throughout the manuscript.

TABLE 1 Abbreviations and their descriptions

Abbreviations	Descriptions	Abbreviations	Descriptions
3GPP	Third Generation Partnership Project	NFV	Network Function Virtualization
5G	Fifth Generation	NOMA	Non-Orthogonal Multiple Access
6G	Sixth Generation	NR	New Radio
AI	Artificial Intelligence	OB	Optical Beamforming
APIs	Application Programming Interfaces	OBUs	Optical Broadband Units
BC	Blockchain	OFDM	Orthogonal Frequency Division Multiplexing
CA	Certificate Authority	OPEX	Operational Exchange
CAN	Common Arbitrator Network	OPU	Optical Photonic Units
CASVs	Connected Autonomous Smart Vehicles	PB	Petabytes
CIoV	Cloud-based IoV	PHY	Physical Layer
CNN	Convolutional Neural Networks	PKI	Public-Key Infrastructure
CSI	Channel State Information	PoS	Proof-of-Stake
C-V2X	Cellular- Vehicle-to-anything	PoW	Proof-of-Work
D2D	Device-to-Device	QAM	Quadrature Amplitude Modulation
DAO	Decentralized Autonomous Organizations	QML	Quantum Machine Learning
DBSCAN	Density-Based Spatial Clustering of Applications	QoE	Quality-of-Experience
DDoS	Distributed Denial-of-Service	QoS	Quality-of-Service
DL	Deep Learning	RAN	Radio Access Network
DNNs	Deep Neural Networks	RBM	Restricted Boltzmann Machine
DPoS	Distributed PoS	REC	Responsive Edge Computing
DRL	Deep Reinforcement Learning	RF	Radio-Frequency
DSRC	Dedicated Short Range Communications	RL	Reinforcement Learning
ECC	Elliptic Curve Cryptography	RNN	Recurrent Neural Networks
eMBB	enhanced Mobile Broadband	RSUs	Road-Side Units
FCC	Federal Communications Commission	SC	Smart Contract
FCSNN	Fully Connected Supervised Neural Network	SDN	Software Defined Networks
gNB	Next Generation Evolved Node	SIC	Successive Interference Cancellation
GPS	Global Positioning Systems	SM-MIMO	Super-Massive MIMO
HBF	Holographic Beamforming	SVM	Support Vector Machine
HOG	Histogram of the Oriented Gradient	SWIPT	Simultaneous Wireless Information and Power Transfer
IoT	Internet-of-Things	TCP	Transmission Control Protocol
IoV	Internet-of-Vehicles	TDD	Time-Division Duplex
IPFS	interplanetary File System	TE	Terminal Equipment
KCF	Kernel Correlational Filters	THz	Terahertz
LBUs	Local Blockchain Units	UAV	Unmanned Aerial Vehicles
LiDAR	Light Detection and Ranging	V2C	Vehicle-to-Cloud
LIN	Local Interconnect Network	V2G	Vehicle-to-Grid
LIS	Large Intelligent Surfaces	V2I	Vehicle-to-Infrastructure
LSTM	Long-Short Term Memory	V2N	Vehicle-to-Network
LTE	Long-Term Evolution	V2P	Vehicle-to-Pedestrian
MAC	Medium Access Control Sublayer	V2R	Vehicle-to-access (Residential Units)
MBMS	Multimedia-Broadcast-Multicast-Services	V2V	Vehicle-to-Vehicle
MDP	Markov Decision Process	VLC	Visible Light Communication
MEC	Mobile Edge Computing	VU	Vehicular Users
MIMO	Multiple-Input-Multiple-Output	WLAN	Wireless Local Area Network
ML	Machine Learning	YOLO	You Look Only Once

1.1 | Motivation

6G communication leverages real-time edge provisioning for dynamic allocation of resources to CASVs, energy-trading, smart grid optimization, and dense sensor management in C-V2X ecosystems. However, artificial intelligence (AI) techniques enable the edge to become intelligent through effective learning models that leverage high-end control of the 6G aggregator and core units. For the same, machine learning (ML), deep learning (DL), and reinforcement learning (RL)-based techniques are employed heavily at edge nodes, however at low-power and energy costs to communicate with CASV sensor nodes. Thus, edge-AI allows REC and minimizes the training losses and bias convergences of models at dense mobility C-V2X interactions. At core layers, edge-AI models can be trained to locally co-operate with sensing and communication units to form effective D2D offloading and resource management. With more data, the edge weights are optimized, and the models become more responsive with more iterations. At the application layer, BC can be combined to process exchanged data and form a transactional model, with automated execution through smart contracts (SC).[22] Thus, the proposed survey combines the disruptive technologies in C-V2X ecosystems and builds the foundations of the technical perspectives in greater detail.

1.2 | Scope of the proposed survey

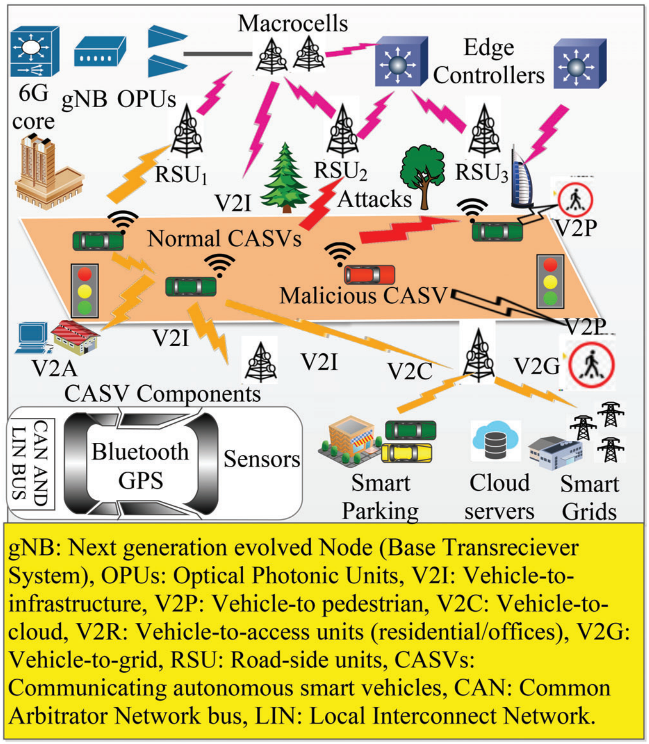
In C-V2X ecosystems, REC has expanded the computational capabilities of cloud-based ecosystems and is considered as a key enabler to leverage communications close to vehicular nodes, which allows short communication latency to access a set of V2X resources. To support REC, responsive AI has attracted researchers globally to provide learning models that serve network delays through intelligent cognition and support computational offloading. This simplifies the task processing at C-V2X nodes and improves QoS. As the second pillar, the generated data is humongous and thus requires communication services as a set of a virtualized toolbox for easy flexibility and reconfiguration. Thus, 6G services are integrated as service sets to leverage the MEC models and allow resilient REC systems. However, the data exchange through open channels is required to be protected against malicious V2X attacks like jamming, impersonation, certificate forgery, and denial-of-service (DoS) attacks. Thus, to secure the CASV ecosystem, BC is a viable choice to induce trust among communicating stakeholders and be secured against alterations.[23]

In existing surveys, the authors have proposed studies on the integration of BC for trust and attack mitigation in C-V2X. As part of network management, authors have proposed surveys that highlight the importance of 5G and 6G on the C-V2X-based ecosystem. Through 5G systems, edge service and D2D computational offloading have been addressed for resource satisfaction in 5G and 6G networks. Via edge intelligence, effective use of ML and DL algorithms are proposed for monitoring the real-time traffic, V2X sensing, and cooperative path planning in C-V2X. However, with the exponential rise in network traffic, resource management has to be resilient in the near future. As mentioned in the Section 1.1, the integration of 6G, edge-AI, and BC into C-V2X is the technology that would drive the future C-V2X ecosystems. The earlier proposed surveys to date have not considered the integration as a coherent unit, which is the requirement to design effective schemes that focus on security, trust, as well as effective network management via edge-AI. Thus, owing to the limitations and gaps in earlier surveys, the proposed survey considers the network, intelligence, and security parameters as a coherent unit and presents a reference architecture specific to C-V2X ecosystems. The survey proposes an umbrella approach to the importance of REC through the fusion of 6G and BC in C-V2X, which is essential in deploying effective solutions by C-V2X stakeholders. Figure 3 presents the organization of the proposed survey.

1.3 | Survey contributions

Following are the contributions of the proposed survey.

1. The authors present the discussion of 6G, REC, and BC in C-V2X ecosystems and present the integration of BC and 6G-assisted edge-AI in C-V2X. The authors have identified the limitations in existing surveys and have proposed a solution taxonomy that bifurcates the functionalities as network orchestration, intelligent functions provided through edge-AI, and BC-based security considerations.



gNB: Next generation evolved Node (Base Transreciever System), OPUs: Optical Photonic Units, V2I: Vehicle-to-infrastructure, V2P: Vehicle-to pedestrian, V2C: Vehicle-to-cloud, V2R: Vehicle-to-access units (residential/offices), V2G: Vehicle-to-grid, RSU: Road-side units, CASVs: Communicating autonomous smart vehicles, CAN: Common Arbitrator Network bus, LIN: Local Interconnect Network.

FIGURE 3 Organization of the proposed survey

2. Based on the solution taxonomy, we propose a reference architecture for the 6G-assisted edge-AI scheme and present the discussions on the network model, AI model, and security model of the proposed architecture.
3. Next, we present the research challenges of highlighting a comparative analysis based on research challenges of 6G, edge-AI, and BC in C-V2X, in terms of associated parameters. We present the open issues, the future scope of presented challenges, and deployment scenarios in explicit detail.
4. A case-study *6Edge* is proposed as a unified layered stack that addresses the possible limitations and addresses the possible integration of BC, edge-AI for REC, and BC in C-V2X as a unified layered model.

1.4 | Layout

The layout of the survey is as follows. Section 2 presents the formulation of the review method. Section 3 presents the background of blockchain, 6G, intelligent edge, and the integration of these disruptive technologies in C-V2X-based ecosystems, with the discussion on the existing state-of-the-art surveys in a similar domain, along with the pros and cons. Section 4 presents the solution taxonomy of the proposed survey. Section 5 presents a proposed reference architecture of a 6G-leveraged edge-AI scheme with BC nodes to process transactional entries. Section 6 discusses the research challenges and future key directions. Section 7 presents the proposed *6Edge* case study as layered stack model based on specific functionalities. Finally, Section 8 presents the concluding remarks.

2 | REVIEW METHOD

The section discusses the review methodology presented in the paper for the amalgamation of BC in 6G-envisioned edge orchestration schemes in evolving C-V2X-based ecosystems. The technique of conducting the review is formulated according to principles proposed by Kitchenham et al.[24-26] To formulate the basis of the survey on the integration, we select the survey criteria, the process of inclusion and exclusion, and propose the research questions for the survey. The details are presented as follows.

2.1 | Review plan

To propose the survey, an initial brainstorming was conducted among the authors to formulate the importance of the survey in current research, and a careful outline of the benefits of the survey is highlighted. Once the research questions are formulated, we selected matching research questions from various academic databases, data sources, and the criteria of inclusion and exclusion were identified. Based on the defined criteria, inclusion and exclusion of research papers are conducted based on the title of articles, then the abstract, introduction, and the importance of the paper, based on the reads and citations at the journal database. A careful screening is conducted, and relevant papers are selected.

2.2 | Research questions

As mentioned in the preceding Section 2.1, the authors studied the benefits of the integration of BC and 6G based on key drivers of the disruptive technologies. For BC, the authors perceived the security aspects against adversarial attacks in C-V2X ecosystems, and intelligent edge orchestration through AI was studied in 6G to support REC. On this vision, the authors have prepared some specific questions to evaluate the key drivers, benefits, and challenges in deploying the technologies. Table 2 presents the research questions and their objective.

2.3 | Data sources

Based on the research questions and formulated objectives in mind, the authors have proposed an exhaustive survey of academic databases for reports, journal articles, conferences, and chapters from libraries like IEEE *Xplore*, Wiley, Springer, the ACM Digital Library, ScienceDirect, etc. Also, the authors have read books on the topics of BC and ML through online libraries, technical websites, and qualitative massive online open courses on different platforms.

2.4 | Search criteria

Search keywords are used to gather the relevant literature work. It includes “Decentralized”, “6G”, “V2X”, “BC *AND* V2X”, “6G-envisioned” *AND* “responsive edge”, “Intelligent edge *AND*BC”, “Edge-AI *AND* V2X”, “BC *AND* Edge-AI”, Responsive edge *AND* V2X”, “6G-envisioned security”, *AND* “V2X”, and “Responsive Edge orchestration” . Figure 4 shows these selected keywords.

TABLE 2 Research questions

Question number	Research question	Objectives
RQ-1	How many key services are present in 6G to leverage intelligent network orchestration for C-V2X?	To explore 6G standards and services about C-V2X based ecosystems
RQ-2	Which type of AI algorithms are most suited for REC?	To find the scope and working nature of these algorithms
RQ-3	How to formulate effective learning models with high accuracy and at low computation cost?	To study low-powered ML, DL, and RL schemes suitable for sensor-based integrations
RQ-4	Which kinds of issues arise with C-V2X based nodes when resources are provisioned through 6G networks?	Formulate a secure decentralized approach through BC to ensure chronology and trust
RQ-5	How to integrate intelligent-edge services with a 6G communication stack?	Study about intelligent offloading schemes and nature of learning models
RQ-6	How to integrate BC with edge schemes?	Formulation of a proposed reference architecture that formulates models specific to functionalities of the network (6G), learning (AI-models), and transactions (BC)

Abbreviations: 6G, sixth-generation; BC, blockchain; C-V2X, cellular-vehicle-to-anything; DL, Deep Learning; ML, Machine Learning; REC, responsive edge computing; RL, Reinforcement Learning.

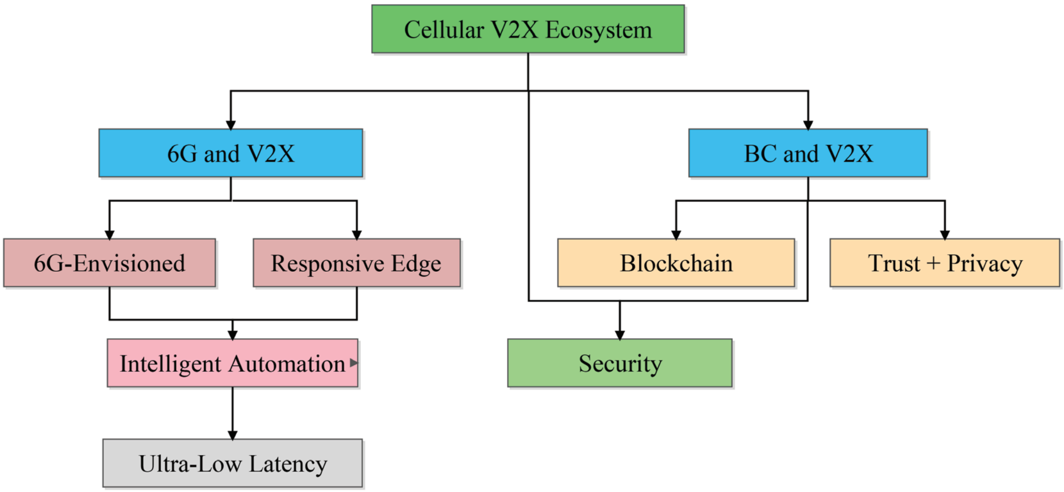


FIGURE 4 Search string

2.5 | Inclusion and exclusion

We considered suitable keywords shown in Figure 4 to formulate the search string as *"Cellular V2X Ecosystem + keyword*"*. Later on, 256 relevant research articles are collected from the databases as mentioned above. Then, we scrutinized these publications according to the inclusion-exclusion principle. We set up the filtering policy based on the match of titles and citations in SCOPUS and Google Scholar to find relevant items. This allowed articles to be selected based on a match of the set search string, quality, and relevance of the proposed survey. Some important papers are not found based on the applied search methodology. Therefore, some relevant publications are then collected manually. Finally, we scrutinized and selected relevant 80 publications in total. Figure 5 presents the details.

2.6 | Quality screening questions

To ensure quality-review, a quality screening round was conducted based on the proposed abstract, and the formulated research questions. Table 3 presents the quality screening questions to evaluate the survey importance and scope.

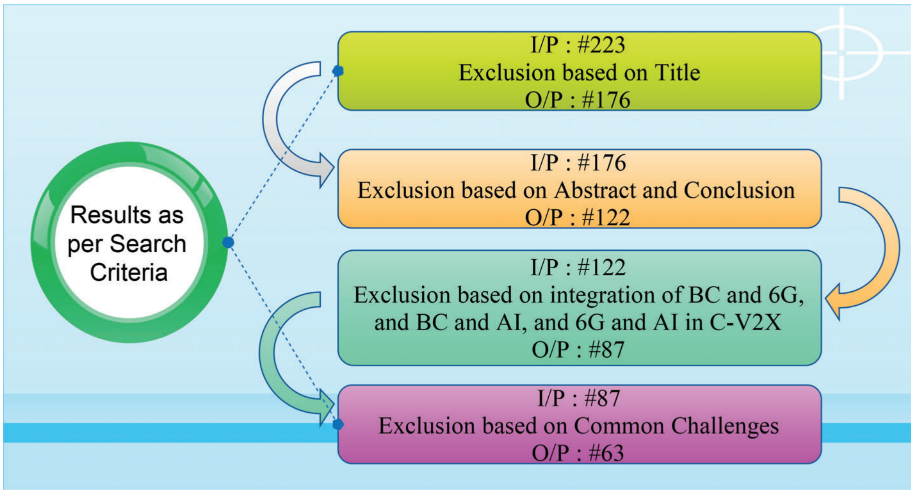


FIGURE 5 Inclusion and exclusion

TABLE 3 Questions used for screening

S. No.	Question	Yes/No
1	Does the publication is related to the 6G-envisioned responsive edge orchestration in future cellular V2X ecosystems?	Yes
2	Where the word "6G-envisioned responsive edge" is not being used in cellular V2X ecosystems, such publications are not considered in related work?	No
3	Does the abstract, title, and related work in the article discussed on the 6G-envisioned responsive edge orchestration cellular V2X ecosystems?	Yes

Abbreviations: 6G, sixth-generation; V2X, vehicle-to-anything.

3 | STATE-OF-THE-ART

The section presents the background and technicalities of 6G and BC in C-V2X and presents the parametric analysis of the proposed survey with existing state-of-the-art surveys in C-V2X.

3.1 | Background

The section presents the background of BC, 6G services, and intelligent edge control, and the possible integration scenarios in C-V2X environments. The details of the same are now presented as follows.

3.1.1 | Blockchain: Block structure and chaining

BC is a transactional chain ledger that can be used to store transactions by any participating entity in the chain. The participating entities can share data as transactions over different autonomous systems in a reliable and distributed manner through open channels.[30-32] The shared data is chronological, immutable, and tamper-resistant. A block in a BC is divided into block header and transaction body. Figure 6 depicts the general structure of any N^{th} block in BC, and then presents the logical chain structure.[28,33] As evident, a block consists of Merkle root value, nonce, the difficulty of a miner, the current block hash, and a pointer to the previous block hash. With Merkle value, the chain structure root hash is stored in each block, and thus every participating entity knows the complete chain, right from the *genesis block*, or the zeroth block. The *genesis block* does not contain any previous hash pointer. Now the blocks are linked with each other, and the linkages ensure the data is immutable. For adding a block, the miners need to solve the nonce value smaller than the target hash. Once a block is added, the copy of the chain is updated to each participating node to maintain consensus. Hence, BC allows the secure and chronological maintenance of transactional entities and removes the requirements of third-party entities among transacting entities.

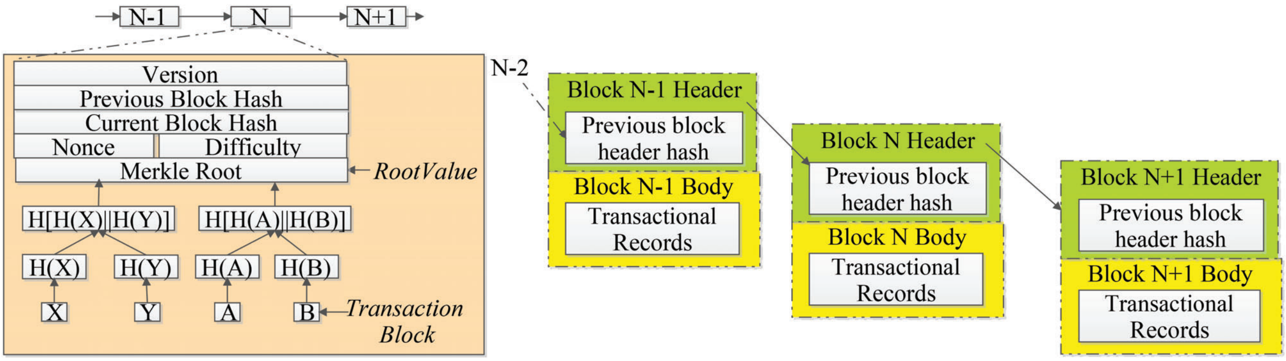


FIGURE 6 The basics of blockchain[27-29]

3.1.2 | 6G services and intelligent edge

By 2030, communications will be intelligent, data-driven, ubiquitous, and with high connectivity and dense mobility. To support the vision, 6G would be a potential driver to achieve connectivity to anything and would integrate massive sensing, computing, caching, navigation, radio imaging, and secured data exchange. 6G envisions both human and device-centric communication supported through a full-layered AI stack to allow intelligent applications.[34] 6G would support tera-hertz (THz) communication bands, with a peak data rate of $1-10$ Tbps, a user-throughput of $1-10$ Gbps, and very low latency of $10-100\mu$ s, at high mobility of 1000 km/h. In the future, 6G is envisioned to support a connection density of $10X$ times of 5G, with energy efficiency close to $10-100X$ that of 5G. With improved connection density, 6G would support a range of applications related to holographic, tactile internet, automated driving, Industrial IoT, deep-sea networks, and the internet of bio-nano things.[11] For the same, 6G proposed super-massive MIMO, with laser and visible light communications (VLCs). In C-V2X, 6G supports highly reliable and low-latency communications, with intelligent analytics, caching, and decision control through ML/DL/RL models.

As mentioned above, to allow REC, 6G employs edge-AI that combines 6G macro-cells close to edge servers. The details of 6G-assisted intelligent edge is presented in Figure 7. As shown, the CASVs can intelligently offload tasks to nearby cells automatically managed through the task offloading device. The device sends the requests to nearby edge-servers that learn through ML/DL models to form a task mapping based on network input and output conditions. The model optimizes itself and is self-learning. Based on changing C-V2X conditions, the model segments itself to provide optimized solutions to the neighboring cells.[35]

3.1.3 | Integration of BC and 6G-assisted edge-AI in C-V2X

In C-V2X, sensors are deployed as building blocks to collect data, which is classified as sensing and CASV status data. The sensing data is gathered from embedded sensors, for example, GPS, brake sensors, temperature sensors, and light detection and ranging sensors. CASV status data shows the computational capability, energy, and storage capacity of the vehicle. Based on collected data, edge devices train the local models for parameter optimization and upload the results on edge servers to form intelligent decisions in real-time. The process is iterated multiple times, and the model converges to an optimal state. Based on learned parameters, intelligent and cooperative offloading is performed and optimized for performance metrics in real-time.[36] To reduce the computational cost, learning results are stored locally at edge devices to allow REC. To exchange the results, BC can be used as a transactional model to store the data as chronological ledger entries, so an adversary cannot change the results of the learning patterns.

Thus, the convergence of BC in 6G-assisted edge to leverage REC in C-V2X can drive secure data sharing, trust, and provenance. It allows distributed edge intelligence to guarantee high security and reliability while maintaining vehicular nodes' massive and dense connectivity. Thus, the integration can support mission-critical operations in C-V2X and can allow local sensor objects to interact with other devices with reduced operational complexity. Through AI, it can support operations that offer real-time and on-demand services to CASVs through the 6G communication channels,

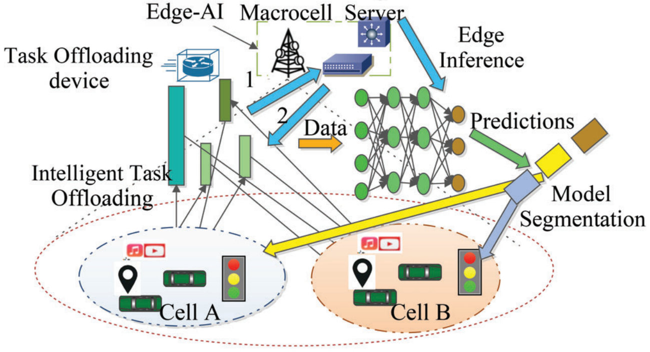


FIGURE 7 Sixth-generation-assisted intelligent and responsive edge[35]

minimizing road accidents. We present two of the possible use-cases that benefit from the possible integration. The details are presented as follows.

- *Accurate traffic-flow predictions*: Analysis and prediction of traffic-flow information is a critical problem of study. As the generated V2X data is humongous, computational processing capacity is required at edge nodes to power AI models to form accurate predictions on traffic behavior. For the same, either historical, or real-time data is fed from heterogeneous V2X sources, and models are exploited to produce accurate results. BC leverages trust among sources that share data with the AI models.
- *Routing and mobility predictions*: In C-V2X, due to the high mobility of vehicular nodes, the nodes position and connection topology pattern changes dynamically. Data collected from different sources like CASVs, RSU, and grid units, are transmitted to REC nodes that employ local learning models to form valuable predictions. In such cases, fuzzy systems and RL are preferred to decode effective routing strategies to dynamic changing patterns. Through edge-AI, the dynamic patterns can be stored in local servers, which reduces the training loss of the local models, and converges faster to the global state. BC facilitates that correct and trusted updates are chosen for the formation of topological paths, as incorrect updates are not validated in the transactional ledgers.

3.1.4 | BC-based transaction updates in C-V2X

This subsection discusses the different types of transactions and message updates among CASVs in 6G-assisted C-V2X environments. In C-V2X, owing to the critical infrastructure, high reliability in information dissemination is required. C-V2X supports 5.9 GHz DSRC links to communicate with infrastructures, cloud, grids, pedestrians, and peer vehicles. The communication is assisted through on-board sensor units (OBUs) that builds an on-demand ad-hoc network to communicate in a distributed manner. The communication is assisted through 6G-virtualized service sets, and communication channels are set up. However, an adversary can impersonate a malicious RSU unit and alter the sent messages due to open channel stacks. To mitigate this, we consider that each RSU unit has a trust value in the network. The RSU with trust values higher than a threshold is allowed to create a genesis block to start a communication event in C-V2X. Moreover, we assume that V2X nodes with high trust levels, and computing power, are considered for the miner election process. In V2X, we consider blocks initiate three different types of transaction sets: the event-based transactions (vehicle information and RSU setup), trust-based transactions (CA, signature, and cryptographic primitives), and communication-based transactions (6G-based network information and service setups). Based on the transaction type, two types of messages are communicated between CASVs in C-V2X ecosystems, one is the beacon message and the other is the event safety message. Beacon messages are periodic broadcasts to peer nodes in C-V2X to inform them about the location, status, and routes. This ensures cooperative vehicular management and mitigates road accidents, congested lanes, and hazardous conditions. Event safety messages inform about specific events that are registered by nodes in C-V2X and are categorized into different priorities, depending on the criticality of the event type. The beacon and the event messages are stored as transactions in BC, and are verified and signed by near RSUs and forwarded to the miner nodes. The added block can be viewed by all nodes in C-V2X based on public/private key pairs, and the signature of the corresponding RSU unit.

We present a high-level view of the BC-based transaction scheme in C-V2X based on beacon and event messaging paradigms. Figure 8 presents the flow-based scenario that stores event messages as transaction logs, along with the trust value of nodes in V2X. As BC is immutable, the trust values of nodes cannot be altered, and it ensures reliability in the ecosystem in case malicious RSUs hijack the network infrastructure. We assume that there are n CASVs, denoted as $\{\mathrm{CASV}_1, \mathrm{CASV}_2, \dots, \mathrm{CASV}_n\}$ that register there details $\{\mathrm{CASV}_{\mathrm{ID}}, \mathrm{CASV}_{\mathrm{type}}, \mathrm{Tx}_{\mathrm{type}}\}$ in the BC network. $\mathrm{CASV}_{\mathrm{ID}}$ denotes the identifier information of any nth CASV, $\mathrm{CASV}_{\mathrm{type}}$ denotes the type of vehicle, and $\mathrm{Tx}_{\mathrm{type}}$ denotes the type of transaction they float in the network. Initially, all CASVs form the cooperative control and broadcast their location coordinates $\{L_1, L_2, \dots, L_n\}$ in V2X. A mapping $M : \mathrm{CASV}_n \rightarrow L_n$ exists to map independently the location information to the particular CASV. In case an event E is updated (route changes, road conditions), the information is broadcasted to all neighboring CASV units inside a jth servicing RSU unit. If events are not updated, the cooperative information from peer CASVs is further collected to ensure a global common state of topology. Once the information is broadcasted, the CA verifies the transaction state and adds its signature to the event. A CA is selected based on trust value in the network to ensure malicious nodes do not forge any wrong updates in the network. Once CA signs the event, all CASV

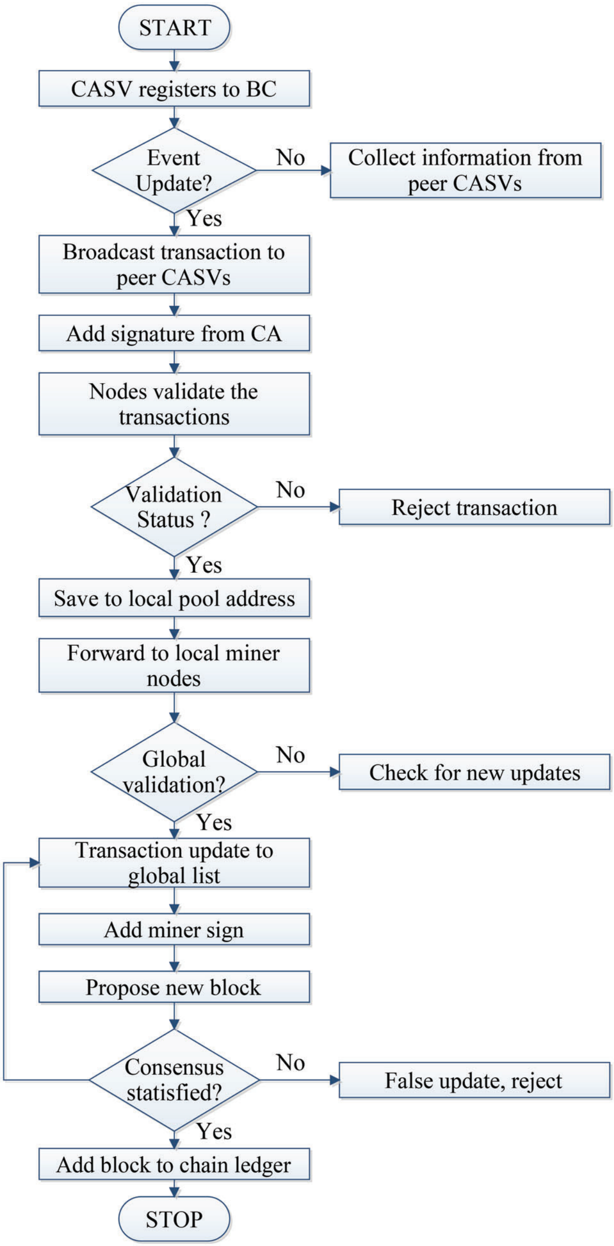


FIGURE 8 A high-level event and transaction flow of blockchain-based cellular-vehicle-to-anything[2]

nodes can access and verify the transaction copy based on its associated public and private keys, denoted by $\mathrm{Pub}_{\mathrm{CASV}}$, and $\mathrm{Pr}_{\mathrm{CASV}}$, respectively. The transaction is forwarded to validator nodes $V_1, V_2, \dots, V_k$ that validates the transaction and updates the validation status, as success and failure. If all the k validators reach a common consensus state C_V, the transaction is saved in a local buffer pool L_p, and an address to the transaction is allocated, denoted by $A(L_p)$. In case of consensus is not achieved, transaction Tx is rejected. $A(L_p)$ is forwarded to the q local miner nodes, denoted by $\{M_1, M_2, \dots, M_q\}$ to form the global validation state of Tx. The global state of the transaction, denoted as GS(Tx) is achieved by peer consensus of miner nodes, and the Tx is added to global buffer pool G_p. In case the consensus fails, new updates are searched, and the process is iterated. Any unconfirmed transaction is rejected, and hence, any forged update is not possible, as they would get rejected by V_k, and M_q, respectively. The miner signs Tx in G_p, and the transaction is proposed to be appended in new block B_n. Finally, B_n is assigned a block header, and the body consists of a list of verified transactions from G_p. The header consists of the previous block hash and current block hash address and is then added to the on-chain structure. The timestamp T of B_n is recorded and stored in L_p so that all V2X nodes can access the recorded block.

3.2 | Related work

To date, many surveys have been conducted, that explored various security aspects of decentralized C-V2X-infrastructures CASVs. Table 4 depicts a comparative analysis with the existing state-of-the-art with the proposed survey along with its pros and cons.

Zhang et al[34] presented various key features of 6G technology and demonstrated a novel architecture for the autonomous network. The authors highlighted the roles and pros of various technologies to improve the overall performance of the 6G network. It includes orbital angular momentum (OAM) multiplexing, BC-based spectrum sharing mechanism, super-massive MIMO (SM-MIMO), and molecular communication. Yang et al[35] proposed a four-layer novel AI-based framework 6G networks for better service provisioning through which network adjustment is carried out automatically. Authors in Reference 37 performed the comparative analysis of cellular V2X and 802.11 V2X and provide a concluding remark to excel in the performance of the IoV network. The authors also discussed future directions and potential solutions/technology for the big data-driven IoV and CIoV. Li et al[38] presented a BC-based data security scheme that leverages AI for 6G-assisted terrestrial networks. They proposed applications specific to AI indoor navigation and secure and tamper-proof exchange of data through BC. A case study is also presented in the survey. Authors in References 39,45 proposed BC-based countermeasures for security attack vectors in vehicular environments based on different threat classifications. However, the authors have not discussed the network performance characteristics in the study.

Authors in Reference 40 proposed survey on AI-based network orchestration to resource management. They proposed a four-layer network stack for intelligent sensing, mining, automation, and control. They discussed the mobility and handover schemes based on smart spectrum sharing and discussed potential applications. However, the security of exchanged data is not discussed. Authors in References 43,44 discussed performance analysis of BC and countermeasures of attacks in V2X ecosystems. However, resource provisioning approaches through BC are not discussed.

For resource sharing Xu et al[41] proposed a BC-assisted resource sharing framework in 6G networks for D2D communications, with an effective network slicing technique. Rahim et al[42] proposed 6G for V2X ecosystems and focused on how ML can be a potential solution to handle challenges of co-operative sensing and control among V2X nodes. The survey did not discuss the potential attacks on the V2X nodes and the countermeasures. Authors in Reference 21 discussed a comprehensive survey on ML approaches in 6G for intelligent radio and self-learning network management with fine-tuned models. The survey discusses the possible integration of ML models to assist the cause. The authors did not focus on the key aspects of 6G communication that drive the ML to form intelligent learning models. Gupta et al[39] proposed a 6G-envisioned edge intelligence- (EI) based protocol stack that handles the issues of 5G in terms of latency and reliability schemes and has demonstrated the use-case of COVID-19 situation handling through 6G-enabled EI. The paper discusses the comparative analysis of the use-case in the backdrop of 4G- and 5G-based key deployments. However, the authors did not explicitly discuss security and privacy-based issues when a humongous amount of data is exchanged through open channels. Ji et al[47] discussed 6G-envisioned network in box (NIB) solutions for network management, which allows dynamic reconfiguration and deployment of key network services and orchestrates the inherent capabilities of intelligent computational models. For the same, the authors have considered integrating evolutionary computation and neural and fuzzy systems as part of NIB for a range of applications about edge and cloud services. However, the authors have not explicitly considered the security issues in NIB management and attack scenarios during resource provisioning among 6G-enabled edge nodes. Authors in Reference 48 presented a BC-based edge-of-things (BEoT) ecosystem that can address the dual issues of low-latency and high security for IoT applications. This survey presents insights about the advantages of BEoT integration in health care, smart grids, and vehicular networks and presented solutions for attack vectors through the BC-based trust ecosystem. However, the survey does not address the issues of resource orchestration in EoT to handle the massive data flux of industrial IoT devices. You et al[49] presented a comprehensive survey on the 6G visions and capabilities to support future wireless application requirements through a detailed explanation of 6G waveforms, channel access, network slicing, and services in a space-air-ground sea integrated communication. The authors, however, did not address the discussions on the security of applications in greater detail.

Based on the comparative analysis shown in Table 4, existing surveys in C-V2X are broadly divided into three category sets, the communication perspective, edge computing models, and security perspective. Through communications, the issues of vehicular mobility, control, positioning, channel models, and services are presented. Edge computing-based surveys have focused on intelligent resource provisioning, content caching, and offloading at local V2X nodes, whereas security-based surveys are focused on secured data dissemination and trust-based computing models. However, in modern-day V2X, with the rise of edge intelligence in 6G, V2X attack boundaries have increased, and thus, there is a requirement for a comprehensive survey that addresses the challenges as a single coherent unit. Thus, in the survey, the

TABLE 4 Comparative analysis with the existing state-of-the-art with proposed survey along-with its pros and cons

Contribution of Author	Year	1	2	3	4	5	6	7	Pros	Cons
Zhang et al[34]	2019	N	Y	N	Y	Y	Y	N	Key requirements and vision of 6G technologies for different applications are discussed	More insights on BC-based spectrum sharing and quantum key distribution is not present
Yang et al[35]	2019	Y	N	N	Y	Y	Y	Y	Paper proposed two-layer edge learning-empowered ML based framework for autonomous vehicles (AVs)	Focused more on a centralized approach
Zhou et al[37]	2019	Y	Y	Y	Y	Y	Y	N	Paper proposed novel dedicated short range communications (DSRC) technology for V2X communication	Integration of IoV and cloud-based IoV (CIoV) was not explored in detail
Li et al[38]	2020	Y	Y	Y	Y	N	Y	Y	Paper proposed BC-enabled secure scheme in 6G network for AI applications	Rules and regulations for usage of data were not highlighted in paper
Gupta *et al.*[39]	2020	Y	Y	Y	N	N	N	N	Classification of threat by considering Authentication and serviceability	No discussion on network latency
Yang et al[40]	2020	N	N	N	Y	Y	Y	Y	Intelligent service provisioning enabled 6G network is discussed in detail	Trust, data privacy is not explored
Xu et al[41]	2020	Y	Y	Y	Y	Y	Y	N	Paper explores usage of BC for resource sharing its management in 6G-enabled network	Intelligent Offloading, BC-enabled low-cost and lightweight solution for 6G-enabled ecosystem
Rahim et al[42]	2020	Y	Y	Y	Y	Y	Y	Y	ML adoption for V2X communication	Security attacks and countermeasures in V2X ecosystems are not discussed.
Tang et al[21]	2020	Y	Y	Y	Y	Y	Y	N	Mobility prediction, dynamic routing of vehicles, and Network intelligence	Case-study for intelligent provisioning is not explored.
Wang et al[43]	2020	Y	Y	Y	Y	N	N	N	Trust management and privacy preservation in V2X entities were discussed appropriately in paper	Resource Provisioning is not explored
Mollah et al[44]	2020	Y	Y	Y	Y	N	N	N	Resource Sharing in V2X environment was presented in effective way	Implementation even at small scale was not observed
Peng et al[45]	2020	Y	Y	Y	N	Y	Y	Y	Requirement to achieve QoS was discussed	Issues and its countermeasures related to network latency
Gupta et al[46]	2021	N	N	N	Y	Y	Y	Y	6G-based intelligent resource provisioning for addressal for massive IoT and holographic based communications	Security of massive data collection and integration is not discussed
Ji et al[47]	2021	N	Y	N	Y	Y	Y	Y	6G-based computational intelligence models as network-in-a-box architecture that orchestrates the 6G services through virtualization for support to next-generation models	The security evaluations of open 6G interfaces and standards are not discussed
Prabadevi et al[48]	2021	Y	Y	Y	Y	Y	N	N	Amalgamation of BC and edge-computing, termed as BC-enabled edge-of-things (BEoT) as enablers for future low-latency and security considerations	AI-based intelligent and context aware offloading for resource provisioning in edge models are not discussed
You et al[49]	2021	N	Y	N	Y	Y	Y	Y	A comprehensive survey of deployment of 6G and protocol models and associated services in future wireless infrastructures	Discussion on security enablers of communication parameters and services are not discussed
Proposed Survey	2021	Y	Y	Y	Y	Y	Y	Y	A proposed survey on integration of BC with 6G to assist edge-AI for responsive network orchestration, with mitigation of attack vectors in C-V2X based ecosystems	-

Abbreviations: 6G, sixth-generation; BC, blockchain; ML, machine learning; V2X, vehicle-to-anything.

Notes: 1. Data Privacy, 2. Authentication, 3. Trust, 4. Network Latency, 5. Responsive edge, 6.Resource Provisioning, 7. Intelligent Offloading Y-Yes, N-No authors have proposed a reference architecture and a case study to support the integration of 6G, responsive edge, and secured and decentralized data access via BC.

3.3 | Key takeaways of this survey

The following are the key takeaways of the survey.

- Motivated by the comparative analysis of related state-of-the-art surveys, researchers globally have proposed surveys on 6G and its integration to C-V2X environments and have addressed the issues of network management, resource provisioning, and mobile edge computing-based services in 6G.[50]
- Also, surveys are proposed in the security domain that addresses solutions towards attack perimeters in V2X, and possible security solutions through cryptographic primitives, that involve adversarial learning, CASV security through BC, and secure routing principles.[48] However, less focus has been directed toward integrating AI techniques to address the issues of REC in 6G ecosystems, which allows the formation of intelligent edge models that leverages responsive learning and focus on real-time sensing and cognitive models.
- To address the research gap, as per the author's knowledge, this is the first survey that focuses on the discussion of network and security drivers in C-V2X communications and has highlighted the importance of edge-AI for resource orchestration in detail. The survey bridges the gaps in existing surveys through the comprehensive integration of AI for REC in 6G-V2X environments. The survey studies the backdrop and importance of AI-enabled edge intelligence in C-V2X and proposes the integration of BC to address the trust, interoperability, privacy, confidentiality of data, and mitigation of attack scenarios in 6G-envisioned C-V2X. Thus, the survey intends as the starting step toward building AI-based solutions for 6G-assisted C-V2X, and intelligent resource provisioning with edge computing.
- Thus, the proposed survey specifically focuses on research questions and proposes a reference architecture that integrates the key drivers. Moreover, the survey proposes a case study, *6Edge*, that presents the layered protocol stack model that presents the interoperability of 6G, edge-AI, and BC in C-V2X, and discusses the key challenges and limitations in the integration. This serves the purpose of the survey to assist researchers to build smart and intelligent solutions directed towards 6G-based BC-assisted edge models.

The survey starts with the presentation of the solution taxonomy of BC-based 6G-edge. It then discusses further the reference architecture, open challenges of integration of BC and 6G-assisted edge in C-V2X, and the proposed case study that proposes the integrated solution of the key technologies.

4 | SOLUTION TAXONOMY OF BC-BASED 6G-EDGE

The section presents a solution taxonomy of fusion of BC and 6G for REC in C-V2X-based ecosystems. The details of the taxonomy is illustrated in Figure 9. In the automobile industry, the prime objective is to ensure responsive network orchestration and the safety of CASV drivers, pedestrians, and local C-V2X infrastructures like RSU, smart grids, and cloud servers, as they contain the bulk of user private transactional records. Thus, BC is a viable solution to mitigate attacks, and 6G offers intelligent functions for network and edge control. Based on the above, we have categorized the taxonomy into three parts (1) The security-based configurations, (2) Intelligent functions achieved through AI-empowered edge, and (3) Responsive network orchestration through 6G. The details of the same are now presented in the following subsections.

4.1 | Security configurations

Security-based solutions for C-V2X involve mainly privacy, authentication, and trust-based solutions to mitigate the attack vectors. For trusted access, Gao et al[51] proposed a trusted framework for malicious behavior in V2X, that involves a fog-based architecture that integrates 5G and BC through software-defined networking (SDN) model. The architecture proposes a secure message dissemination scheme through BC and improves service availability and reliability through SDN-embedded 5G network. Yang et al[52] proposed a BC-based chronological inference model using Bayes indicators that

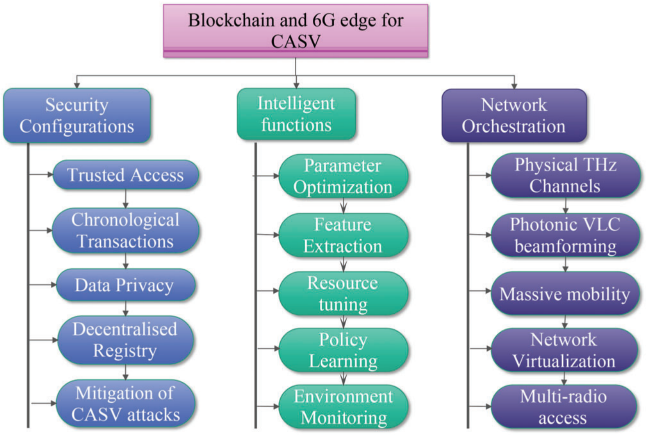


FIGURE 9 Proposed solution taxonomy depicting amalgamation of blockchain and sixth generation for a responsive edge in cellular-vehicle-to-anything

upload the rating of CASVs through trust offsets, and RSUs pack the offsets as transactions, to be mined further as blocks. The scheme ensures joint consensus through Proof-of-Work (PoW) and Proof-of-Stake (PoS)-based mechanisms. They proposed a direct relationship between offsets in block ledger to ease computations for miners in PoW. Shen et al[53] formulated a privacy-preserving classifier for vertically partitioned datasets via support vector machine (SVM) in consortium BC environments. The scheme forms local training operations with secure exchange through the BC ledger. In permissioned and private BC, to mitigate attack vectors, authors have proposed public-key infrastructure- (PKI) based solutions for vehicle registration and verification of records by a certificate authority (CA). For the same, PKI has a registration authority that validates the certificate freshness to CASVs. In a similar direction, Bao et al[54] proposed a pseudo-random certificate management scheme based on distributed maintenance of the certificate revocation list. The scheme embeds the list in the secure applications to address the overhead and cost-based scenarios in IoV. In IoVs, sensor-based attacks are performed on CASVs to jam hardware units and cause collisions in lanes, affect routing paths, propagate false alarms and incorrect updates. Vasudev et al[55] presented a comprehensive survey on different attacks in IoV and proposes countermeasures on the same.

4.2 | Intelligent functions

In 6G, AI leverages intelligent self-configured edge services that can be provisioned to optimize themselves through learning models. To support thousands of transmitting and receiving antennas, spatial beam-forming parameters are optimized to minimize nonlinearity. For the same, recurrent neural networks (RNN) have been found as a suitable choice that learns and captures array data from amplifiers and optimizes power levels.[56] For parameter optimization, authors have explored deterministic rule-based schemes to maximize the quality of service of users. They have explored effective gradient schemes that adapt themselves to converge the parameter tuning at fewer costs. Authors propose AI-based feature extraction methods to generate quantitative features extracted from massive datasets and discover fine patterns or regions of interest for applications about traffic predictions, flow management, handover scenarios, and RF spectrum allocation. Restuccia et al[57] proposed a survey of DL-based techniques to extract spectrum information in real-time to allow a decision on adaptive beam management and modelling traffic networks at physical and MAC layers of beyond 5G networks.

Dong et al[58] proposed a cascaded structure of a fully connected supervised neural network with a deep transfer learning mechanism, where the starting neural network (NN) formulates the bandwidth requirements of users and a second layer of NN forms the resource optimizer by maximizing power levels to satisfy the QoS requirements of spatial users. An optimal policy is mapped to a feed-forward NN that maps the network states to resource allocations and converges to a globally optimal solution. To optimize and fine-tune the process, a labeled training sample is considered. In 6G, frequent handovers are present due to the massive mobility of CASV users among different regions. To optimize the handover strategy, authors have proposed deep reinforcement learning (DRL) techniques that learn from external environments and moves and exhibit a dynamic temporal mobility behavior. Liu et al[59] proposed a unmanned aerial vehicles (UAV)-assisted handover scheme based on DRL. The UAV is considered a learning agent, and it forms policy-based learning by interacting with an external environment. For the same, UAV senses the location, trajectory, velocity, and link-state and forms relevant actions, where a reward is based on persistent connectivity during a handover. The scheme measures the handover probability and reduces the latency of the UAV network from ground control. Yang et al[35] proposed object detection for CASV based on optimized offloading from base station. A multiclass classification problem is presented for the same, and edge resource allocation is considered as regression with mean square error training. During training, they considered the Adam optimizer that minimizes the edge-weight losses, at low storage, and computational costs.

4.3 | Network orchestration

This section presents the key characteristics of 6G networks to support a high volume of CASV sensor data. As earlier indicated, 6G would support the full spectrum of extreme high throughput and low-latency, suitable for C-V2X. 6G is envisioned to support extreme low-power consumption and also supports underwater and space communication. The range of the Terahertz frequency band varies from 0.1 to 10 THz. It is also considered as the Terahertz gap and kept at the last point of the radio spectrum. For the 6G communication, this band provides less latency, and very high-efficiency.[60,61] The system that supports merely a 1GHz processor makes it impossible to execute such a kind of band. In March 2014, the initial project of IEEE 802.15d, 100 Gbps in IEEE 802, was approved, but there was no industrial plan for the same. Scattering, reflection, and high path loss are several new areas that need to be addressed before acquiring the Tbps (terabit(s) link). For the performance of indoor wireless communication, VLC can be considered as a potentially strong feature.[62] When compared to the wireless local area network (WLAN) communication, it gives an unsatisfactory performance. Various techniques have been proposed to improve the performance of VLC concerning both electrical and optical domains. Among them, OB is the technique that can focus light in a specific direction or at a target location.[63] As it does not depend on electrical modulation schemes, it undoubtedly improves the VLC performance. Integration of 6G networks can be carried out with underwater, aerial, and ground communications into a robust network that can support various devices with faster, ultra-low latency requirements and that can be more reliable. Researchers in various domains proposed quantum machine learning, AI/ML, millimeter waves communication, blockchain, terahertz, tactile internet, fog/edge computing, etc., as the important technology for the realization of 5G and 6G communication.[64,65] NFV is the key performance indicator (KPI) and full dynamic network orchestration because it does not require direct input policy commands, but this variable can capture the demands of services and applications. Meanwhile, autonomous networks can continuously verify the match between the actual network state and the expected network state through real-time monitoring of network KPIs and real data training to continuously provide a better quality of experience (QoE) to adjust network parameters.[66] Wireless communication beyond 5G networks in multi-RANs requires technological advances and development. In particular, we envisage the upcoming 6G network, which calls for various devices with high-performance, high-density, and dynamic environments such as high-performance interconnect..[67]

5 | PROPOSED REFERENCE ARCHITECTURE OF 6G-LEVERAGED EDGE-AI SCHEME

This section presents a proposed reference architecture of a 6G-leveraged intelligent edge scheme in C-V2X ecosystems and addresses the objectives highlighted in RQ-5 and RQ-6 as shown in Table 2. To formulate the same, Figure 10 presents the proposed architecture.

In C-V2X, we consider there are q CASV nodes $\{C_1, C_2, \dots, C_q\}$, where any qth CASV is equipped with m sensor units. We assume that k CASVs are serviced into a cellular range, where they communicate with close peer CASV nodes, RSUs, and infrastructure services through servicing links. A total of w cluster units are presented, depicted as $\{U_1, U_2, \dots, U_w\}$. Based on the generated data, real-time datasets are formed for learning models. In ML-based models, channel measurements are formed based on wireless channel allocations and form intelligent predictions. For classification, important features are extracted and predicted AI models are formed. For DL, cellular base stations are embedded with DL chips that can read traffic fluctuations to form intelligent edge resource allocations. For RL, network orchestration is done through DRL network controller, where the channel state information (CSI) is sensed as α. Based on α, the network controller forms the action states for configurations, denoted as β. On β, DRL allows optimal policy formation p to maximize the channel performance gain. Once p is decided, a feedback path f is also made to optimize the gain factors.

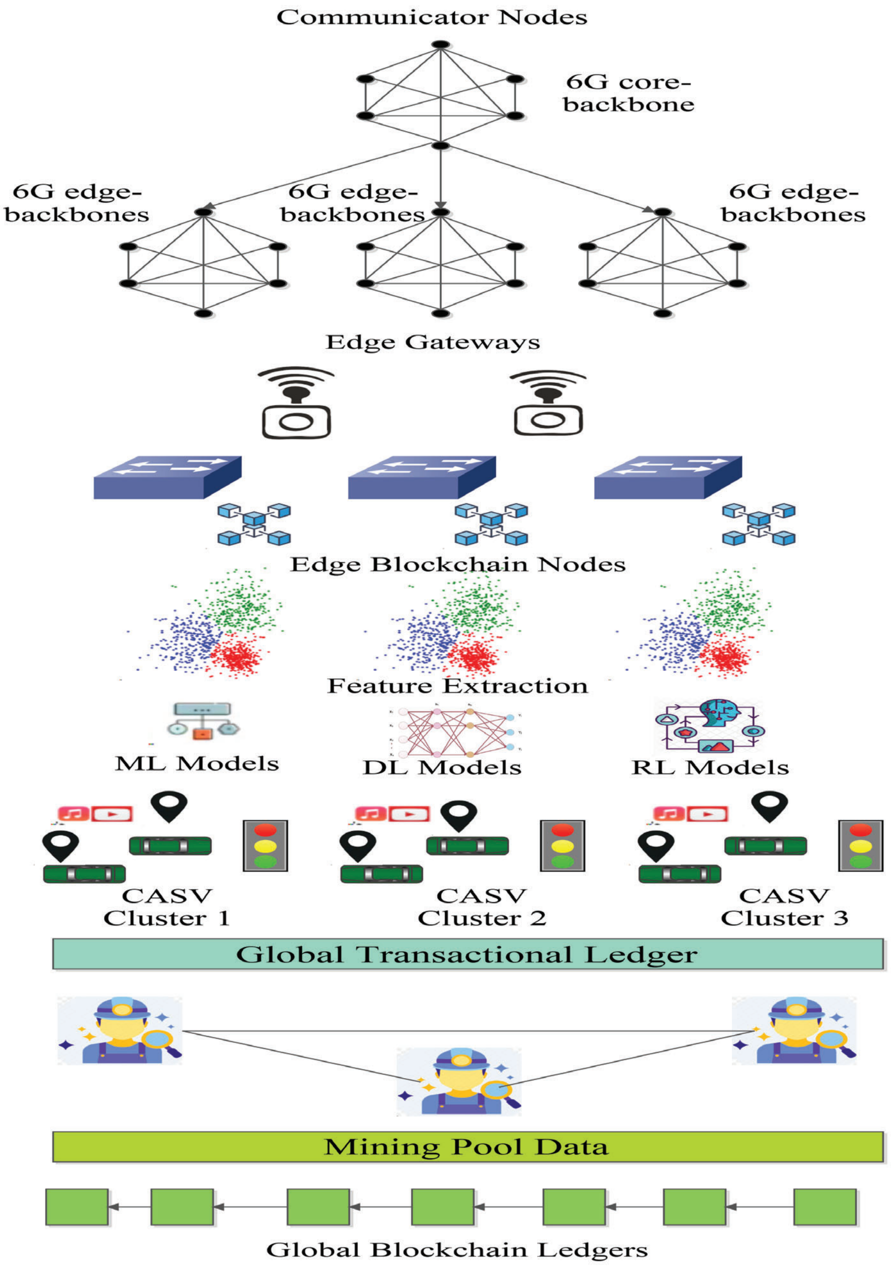


FIGURE 10 Proposed reference architecture

To support the learning models, a 6G-leveraged backbone is formed through communicator nodes to communicate with sub-6 GHz mmWave bands. 6G would envision a photonic core network that supports the 6G edge-backbones that allows supports to edge gateways through edge-backbones. For data exchange, lightweight edge BC nodes are present to record transactions as an immutable ledger. The proposed reference architecture thus highlights the importance of a 6G-leveraged backbone that assists edge nodes in C-V2X to manage the resource sets judiciously, like spectrum assignment, node storage, transmission power, and raw computing that assists the proper functioning of vehicular nodes, and drives a range of applications. C-V2X resource management through AI models is formulated as optimization problems where a conflicting trade-off is a setup between network performance and leveraging AI to reduce the resource complexity. The reference architecture addresses the trade-off that formulates the scenario as an optimization problem, and in real practice, solutions are oriented toward leveraging AI models to learn from dynamic V2X environments and propose time-varying optimal solutions. Through AI, the architecture proposes small-scale subproblems that can be solved through AI modes that recompute the requirements as a function of time and recomputes with small changes in the system.[68] This reduces the overall network provisioning overhead of the 6G backbone. Finally, once solutions are computed, transactions and consensus is facilitated through BC that interfaces with edge systems through service-oriented micro-architectures. Based on the reference architecture, we present a 6G-envisioned network model, intelligent edge model, and security model in the following subsections.

5.1 | Network model

In 5G, subband and carrier-filtering schemes are heavily employed with OFDM, and with the emergence of 6G systems, new waveforms are proposed to support virtual slicing in the 52.6 GHz band. 6G would support low-amplifier efficiency, with higher spectral density than 5G waveforms. 6G would support a new waveform structure orthogonal time-frequency technique that modulates signals in the doppler domain and supports the time-varying multipath channel. In network orchestration, 6G would support AI-enabled techniques to allow less context switching time during high mobility of CASVs, and low-order losses at the PHY layer. The details of AI adoption to support network model scenarios are presented in Table 5.

5.2 | AI model

We now present intelligent edge models for REC that include allocation of 6G network resources and power transfers at low computational complexity. In C-V2X, CASVs communicate through dynamic links with high topology mobility, and thus persistent QoS to V2X nodes is a major challenge. Different preferred AI models allow intelligent edge resource allocations, traffic predictions to smoothen out V2X traffic, support CASVs, and consistent QoE in surfing live streaming applications, including location services, multimedia control, and many more. Through precise and accurate models in V2X, CASVs communicate with other nodes to identify autonomous allocations, congestion mitigation, and avoiding lane-based accidents. The models are self-adaptive. 6G is also envisioned to support effective NFV by optimizing and allocating tasks to support task offloading and edge-inference-based predictions. DL models like CNN or deep belief networks (DBN) are heavily employed to predict heterogeneity in traffic models and form intelligent caching and control. With CNN, models are fed the real-time traffic patterns to predict future patterns based on a time window. DBN is used

TABLE 5 Preferred AI adoption for network model for cellular vehicle-to-anything ecosystems

Network model	Preferred AI techniques	Advantages	Challenges	Real-life deployments
Multichannel access	Markov decision process (MDP), deep nueral networks (DNN), multiloss DL for grant-free nonorthogonal multiple access (NOMA), Autoencoders, Restricted Boltzman Machine (RBM),	Less switching time for CAVs during handover, low bit-error rates at PHY, effective channel access than conventional NOMA	High resource consumption, not suitable for edge processing	Decoding corrupted modulation signals, channel grants
RF configuration	DNN, Autoencoders, RBM with long-short term memory (LSTM), Modulated convolutional neural networks (CNNs), Federated ML	Channel configuration without signal processing block units, More accuracy than artificial neural nets, reliable learning	Channel distortions can induce additional noises, high power impedance at antennas	Antenna signaling
Beamforming	DL models	High mobility for CASVs due to learned topology scenarios, context-aware beam selection, co-ordinated antenna beamforming for mmWave prorogation	Accuracy of channel models are less	Beam-selection

to allocate channels once the patterns are fixed. Also, RL methods like Q-Learning are used that form optimal policy sets based on dynamic topology and mobility changes. RL also supports location and energy-aware routing to support extremely low-latency applications. Through RL, agents can infer optimized link-states at the edge nodes to support V2X nodes. In CNN, the gradient-descent technique can be employed to allow high data availability at less delay. DBN allows intelligent buffering of network packets to process and estimate the MBMS in the C-V2X ecosystems. Table 6 presents the advantages, challenges, and real-time deployment models for edge resource provisioning in C-V2X.

5.3 | Security model

This section presents the security aspects of 6G-assisted in C-V2X ecosystems. The transactions or exchanged data captured through m sensor nodes are serviced through U_w and passed to edge nodes for distributed content caching.[69] With REC, the computational delay is minimized, suitable for constrained applications. An adversary can launch informed security attacks on V2X ecosystems, and hence BC allows decentralized consensus through low-powered protocols, namely, Proof-of-Concept, that reduces the storage node and processing overheads at edge servers. Along with BC, to leverage edge resource allocations, AI models like DBN and Q-Learning can be incorporated to scale intelligent and dynamic topology solutions. To mitigate the effects of mimic-based attacks, BC forms chronological ledgers combined with hidden Markov models to form statistical inferences from captured packets in the network. Table 7 presents the AI techniques for secured data exchange in C-V2X ecosystems.

5.4 | Limitations of the proposed architecture

The proposed architecture of the 6G-leveraged BC-assisted edge-AI scheme has some potential limitations. The same are highlighted as follows.

1. *Massive offloading*-6G-envisioned V2X is expected to support massive data ingestion, and thus would require high computational requirements to process the data. In such cases, edge servers are expected to support offloading schemes

TABLE 6 AI models for responsive and intelligent edge provisioning in cellular vehicle-to-anything

Edge models	Preferred AI techniques	Advantages	Challenges	Real-life deployments
Edge resource allocations	Graph coloring Models, DRL, CNN, Deep Belief Nets, Q-Learning	Joint-optimizer models for resource allocation, low-sub optimal solutions, adapt to dynamic topology	Only traffic patterns are considered as features, network-dependent control	Responsive Edge Provisioning, Support to NFV
Traffic predictions	DBN, and CNN	High data availability, Lower Hop Delay	Increase in disconnection probability with the rising number of CASVs in single-cell	Content and data-centric applications
Connected autonomous driving	k-nearest neighbor (KNN), Naïve-Bayes, you look only once version 3 (YOLOv3), and SVM	CASVs can detect pedestrians through V2P links, better accuracy at low-resolution images	Models, accuracy drops with increase in pedestrians on a single V2P link, the good-frame rate required for learning, heavy computations	Autonomous road-crossing junctions
Streaming live applications at CASVs	NaïveBayes, DNN, YOLO, histogram of the oriented gradient (HOG), SVM with kernel correlation filters (KCF)	Low-computational maps for edge services simulate parallel queries on large datasets, voice recognition of vehicular users (VUs), on-site data processing	Mostly applicable on video datasets, expensive detection models, high query latency on voice recognition, high power requirements at edge servers	Smart surveillance systems, health care signals, voice codecs, EdgeSpeech Nets

TABLE 7 AI techniques for secured data exchange and mitigation of attack vectors in cellular vehicle-to-anything (C-V2X)

Security model	Preferred AI techniques	Advantages	Challenges	Real-life deployments
Detection of attack vectors in C-V2X	KNN, Naïve-Bayes, DNN, CNN,	Real-time malicious behavior detection, rule-based inference schemes for learning attack features	Explicit requirements to fine-tune hyper-parameters, slow segementation, classification burden the edge server processing overheads	Attack detection through surveillance cameras, and UAVs
Speech recognition authentication systems for VUs	DNN, Distillation Training, Electroencephalography for health care signalling in IoVs	Effective learning due to simple feature maps	Libraries with specific functionalities, needs to build more general models	Bio-metrics at IoVs, Mitigation of Mimic-based attacks
Location prediction and routing	Hidden Markov Models, Recursive Least Squares, k-Means Clustering	Statistical inferences of packets captured in V2X systems to detect synthesized anomalies	Processing of encrypted headers	Packet-based detection to mitigate location and routing attacks
Privacy of CASV sensor data	Time-series models, LSTM, Multilayer Perceptrons	Real-time sensor data captured to build time-series forecasting and validation of secure exchange	The optimal decision of prediction window size determines the accuracy of results	Prediction models on sensor datasets

based on intelligent learning models on real-time traffic generation. However, the gathered data is highly multidimensional, and thus the selection choice of an ML/DL model for effective hypertuning is a black art.[70] Thus, models are required to be highly optimized in terms of parameter selection and should focus on limiting the training losses to the minimum.

2. *Off-chain computation*- In the proposed architecture, BC mitigates the attack vectors from malicious entities on the C-V2X ecosystem, and presents chronological and timestamped ledgers of the CASV data. However, for real-time processing, the selected consensus protocol design is critical. In the scheme, we have suggested effective low-powered consensus protocols, but the selection choice of a particular consensus to fit the application need is difficult, owing to the complex requirements of the ecosystem. Thus, in such systems, off-chain computation storage like IPFS is included that can store the C-V2X data. Once the data is stored in IPFS, a hash reference is generated and stored in the global BC ledger. As meta-information is of 32 bytes, thus more transactions can be packed into a single block, which improves the scalability.[71] However, the seamless integration of low-powered consensus with off-chain computation is an emerging direction of research.

6 RESEARCH CHALLENGES AND FUTURE DIRECTIONS

BC and 6G can optimize the performance of cellular networks due to their powerful learning and reasoning ability. In this section, we present the research challenges of usage of BC, 6G, and edge-AI models in C-V2X. We highlight the key issues and present the possible deployment solutions. The section addresses the research question RQ-4 and highlights the objectives as shown in Table 2. Functional parameters are discussed with open issues and future scope of work in selected areas. Also, we discuss the maturity of the deployment level of each supporting technology at the corresponding layered stack. Table 8 shows the details of the research challenges are categorized based on 6G, edge-AI, and BC in C-V2X.

6.1 Computation efficiency and accuracy

In 6G-assisted C-V2X, CASV sensors generate massive data with varying character tics and features. Thus, the learning models face stringent challenges to process the multidimensional high influx data and require high computing resources

TABLE 8 Open challenges and possible directions for key drivers in V2X

Challenges	Parameters	Open issues	Future scope	Deployments
6G	THz bands	Practical solutions for traffic channel models, loss and prorogation models sending and receiving transmitters	Effective channel modelling and aided-antenna design	At PHY layer in early stages
	Ultra-Low Latency communications	High dense requirements at variable rates, high reliability, dense mobility, and suitable codecs required for low-powered transmissions for IoV scenarios	Effective codecs schemes for real-time data access and reliable protocol stack formations	At PHY and MAC layers in medium stages
	Software-based configurations	Traffic estimation, SDN flow optimizers, effective transmission control protocol (TCP) standards, matching SDN flow table structures, and effective filtering	Study of packet losses, design of TCP congestion models, Bloom filters for flow tables	PHY and MAC layer in medium stages
	Hybrid RF and photonic VLC	Proprietary VLC standards, physical layer VLC losses, high-interference, and data privacy	Low-powered codecs for VLC models, effective interference for RF models, and secured data sharing models	PHY layers at early stages
	NOMA	Receiving and sending antenna power models, cross-layer optimization, resource grants, and collision handling, Adaptive rate allocations, simultaneous wireless information and power transfer (SWIPT)-based energy harvesting	Massive device connectivity, rate allocation models, energy and power allocations, resource models	PHY and MAC layer in medium stages
	Multiple Radio Access	Differentiated QoS Provisioning, Beam Management, Spatial Interference mitigation, high-data throughput	Further exploration of 6THz bands, communication-based protocol developments, submmWave low powered beam management	PHY Layers in early stages
Edge-AI	Accurate Channel estimations	Inference data-driven ML models, channel dynamics, user input behaviours, effective traffic datasets	ML-based estimators, clustering approaches K-Means Clustering, Mean-Shift Clusters, and with Noise density-based spatial clustering of applications (DBSCAN) techniques	Network and Application Layers in near-convergence stages
	Flexible and adaptive rate management	The long training period for ML/DL models leads to the observed difference between potential predictions in a given frame, dynamic veracity of channels	Fine-tuning of training length, optimization models of frames, federated-learning based approaches	MAC and Network in early stages
	Limited hardware and computing resources of sensor nodes	High-dimensional data and inherent complexity of DL models	Energy-efficient AI optimizations, feature matching, residual networks, offline training	Application at medium stages
	QoS adaptations and flexible learning models for 6G-V2X	Hyperparameter selection in fine-tuned real-time QoS provisioning	Nature-inspired algorithms for the selection of hyperparameters	Network, Transport, and application at early stages
BC	Identity and forged message attack vectors in IoV	Trust models, conditional anonymity, and transparency of certificates	Reputation, Pseudonym addresses of CASVs, reputation models	Application at medium stages
	Decentralization in modern encryption schemes	Design of lightweight and anonymity-based authentication and key-exchange schemes	Certificate-less and group-based encryption schemes, Differential elliptic curve cryptography (ECC)	Application at medium stages
	Location-based attacks	Sensing on channels, read insecure location APIs, attacks on micro-services	Dirichlet distribution based trust framework, trust scores, Policy forming	Application at medium stages
	Scalability	Low-latency for resource trading and block additions	DRL-based approaches	Application at early stages
	Collusion and distributed PoS-(DPoS) based consensus attacks	Choosing colluding miners through stakes, a forged voting procedure for miner elections,	Reputation-based miner selection algorithms, audit-control, two-step verification, and contract theory approaches	Application at early stages
	Incentives for miners	Lack of proper coordination for miners to participate and propose incentives due to constrained resources	Brokerage based approaches, Game-Theory for incentive maximization, pricing and satisfiability theories	Application at early stages
	Resource trading	High-volumes of transactional data, slow-update of transactional ledgers, chain addition, storage constraints	Parallel approaches for bulk transaction verification, distributed clustering approaches,	Application at medium stages
	Smart contracts	Security attacks on smart contracts-reentrancy, decentralized autonomous organizations (DAO), ordering, timestamp dependence, gas, integer underflow/overflow attacks	Formal verification tools like Slither, Mythx, MyThriil, Smart Check, Oyenete, and Vandal can be used to verify smart contracts vulnerabilities	Application at end-stages

to process them. With the introduction of edge-AI models, the devices are computationally constrained in terms of storage, power, and I/O, and thus cannot process the data accurately. Due to this, the ML/DL models suffer from training losses and thus are stuck at local-minima-based solutions. Apart from the challenge of learning models, BC requires mining resources from the network edge to solve nonce in REC. Thus, there is a need to design effective optimizer models to train the network accurately and also design effective consensus schemes to solve mining resource problems.[72] This leverages a scalable solution and allows proper mining incentives to the miners in the 6G ecosystems.

6.2 | Robustness, scalability, and flexibility of learning frameworks

6G networks are envisioned to support holistic space, ground, and underwater communication with high density and frequent mobility. Due to this, there are frequent handovers of V2X nodes among different 6G base stations, which allows a maximum proportion of the channel bandwidth to be utilized in handling the association and V2X movement dynamics. To deploy an automated solution for handover management, 6G employs AI-enabled radio that monitors and senses the channel states in real-time and feeds the parameters as input to the model. However, in the case of the high dynamic movement of V2X nodes among different base stations, the channel states are continuously updated. This updates the learning weights of the model in real-time, and the frequency of change in model parameters persists. Also, every V2X node might require a different QoS from the network, which adds a certain uncertainty in the model.[73] Thus, effective, robust, and intelligent channel modeling through AI-enabled radio is a key challenge in 6G networks. With effective tuning of models, a seamless communication infrastructure can be leveraged to provide differentiated QoS as per the requirements of each V2X user. This allows a design of a resilient and scalable learning framework in such ecosystems.

6.3 | Hardware development

At physical layer RF communication, 6G BS communicates through effective antennas at sender and receiver site. Effective antenna design requires hardware components to support the mmWave spectrum and THz band frequencies at low energy costs. However, 6G encompasses the benefits of intelligent cognition through AI-enabled RF but requires correct hardware to support the functionality. With 5G-deployments, most vendors have formed proprietary-based network stack drivers that cannot communicate with other vendor hardware devices. Due to this, despite cognitive benefits through AI, the power consumption and resource dissemination by 5G-targeted antennas are not massive. Therefore, to support the vision of 6G communication requirements and support photonic bands, effective graphics processing unit (GPU)-accelerated hardware needs to be combined with a low-powered networking stack to allow interaction of AI models and communication parameters.[74]

6.4 | Energy management

6G leverages last-mile connectivity to devices' location on the ground, underwater, and air channels. Most devices or nodes need spectral power to communicate in their range due to high interference and blockages. Thus, they require proper power stations nearby to support the power consumption of batteries due to the small battery size in IoV environments. Thus, to extend the device's lifetime, effective power management schemes are required to be designed to support a range of power management modes. In 6G, AI models can support the power management of batteries to consume less power for distant communication and dissemination of data. Also, 6G needs to design effective harvesting mechanisms to support low-powered dissemination among holistic networks. For the same, 6G radio cores need to support SWIPT based solutions to extend green power and increase network lifetime.[75] Thus, the design of effective SWIPT-based models of energy harvesting is an open challenge for 6G-based ecosystems.

7 | *6EDGE*: A CASE STUDY OF 6G-ENVISIONED REC-V2X ECOSYSTEMS

This section presents a case study on the 6G-assisted intelligent edge service layer to facilitate REC. The data generated through sensor nodes in C-V2X through different communicating links are forwarded to 6G edge controller nodes that interact with 6G THz physical RF channels, supported through 6G-based service layer. At the core, the 6G service layer interacts with optical broadband units (OBUs) to form a resilient communication backbone.[76] The collected data is analyzed through effective edge-AI models for edge inference to RSUs that includes channel monitoring, virtual resource allocations, edge forward node interface, intelligent caching, device mobility, and real-time sensing and feedback channels. Once the data is classified and clustered by the edge-AI nodes, they are forwarded back to edge controllers for provisioning. At the application level, BC is integrated with V2X nodes to form a lightweight transaction pool, then communicates locally to form local blockchain units (LBUs). Once the local transactions are verified, SC among C-V2X stakeholder nodes are executed, and transactions are mined to global BC through an energy-efficient consensus scheme. The details of the layered stack is shown in Figure 11. The explanation is now presented as follows-

1. *6Edge: Physical layer*: At the physical layer, we present the communicating entities for C-V2X- CASVs embedded with sensor nodes, RSUs, smart grids, smart parking ecosystems, and cloud data centers. We assume a cell-based communication structure of k nodes in any mth servicing RSU RSU^m. The k nodes communicate with each other inside

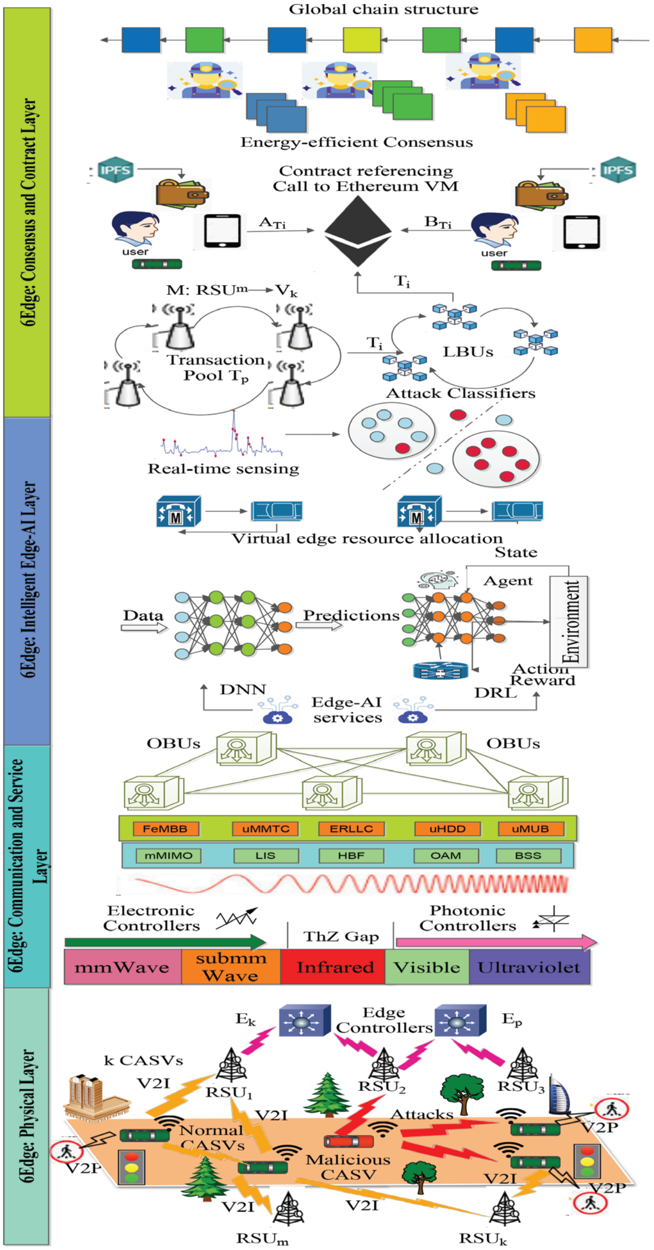


FIGURE 11 *6Edge*: Layered stack model for the proposed case study in cellular-vehicle-to-anything

RSU^m or may communicate to a node in rth servicing RSU RSU^r, through a directed inter-RSU communication link. Any CASV communicates through the CAN and LIN bus scheme with other nodes through a DSRC link. Also, we consider that malicious CASVs are present in the case that can perform informed attacks on the C-V2X ecosystems through incorrect updates and false propagation of oral messages. CASV communicate through q embedded sensors units $\{S_1, S_2, \dots, S_q\}$ to RSU and charging units through the V2I links. To allow the safety of the pedestrians, a V2P link is utilized. Similarly, to communicate with smart grids for energy exchange, a V2G link is utilized. Any CASV can offload requests from cloud nodes through the low-latency V2C link. As any mth RSU communicates infrastructure and services in its spatial range R_m, we consider that RSU forwards the data requests to edge service nodes. We consider p edge nodes $\{E_1, E_2, \dots, E_p\}$. Any E_p is responsible for providing real-time intelligent services to RSUs to disseminate to local V2X nodes. E_p communicates with the local 6G RAN core that consists of high-performance switching units.

2. *6Edge: Communication and service layer*: At communication layer, any mth RSU units communicate with the 6G RF band that operates in $0.1 - 10$ THz range as defined in IEEE 802.15.3d stack.[34] The PHY layer of the THz channel consists of a single on-off keying technique and can leverage support to 10 000 servicing RSU units. For the same, they employ super-narrow beam formation with SM-MIMO patterns. It also supports a photonic VLC through passive reflectors and large, intelligent surfaces (LIS). LIS overcome the challenges of near-field line-of-sight losses and can be deployed for indoor communications as well. Through this, holographic beamforming (HBF) can be generated with directed phased antenna arrays. The multiplexing technique deployed is OAM that supports multi-separated spatial transmit and receiving channels. Post the PHY layer, at link-level, MAC sublayers design the service adaptation based on AI-enabled radio, with low convergence losses. AI-radio also supports optimized flow mechanisms to enhance the routing of control packets at OBU units, thereby reducing retransmission and error frames at the massive transmission of data.
3. *6Edge: Intelligent Edge-AI layer*: Based on collected data at OBU units, at edge-AI layer statistical inferences are modelled to generate effective traffic patterns, precoded caching, and responsive automation for V2X nodes. AI models learn from available data patterns and forms transfer states from CSI between transmitting and receiving antennas. For optimizing power, power domain-NOMA can be utilized to select heterogeneous power levels based on channel states to optimize performance. V2X nodes information signals are superimposed at transmitting antennas, and successive interference cancellation (SIC) is designed to allow signal decoding with desired power levels and allow fair-resource ecosystem.[77] For SIC coding patterns, autoencoders are used to present a representational encoding pattern for receiving CSI states. With effective denoising, the raw noise patterns can be flattened.

   For nonlinear CSI, DNNs are formed that optimize the nonlinear CSI states to offered output variables. Also, DRL, Q-learning, and transfer learning models have been deployed to form intelligent agents that learn from the external environment and optimize proximity cells by offloading patterns of interest. Thus, DRL allows fast mobility predictions and allows easy handover scenarios for edge-AI. Through RNN and time-series models, effective routing policies are built at the network layer from raw generated data in real-time.[78] Also, through effective real-time sensing and monitoring, anomaly nodes in V2X can be classified, and information of attack classifiers can be generated. For attack classification, CNN is built that can form densely connected layers with a pooling layer that can interpret anomalous features from C-V2X nodes and can extract the patterns. To reduce complexity, CNN can deploy flatten maps to optimize the model state space. For clustering, k-means clustering can be formed to locate proximity information to CASVs for nearby edge nodes for resource provisioning.
4. *6Edge: Consensus and contract layer*: Once edge-AI leverages intelligent services, CASVs can trade resources from edge servers or nearby peer-node in a servicing mth RSU unit. For intercell communication, RSU^m interacts the performed transactions by any kth CASV to RSU^r. To manage the bulk transactions effectively, a transaction pool T_p is designed that consists of mapped transactions from RSU units, based on mapping function M : RSU$^m \rightarrow V_k$, where V_k denotes the vehicular entity. An LBU stores the transaction index T_i to form local reference entries. Based on T_i, SCs are initiated between peer V2X vehicular users that facilitate automation of payments based on specific rules in the contract. To secure the contract against adversarial attacks, keys are fetched from the interplanetary file systems (IPFS) that act as an offline registry authority for the network. Once SC is executed, local reference entries from T_i are processed from LBUs, and transactions are appended to the global BC structure.

   IoTA is an open-source distributed ledger specifically designed for the IoT network to handle micro-payments on a large scale. It is modular, more scalable, and decentralized in nature. To perform and validate the transactions require high computational power in a BC-based network. Hence, to facilitate low-powered consensus formation, effective consensus schemes to support micro-service payments can be designed through IoTA.[79] However, other different consensus mechanisms are also suitable for V2X ecosystems. For database validations, authors can use PoW, but it suffers from the downside of slower transactional throughput. Proof-of-energy (PoE) is a specially designed consensus scheme for facilitating energy transactions among CASVs and grid environments and can also be used to validate traffic messages. Proof-of-relevance is suitable to filter incorrect transactional ledger updates in V2X. A hybrid design is also used in recent schemes that combine PoW and DPoS to order and add transactions. For the proposed case study, proof-of-elapsed time (PoET) is a more preferred consensus that allows permissioned BC nodes to decide on block winners and enables mining rights based on a fair lottery scheme. The PoET algorithm ensures the fairness property among all miners by allowing equal winning chances to each node. To exploit this, it ensures a random wait time for each node in BC, during which all miners are put to *SLEEP* state, and the first miner node to *WAKE* up and change state is the one with the shortest timer. The node is then allowed to add transactions to BC.[80] PoET is suitable for C-V2X scenarios due to its low power consumption due to mine, and fair validation, with comparable security as its close counterpart PoW.[81]

In *6Edge*, the layered protocol stack offers intelligent communication edge service based on intelligent orchestrations through 6G. Then, intelligent edge layers form accurate predictions on data that allow real-time sensing and cognition for C-V2X nodes. Finally, through the transaction pool, the data is stored in BC. The layered stack offers the following advantages in C-V2X ecosystems.

1. Through effective cell-based communication structure for mth servicing RSU, through DSRC link, and effective control support via 6G communication layer, data ingestion through physical C-V2X layer to edge layer is facilitated. This provides the key benefits of high-ingested data, effective learning models, and real-time sensing. This addresses our original objective of the address of RQ-1 that involves exploring standard 6G key service sets in C-V2X-based ecosystems.
2. The collected data at OBU can generate effective traffic patterns as data generated through the 6G physical layer can be bifurcated based on content, and cache support is available. Thus, AI models can learn fast from available patterns and effectively form CSI patterns among antennas. To address nonlinear patterns, we have proposed the inclusion of DNN and the transfer learning approach. For time-series data in the case of effective route optimization in C-V2X, LSTM, and GRU variants is an optimal choice. This addresses RQ-2 and RQ-3 that propose suitable AI models for REC and the formation of effective learning model sets.
3. Once effective AI services are orchestrated, the case study proposes a BC-based consensus and contract layer that can effectively trade bulk transactions through T_p. Moreover, we propose the inclusion of SC to automate payments among different V2X stakeholders and IPFS to secure contracts against malicious adversarial certificate and registry attacks.

8 | CONCLUSIONS

The proposed survey presents a systematic outlook on the possible amalgamation of BC and 6G to orchestrate REC in C-V2X-based ecosystems. It is envisioned that future C-V2X ecosystems would generate high volumes of sensor data, and thus the edge devices have to process huge information at low latency. With the emergence of the 6G stack and THz bands, massive device bandwidth and connectivity can be ensured at extremely low power and latency for constrained V2X nodes. Fusion of BC with responsive edge-AI schemes in 6G brings about trust and auditability in proposed transactions. The survey presents a detailed taxonomy of the integration and highlights a case study *6Edge* that presents a layered stack for the possible deployment. The survey also presents the open issues and challenges that are presented by the integration. The proposed survey would help the research scholars, industry practitioners, and V2X stakeholders to provide effective solutions in vehicular ecosystems. In the future, we would like to explore DL models to fine-tune the network parameters in 6G macrocells and design SC for vehicular transactions for resource sharing in V2X ecosystems.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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