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REVIEW

REVISED Edge computing for Vehicle to Everything: a short review [version 4; peer review: 1 approved, 2 approved with reservations, 3 not approved]

Mohd. Fikri Azli Abdullah[1], Sumendra Yogarayan[1], Siti Fatimah Abdul Razak[1], Afizan Azman[2,3], Anang Hudaya Muhamad Amin[4], Mazrah Salleh[5]

[1]Faculty of Information Science and Technology, Multimedia University, Ayer Keroh, Melaka, 75450, Malaysia
[2]Faculty of Innovation & Technology, School of Computer Science, Taylors University, Subang, Java, 47500, Selangor, Malaysia
[3]Research and Innovation, Kolej Universiti Islam Melaka, Melaka, 78200, Malaysia
[4]Faculty of Computer, Information Science and Applied Media, Higher Colleges of Technology, Dubai, United Arab Emirates
[5]Civil Aero Data and Information, Rolls-Royce, Derby, England, UK

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Abstract

Vehicle-to-everything (V2X) communications and services have sparked considerable interest as a potential component of future Intelligent Transportation Systems. However, the large amount of data generated by V2X communications can pose challenges for processing and distribution. Edge computing (EC) is a promising solution to these challenges, as it allows part or all of the data processing to be performed at the edge of the network, closer to the data sources. This paper reviews the existing literature on EC for V2X communications and services. We focus on several methods for implementing EC, including mobile edge computing, cloudlet, and fog computing. We compare them according to their applicability to V2X. The findings of this work indicate that EC can be a feasible solution for V2X communications and services. However, there are still some challenges that need to be addressed, such as the need for more efficient data processing algorithms and the need for a more comprehensive understanding of the trade-offs between EC and other solutions. The outcome of this work could considerably help other researchers better characterize EC applicability for V2X communications and services.

Keywords

V2X, Edge Computing, Review

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1. **Danilo Amendola**, University of Trieste, Trieste, Italy
Vicomtech, Donostia-San Sebastiá, Spain
2. **Lionel Nkenyereye**, Pukyong National University, Busan, South Korea
3. **Muhammad Saleh Bute**, Southwest Jiaotong University, Chengdu, China

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4. **Mahmood A Al-Shareeda**, Iraq University College, Basrah, Iraq
5. **Qiong Wu**, Jiangnan University, Wuxi, China
6. **Preeti Rani**, SRM Institute of science and Technology,, Delhi-NCR Campus, India

Any reports and responses or comments on the article can be found at the end of the article.

Corresponding author: Mohd. Fikri Azli Abdullah (mfikriazli.abdullah@mmu.edu.my)

Author roles: Abdullah MFA: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Yogarayan S**: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Abdul Razak SF**: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Azman A**: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Muhamad Amin AH**: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Salleh M**: Investigation, Writing – Original Draft Preparation, Writing – Review & Editing

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REVISED **Amendments from Version 3**

The updated version incorporates an enhancement in the form of solidified support for Edge Computing within the ecosystem of Vehicle-to-Everything (V2X) technologies. This version includes an important addition of the European Telecommunications Standards Institute (ETSI) standard specifically designed to govern Edge Computing in V2X systems. Furthermore, this version introduces a clear differentiation between Cellular V2X (C-V2X) and Dedicated Short-Range Communication (DSRC) technologies, acknowledging their distinctive characteristics and functionalities. The version includes relevant references that support the information presented. Lastly, this version also contains a forward-looking stance by probing into the potential future directions of V2X technologies.

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Introduction

The automobile industry is changing in various ways, and this provides a chance to address potential transportation-related difficulties. This includes transitioning a traditional independent network to a connected network within and outside the vehicle.[1] The evolution of drivers' and passengers' involvement with vehicles has been evolving both in technology and style.[2] Figure 1 depicts the evolution of the interaction between drivers and passengers from 1807 to the present.

Almost everyone is connected to the Internet, with around six connected devices per person and hundreds of new connections created each second, resulting in billions of connected ecosystems.[3] Furthermore, research has projected that by 2025, connected vehicles will produce over 200 petabytes of data, with at least four terabytes of data generated continuously. This would increase the number of connected vehicles on roads by approximately four hundred million.[4] A connected vehicle is one that is equipped with both Internet and wireless LAN connectivity, allowing data to be transmitted between devices both inside and outside of the vehicle. The Internet of Vehicles or Vehicle to Everything (V2X) is a common network for connected vehicles.[5,6] However, the most challenging problem is efficiently processing and sending enormous data over communication networks.

The difficulty is not just handling data produced by these connected vehicles that are constantly exposed but also maintaining security, deployment, and performance.[7,8] Therefore, the potential of edge computing (EC) for V2X can play a prominent part. EC is a distributed computer system that carries out computational tasks (such as collecting and analysing data) on a device, particularly a vehicle. In turn, this reduces the transmission of data from the cloud back and forth.[9,10]

The prospects of V2X and EC has significant potential for enabling a wide range of innovative applications and services for connected and autonomous vehicles. One of the main advantages of EC is its ability to enable real-time decision making for autonomous vehicles.[2,3] This includes tasks such as detecting and responding to obstacles or hazardous road conditions. By processing sensor data in real-time at the edge of the network, autonomous vehicles can make split-second decisions that enhance safety and efficiency.[6] In addition to enhancing safety, EC can also be used to provide personalized infotainment and other services to passengers based on their preferences and location. By analyzing data from a variety of sources, including social media, weather, and traffic patterns, EC can provide passengers with tailored recommendations

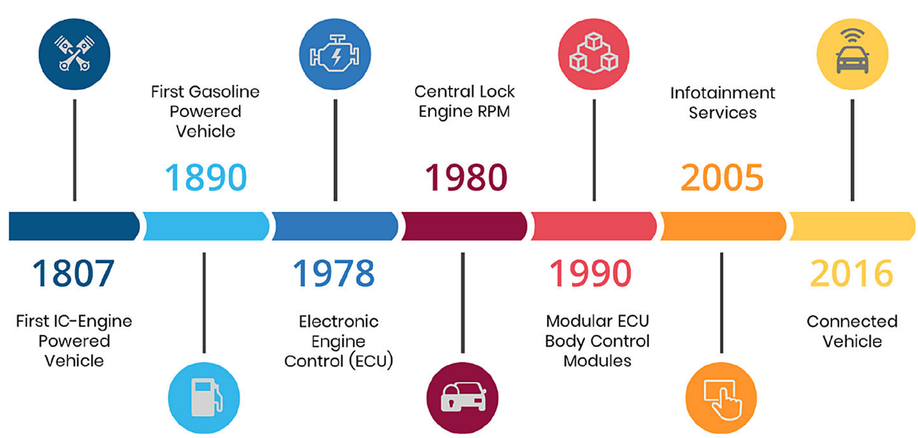

Figure 1. Evolution of driver and passenger interactions.

for entertainment, food, and other services based on their location and preferences.[9,10] This can enhance the overall passenger experience and help differentiate connected and autonomous vehicles from traditional modes of transportation. This review examines EC, in particular for V2X. We discuss the background of automotive evolution, V2X and EC; prior research on the applicability of EC for V2X; the potential challenges of applying EC to the V2X scenario; and the path for the future.

Automotive evolution, V2X, and EC

V2X communication is a crucial component of current intelligent transportation systems (ITS). For example, V2X provides drivers with information about road hazards that they may overlook.[11] V2X encompasses two main technologies: Cellular V2X (C-V2X) and Dedicated Short-Range Communication (DSRC). C-V2X enables direct communication between vehicles and infrastructure using cellular networks, while DSRC relies on dedicated short-range communication protocols such as IEEE 802.11p. Both C-V2X and DSRC are critical components of current intelligent transportation systems. In addition, V2X allows communication between a vehicle and anything that might impact the environment, including the surrounding infrastructure such as traffic lights (infrastructure) and even smartphones (pedestrian), enabling communication between vehicles and pedestrians holding a smartphone.[12] With the technology progressing globally, it is just a matter of time until it is widely adopted and deployed.[13]

EC refers to a technology that allows network-level processing, downstream data for cloud services, and upstream data for IoT service support.[14] The term “edge” refers to any computer device located in the area between data sources and the cloud. EC is more suitable for applications that require rapid and consistent response times.[15] V2X is an example, as computing at the edge can reduce data transfer, decreasing reaction times. The European Telecommunications Standards Institute (ETSI) has defined standards for edge computing, which play a crucial role in enabling efficient data processing and communication in the context of V2X services. By adhering to ETSI’s edge computing standard, compatibility and interoperability of edge computing technologies can be ensured, facilitating seamless integration into V2X applications.[16] For example, when driving, the vehicle captures data via movement, speed, and other sensors, then analyses them to ensure safety and convenience.

For V2X, real-time situational awareness is crucial, particularly on crucial route segments (e.g., an accident is detected by another vehicle on a particular road). Additionally, a backend server will have to provide high-definition local maps. Leveraging local maps and situational awareness is not just about providing data about road traffic conditions. It should also be extended to occurrences where local data must be aggregated in real-time and distributed to drivers on the road through road side units (RSUs). Road users may build and maintain real-time situational awareness using broadcast information from neighbour vehicles as an alternative to EC. Therefore, EC deployment enables shifting such activities to the network edge by combining data from many sources and efficiently broadcasting a huge amount of data to many drivers locally.

EC connects the processing and interpretation of inputs in the direct range to the end devices. The edge is a point of contact between vehicles and the cloud. The edge server has computing and storage means placed close to vehicles. [17] The services furnished by edge computing, conforming to ETSI standards, produce a substantial level of quality of service to the end user (edge node). The current applications of in-vehicle networks should be supported by efficient communication and computational application. Edge servers analyse and store the data acquired by the sensors in vehicles. Low-latency communication is made possible by these services, which also serve to promote awareness.[18,19]

Software Defined Networking (SDN) is characterised by the independence of the data plane and control plane. The connection between the data plane and control plane causes packet flow to be delayed, which increases both the cost and the time required for transmission.[20] Thus, this has led the SDN to be concerned about reducing the amount of communication between the data plane and the control plane. The controller can use the real-time central global information provided by the network infrastructure to make informed management decisions. Through the use of a control plane, the controller has access to a network view.[21,22] It communicates with forwarding devices and offers network control applications with an integrated development environment. As a result, it helps the dynamic adoption and administration of networks without impacting the operations of existing network infrastructures. It helps in the development of new applications and efficient use of resources. The configuration of the SDN control plane enables the network to adapt to changes in network dynamics caused by unforeseen situations, such as traffic accidents or lane diversions. The SDN works in coordination with edge computing and supports the transportation systems’ ability to engage with the uncertainty of a varying and large number of vehicles, massive data volumes, and frequent disconnections to enable immediate vehicle connectivity and thus enhance the safety of the driver.[23–25]

The architecture of EC is composed of three layers: cloud layer, edge cloud layer, and the vehicle network. A number of essential advantages of the cloud layer encompass batch processing, predictive analytics, analytical modelling, caching, high scalability, and data processing of detailed information, which are all far beyond the computing capabilities of the edge devices.[26] The cloud can process large volumes of data in a short time. Cloud infrastructure includes storage and processing. The data collected among many edge nodes will be transmitted to the cloud layer, entirely stored for long-term analysis. Since the data may be utilized over a more extended period, it would not be necessary to do computations in real-time. Components for computing and analysis conduct complicated computations more quickly. Unlike latency-sensitive services, computational processes transmitted suffer from delay.[27]

On the other hand, the edge cloud layer links the vehicle network and the cloud layer. In order to do this, the vehicles are equipped with communication hardware that makes use of wireless communication protocols such as wireless LAN (IEEE 802.11n), dedicated short-range communication (IEEE 802.11p), cellular networks (4G/5G), and LoRa to communicate with one another and with their surroundings.[28,29] The purpose would be to provide reliable communication, emergency services, situational awareness, content identification, storage, processing, and increasing efficiency because it is situated close to vehicles and is used for reliable information. The edge cloud layer is beneficial for applications that need a faster response with very low delay, such as environment detection (flash flood), health recognition (drivers' health condition), and driving behaviour identification.[30,31]

Vehicles are expected to conduct more services. The vehicle network layer includes a collection of topologically nearby vehicles and shares computational and storage capabilities over a wireless network.[32] The vehicle network abstracts information from an on-board unit (OBU), a global positioning system (GPS), embedded sensors, cameras, lidar, radar, and other devices. The information obtained may be transmitted to the edge cloud layer for storing or utilized as a source for services offered at the application layer. As part of the vehicle network, the vehicle will be equipped with communications, intelligence, storage, and adapting capabilities that will allow it to expect the driver's expectations. Additionally, the concept will also assist by offering offloading and computational capabilities for vehicles delivering all preferred services at the edge network.[33,34]

Applicability of EC for V2X

As of recent years, V2X and EC technologies are still in the early stages of development and deployment. However, there have been significant advancements in recent years, and many researchers and industry experts are optimistic about the future of these technologies.[28,31] In terms of V2X, many automakers and technology companies are investing in the development of connected and autonomous vehicles. In addition, several standards organizations, such as the IEEE and the 3GPP, are working to establish common standards and protocols for V2X communication. These standards will help ensure interoperability between different vehicles and systems and enable the development of a robust V2X ecosystem.[29,30] As for EC, there has been a rapid expansion of edge devices and infrastructure, driven by the increasing demand for low-latency and high-bandwidth applications such as autonomous driving and smart cities. Many cloud providers, such as Amazon Web Services and Microsoft Azure, are also expanding their edge computing capabilities to meet the growing demand for edge services. Moreover, there are several open-source projects and industry initiatives, such as the Open Edge Computing Initiative, aimed at promoting the development and adoption of EC technologies.

EC applies to a wide range of uses, from sensor applications (e.g., predictive vehicle maintenance) to the end-user experience (e.g., collision prevention warning). EC has been discussed previously from the perspective of V2X communication applicability. In 2022, Pack proposed a lightweight vehicular edge computing framework to address the security and privacy challenges in V2X communications. The authors introduced the LS-VEC framework, which leverages directed acyclic graphs (DAGs) to record transactions for edge resource allocation and micro-transactions for pricing VEC resources.[35] Additionally, an auction theory-based game-theoretic approach is proposed for efficient allocation and pricing of edge resources supporting computation offloading. The LS-VEC framework presents a promising solution to enhance the security and privacy of V2X services while maintaining low latency and efficient resource allocation. In the same year, Khan *et al.* introduced a modular infrastructure for V2X, presenting "B-UV2X," a blockchain hyperledger fabric-enabled distributed permissioned network-based consortium structure. The participating vehicle nodes are interconnected within the smart city chain, exchanging various information such as movement data, which is securely logged on the blockchain-enabled immutable ledger.[36] The implementation and evaluation of B-UV2X demonstrate its potential to automate IoV transactions with doppler spread, presenting a promising solution for V2X communication.

Vladyko *et al.* addressed the challenge of reliable and secure information exchange in real-time within the vehicle-to-everything (V2X) concept. To achieve this, the authors propose a network architecture leveraging blockchain technology and mobile edge computing (MEC). The authors present a formalized mathematical model considering the interconnection of objects and V2X information channels. An energy-efficient algorithm for traffic offloading to the MEC server is also introduced.[37] Through the implementation and evaluation of the proposed approach using blockchain and MEC in the developed system, the proposed approach demonstrates advantages and disadvantages of the implementation, highlighting the potential of blockchain and edge computing in ensuring reliable and secure V2X communications. Awais *et al.* explored the potential of mobile edge computing (MEC) and blockchain technology. The proposed architecture adopts a hierarchical computing approach with cloud computing (CC), edge computing (EC), and fog computing (FC) nodes to distribute resources and databases based on computing service requirements. A blockchain-based transaction service is integrated to enhance reliability.[38] The approach is experimentally evaluated in two use cases: plug-in electric vehicles in smart grid scenarios and massive IoT data services for autonomous cars. The results demonstrate reduced network consumption, improved security features, and lower computational load for computed log storage compared to a centralized network system.

Al-Bhakri *et al*. developed a simulation models for automotive networks based on mobile edge computing (MEC) and software-defined networking (SDN) technologies. The architecture of the automotive network is to enhance the management of network resources, applications, and users. There were two experiment conducted, the first experiment demonstrates the positive effect of edge and fog computing on the network core load, while the second experiment shows the positive effect of SDN in load balancing between base stations (BS) and roadside units (RSU).[39] Xu *et al.* proposed a computation offloading method called V2X-COM that utilizes vehicle-to-everything (V2X) communication to improve smart vehicle applications in the internet of vehicles (IoV). The method employs vehicle-to-infrastructure communication (V2I) and vehicle-to-vehicle communication (V2V) to determine feasible routes for offloading computation tasks to edge nodes (ENs). The study uses non-dominated sorting genetic algorithm III (NSGA-III), simple additive weighting (SAW), and multiple criteria decision making (MCDM) to generate balanced and optimal offloading strategies, which are experimentally evaluated for validation.[40]

Moubayed *et al.* described an Optimum V2X Service Placement (OVSP) as a binary integer issue in a linear edge context.[41] The authors approached this problem using a low-complexity greedy heuristic technique (G-VSPA). Extensive simulations showed that the OVSP model provides satisfactory results when sensitive services to delays are on the edge and tolerant services to delays are at the core of the process. Furthermore, the proposed algorithm provides near-optimal performance with minimal complexity. In the same year, Shaer *et al*. addressed the efficient deployment of V2X essential services, including various V2X applications in the EC environment.[42] The authors devised an optimisation method for minimising E2E latency in multi-component V2V systems under different traffic situations. The findings indicate that the methodology guarantees an adequate level of service and surpasses solutions developed in earlier studies using realistic scenarios.

Lee *et al.* described an EC approach for minimising trip time at interconnected junctions.[43] The authors suggested a paradigm in which each road side unit (RSU) determines junction scheduling while the vehicles select their travel trajectory through dynamic control. Based on simulation results for optimum scheduling of linked junctions, the proposed framework significantly reduced overall travel time by up to 14.3%. Grammarikos and Cottis investigated the benefits of mobile edge computing (MEC) adopting V2X services linked to traffic efficiency and road safety.[44] A simulation model that represented a long-term evolution (LTE) system with basic MEC capabilities, such as packet routing, was investigated in this work to evaluate the applicability of their findings. The presented approach evaluated the packet delivery ratio and packet loss for applications, such as telemetry and emergency message delivery, respectively. While LTE can transmit traffic data to vehicles in a short amount of time, the simulation results revealed that severe congestion in the backhaul and core networks could result in unexpected packet losses, which could be prevented by the processing capabilities of a MEC server.

In addition, Napolitano *et al.* proposed a fully compatible design and implementation of a vulnerable road users (VRU) warning system, as well as an experimental assessment of the system using MEC- and cloud-based architectures.[45] The authors developed a strategy that would enable road users to communicate information regarding the existence of neighbouring entities in the event of a difficult circumstance (e.g., road accident). This is accomplished by using an architecture that consists of a user-facing Android application and a MEC-based application [cooperative awareness messages (CAM)]. The E2E latency demonstrated a substantial result when visualising the entities engaged between the VRUs application and the CAM server using a preliminary performance measurement. Additionally, Emara *et al.* focused on the case of VRU, examining the safe interaction of vehicles with road users such as motorcyclists and pedestrians.[46] The authors aimed to describe latency improvements using MEC systems through periodic CAM. Extensive simulation results indicated that installing MEC infrastructure may substantially decrease the communication latency. Additionally, Sabella *et al.* suggested a hierarchical MEC architecture for adaptive video streaming in V2X applications.[47] The authors described the acquisition of real-time channel data by local agents stationed at the evolved NodeB (eNB). This information is then communicated to a MEC platform, which automatically changes the video stream's quality to match the channel's conditions. Within a virtualized network context, the authors tested and evaluated a conceptual demonstration of radio-aware video optimization. The results demonstrated that the proposed architecture enhanced the user experience by boosting downlink and uplink speeds and reducing delay.

Bissmeyer *et al*. introduced a network framework that ensures V2X information and data exchange in a MEC-based multi-access technology environment.[48] The authors designed a framework for the integrity of the message, sender authorisation and authentication, and replay detection. This approach is achieved through digital signatures, an authorisation certificate, and public and private key infrastructure. MEC offers local processing capabilities for the exchange of event-driven V2X encrypted messages within the framework. In addition, Balid *et al.* demonstrated MEC traffic management methods for real-time traffic monitoring.[49] The authors developed and deployed a cost-effective wireless sensor traffic monitoring system for highway and roadside traffic. The sensor achieved an acceptable level of accuracy in terms of detection, speed prediction, and vehicle categorisation. Table 1 provides a comprehensive summary of the previous studies, presenting key information on each research work related to V2X and edge computing (EC).

Table 1. Comprehensive summary of previous studies on V2X and edge computing (EC).

Authors	Title	Technology/Concept	Key findings
35	LS-VEC: Lightweight Vehicular Edge Computing Framework	Directed Acyclic Graphs (DAGs), Auction Theory-based Game-theoretic Approach	Enhanced security & privacy in V2X communications with efficient resource allocation and pricing
36	B-UV2X: Blockchain-enabled V2X Consortium Structure	Blockchain (Hyperledger Fabric), V2X	Secure and automated V2X transactions, potential for doppler spread in V2X communication
37	V2X with Blockchain & Mobile Edge Computing (MEC)	MEC, Blockchain	Reliable & secure V2X information exchange, energy-efficient traffic offloading to MEC server
38	Hierarchical Computing with MEC & Blockchain	MEC, Blockchain	Reduced network consumption, improved security features, and lower computational load compared to centralized networks
39	Automotive Network with MEC & SDN	MEC, SDN	Positive effects of edge and fog computing on network core load, SDN load balancing between base stations and roadside units
40	V2X-COM: Computation Offloading with V2X Communication	V2X Communication, NSGA-III, SAW, MCDM	Offloading computation tasks to ENs using V2I and V2V communication, optimal offloading strategies generated using NSGA-III, SAW, and MCDM
41	Optimum V2X Service Placement with Greedy Heuristic	Binary Integer Issue in a Linear Edge Context	Satisfactory results for OVSP model with near-optimal performance and minimal complexity
42	Minimizing E2E Latency in Multi-component V2V Systems	Optimization Method	Adequate level of service with reduced E2E latency
43	EC Approach for Minimizing Trip Time at Interconnected Junctions	Dynamic Control, RSU Scheduling	Significant reduction in overall travel time by up to 14.3%
44	MEC Adopting V2X Services for Traffic Efficiency	LTE System with Basic MEC Capabilities	Evaluation of packet delivery ratio and packet loss for V2X applications
45	VRU Warning System using MEC & Cloud-based Architectures	MEC, Cloud-based Architecture	Substantial reduction in E2E latency in VRU warning system
46	Safe Interaction of Vehicles with VRUs using MEC	MEC	Substantial decrease in communication latency in VRU interaction

Table 1. *Continued*

Authors	Title	Technology/Concept	Key findings
[47]	Hierarchical MEC Architecture for Adaptive Video Streaming in V2X	Hierarchical MEC Architecture	Enhanced user experience by boosting downlink and uplink speeds, reducing delay.
[48]	V2X Information Exchange in MEC-based Multi-access Technology Environment	Digital Signatures, Public & Private Key Infrastructure	Ensuring message integrity, sender authorization & authentication, and replay detection through digital signatures and key infrastructure within MEC framework.
[49]	MEC Traffic Management for Real-time Traffic Monitoring	MEC, Wireless Sensor Traffic Monitoring	Cost-effective wireless sensor traffic monitoring system with acceptable accuracy for detection, speed prediction, and vehicle categorization.

Challenges of V2X and EC

Security

At the edge of a network, privacy and security protection are critical services to provide.[50,51] If the vehicle is equipped with IoT, it can collect sensitive data from sense data.[52] Several ITS implementations would need drivers to grant access to sensitive, confidential data to untrusted vehicles attempting to join as edges in the context of smart cities.[53] Together with data segregation techniques, effective trust management systems may considerably increase edge security.[54] According to El-Sayed & Chaqfeh,[55] although minimal research has been conducted on assuring secure collaboration in an EC scenario, the study does not explicitly address V2X issues.

Deployments

The positioning of edge devices in an urban environment is based on static and dynamic features.[56] Edge nodes may need MEC servers with fixed RSUs or unmanned aerial vehicles (UAV).[57] Many possible ITS applications may be facilitated by autonomous UAVs, improving traffic safety and transportation quality of life.[58] Nevertheless, specific issues must be addressed, such as limited energy, processing ability, and signal transmission range.[59] Given the technological developments such as sensor-based street lights or smart toll booths over the past few decades, the limitations on UAV usage will likely be overcome eventually.

Performances

Each second counts when you're behind the wheel of a vehicle. As a result, vehicles would continuously upload the data collected by their local sensors to the closest edge device.[60,61] Hence, energy and power consumption at the edge should be considered to avoid service disruptions and quality of service (QoS) loss.[62,63] Furthermore, various situations need substantial QoS improvement to cope with occasional high traffic loads like severe traffic congestion, unpredicted weather conditions, or unexpected road construction works.[64] Therefore, further research is necessary to enhance and manage QoS in the V2X context considering a heterogeneous edge-based environment.

Conclusions and future direction

EC adoption is growing in the automotive industry, and ITS, particularly V2X, will certainly change various economic sectors and significantly influence our everyday lives. Despite this, multiple different challenges are limiting its wide implementation. The increasing number of sensors in connected vehicles and roads creates a large data processing and storage issue. This requires new service platforms with strong processing, reliable storage, and real-time communication. EC is indeed a promising way to decrease latency and bring data closer to vehicles and resources. In the future, we will work on a comprehensive middleware solution for V2X communication. In many V2X scenarios, data transmitted between users and network infrastructure is localised and does not need remote access to centralised data centres. Using EC may substantially improve the performance of supporting various applications of V2X. The availability of network resources, storage, and computation near the network edge make EC an ideal option for V2X delay-sensitive applications.

To move towards a promising future, researchers and industry stakeholders need to focus on several key directions. Firstly, substantial efforts should be dedicated to developing robust security mechanisms for V2X communication at the edge, including privacy protection, effective trust management systems, and secure collaboration protocols. Secondly, innovative solutions must be explored to optimize the positioning and deployment of edge devices in urban environments, considering static and dynamic features and overcoming limitations related to energy, processing ability, and signal transmission range. Thirdly, there is a critical need to invest in research and development to enhance the performance of V2X applications in heterogeneous edge-based environments, focusing on reducing energy and power consumption while ensuring reliable quality of service, especially in high traffic load scenarios. Additionally, the creation of comprehensive middleware solutions tailored to V2X communication can significantly contribute to addressing data processing and storage challenges and streamline communication between users and network infrastructure. By adopting these future directions, V2X and EC can unlock their full potential, revolutionizing various economic sectors and significantly enhancing the safety and convenience of our everyday lives on the road.

Data availability
No data is associated with this article.

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Open Peer Review

Current Peer Review Status: ✗ ✓ ✗ ? ✗ ?

Version 4

Reviewer Report 08 April 2024

https://doi.org/10.5256/f1000research.154335.r241475

?

Preeti Rani
SRM Institute of science and Technology,, Delhi-NCR Campus, India

The authors have presented a satisfied review vehicle to everything's techniques. The manuscript may have some merits, but some major concerns are:

1. The presentation of the paper can be significantly improved if the authors review the paper with a language specialist and try to polish it in order to be more readable: such as long sentences, tense, misused punctuation, etc. Try to put some lined space in between each paragraph for better paper visualization.

2. The gap statement of the research is a little bit poor and insufficient and the main contributions of the authors need to be included in the introduction section.

3. The conclusion section includes only a summary of conclusions from the published studies, there are no findings of this review paper.

4. What is the motivation and mechanism behind the survey? The section is completely missing.

5. The abbreviations are repeatedly declared. It needs to be declared once then used as abbreviation only.

6. Authors need to add 2-3 comparatives tables.

Is the topic of the review discussed comprehensively in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?

Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Wireless Technology, Wireless Sensor Network, Networking, Wireless Computing, Satellite Communication, Network Simulation, Computer Networking, Network Communication, Routing Network, QoS, Security Network, Mobile Ad-hoc Network, Vehicular Ad-hoc Network, Internet of Vehicle

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 06 March 2024

https://doi.org/10.5256/f1000research.154335.r241476

❌ **Qiong Wu**
Jiangnan University, Wuxi, China

This article describes the evolution of V2X and EC technology and reviews the references on the new service technologies that are being created by the combination of the two technologies. However, the authors have not given the deep insight on these references, but simply listed them and thus it is lack of contributions. At the same time, the authors also listed the challenges and expectations that exist in the existing works, which are quite interesting to consider. My detailed comments are given as follows,
Major comments
1. "V2X encompasses two main technologies: C-V2X and DSRC" is mentioned in the article, but the application and comparison of the two technologies in the existing works on EC should be added. The authors have not addressed the issues raised in the previous revisions.

2. The article mentions "We compare them(mobile edge computing, cloudlet, and fog computing) according to their applicability to V2X" in Abstract, however, there is only an introduction in the paper without comparison. As a review, the comparison among mobile edge computing, cloudlet, and fog computing should be given.

3. From the Abstract, the paper focuses on EC as a promising solution to the challenge of V2X massive data processing, but does not presents the comparison of specific methods of data

processing. It is more convincing to add horizontal comparisons between the related works to illustrate the performance differences and advantages and disadvantages of the existing methods under the same conditions.

Minor comments
This article is a review that lists some applications, but lacks relevant literature citations, e.g. references should be inserted after "predictive vehicle maintenance".
1) [1]
2) [3]
3) [2]
4) [4]

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Is the topic of the review discussed comprehensively in the context of the current literature?
Partly

Are all factual statements correct and adequately supported by citations?
Partly

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My research area belongs to image processing in self-driving, which involves the processing of a large amount of data, and has some things in common with the problem that the paper aims to illustrate.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 21 February 2024

https://doi.org/10.5256/f1000research.154335.r241478

?

Mahmood A Al-Shareeda
Iraq University College, Basrah, Iraq

The title is timing and interested. There is sound research in the context of the manuscript. The following comments have been provided to improve the quality of the manuscript.

1-add numerical result in the Abstract part.
2-List of contribution should be added to the introduction part.
3-Authors are recommended to add more figures to describe the proposed solution well.
4-What is the difference between the proposal and other relevant research? And how is your proposal outperformed others?
5-Reviewing and citing the following modern solutions in related work part:[1],[2],[3],[4],[5],[6],[7].

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Is the topic of the review discussed comprehensively in the context of the current literature?

Yes

Are all factual statements correct and adequately supported by citations?
Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: VANET, vehicle

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Version 3

Reviewer Report 01 August 2023

https://doi.org/10.5256/f1000research.147679.r184319

✗ **Muhammad Saleh Bute**
Southwest Jiaotong University, Chengdu, Sichuan, China

1. In the abstract, the aim of this work is not clear? Is it about placement of edge computing resources or a review on edge computing and V2X?

2. I think before going into proper review, it is good to look into edge computing standard set by the ETSI. Which is not stated in the work. secondly, V2X is also of two kinds, the C-V2X and DSRC, which are not explicitly discussed in the work.

3. Insufficient references for a review work

4. The authors, did not satisfactorily state the findings of the review nor stating a clear guide for future work/direction.

Is the topic of the review discussed comprehensively in the context of the current

literature?
Partly

Are all factual statements correct and adequately supported by citations?
Partly

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Vehicular Communications, Edge Computing

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Version 2

Reviewer Report 02 March 2023

https://doi.org/10.5256/f1000research.135574.r143530

✗ **Danilo Amendola**
[1] University of Trieste, Trieste, Italy
[2] Vicomtech, Donostia-San Sebastiá, Spain

The work has not been sufficiently improved to achieve a better approval status, as the authors have not address the concerns raised in the peer review report for the first version of the article.

Is the topic of the review discussed comprehensively in the context of the current literature?
No

Are all factual statements correct and adequately supported by citations?
No

Is the review written in accessible language?

No

Are the conclusions drawn appropriate in the context of the current research literature?
No

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 18 July 2022

https://doi.org/10.5256/f1000research.135574.r143531

Lionel Nkenyereye
Research Institute of Engineering, Pukyong National University, Busan, South Korea

The authors have successfully addressed my concerns.

Is the topic of the review discussed comprehensively in the context of the current literature?
No

Are all factual statements correct and adequately supported by citations?
No

Is the review written in accessible language?
No

Are the conclusions drawn appropriate in the context of the current research literature?
No

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 02 March 2022

https://doi.org/10.5256/f1000research.76911.r123882

?

Lionel Nkenyereye
Research Institute of Engineering, Pukyong National University, Busan, South Korea

The paper discussed the successful implementation of V2X communication and services. The V2X services coupled with edge computing prompt new V2X services with low latency. The authors have provided use cases that show the effectiveness of deploying edge computing for V2X-based edge computing applications.

The paper is well written and organized. The following are some comments that should be addressed:

1. The topic of edge computing supported for V2X is wide and there are interesting concepts which the authors have not yet discussed such as the task offloading (vehicle -to edge servers), edge caching to cache the data in edge to reduce communication latency.

2. The paper is well written. Since it is a short review, it is clear that this article lacks new contributions. I would like to ask the authors what the contributions are.

3. Regarding the implementation of V2X communications: How is this implementation achieved?

Is the topic of the review discussed comprehensively in the context of the current literature?
Yes

Are all factual statements correct and adequately supported by citations?
Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Edge computing, vehicle network, V2X, Internet of things

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 26 Jun 2022

Sumendra Yogarayan

The paper has been revised accordingly.

In regards to comment number 2, the study contributes to the domain of edge computing incorporation for vehicular communication particularly in Malaysia context.

In regards to comment number 3, as of recent, the national automotive policy 2020 has initiated the standard for connected vehicles that includes on vehicle to vehicle communication. Thus, this certainly will add to the understanding of edge computing for further integration in safety related or non-related safety application.

Competing Interests: No competing interests were disclosed.

Reviewer Report 20 December 2021

https://doi.org/10.5256/f1000research.76911.r98480

❌

Danilo Amendola
[1] University of Trieste, Trieste, Italy
[2] Vicomtech, Donostia-San Sebastiá, Spain

The article presents in a nutshell a short, partial, and shallow overview of edge computing.

The authors introduce the historic evolution of driver and passengers' interactions since the dawn, however the contribution related to the vehicular communications and edge computing in the paper is not enough wide.

There are no references to the standards, architecture, and challenges about the edge computing. The contribution is poor, and the related works considered are too few to consider the work valid.

The author should extend the paper with more related works and deep analysis about the status of technology on V2X and edge computing.

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Publisher Full Text

Is the topic of the review discussed comprehensively in the context of the current literature?
Yes

Are all factual statements correct and adequately supported by citations?
Yes

Is the review written in accessible language?
Yes

Are the conclusions drawn appropriate in the context of the current research literature?
Partly

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 26 Jun 2022

Sumendra Yogarayan

The paper has been revised accordingly.

Competing Interests: No competing interests were disclosed.