

MINIMIZING E2E DELAY IN V2X OVER CELLULAR NETWORKS: REVIEW AND CHALLENGES

Salim A. Mohammed Ali ¹, Emad H. Al-Hemairy ²

^{1,2} College of Information Engineering, Al-Nahrain University, Baghdad, Iraq
 {salimm ¹, emad ²}@coie-nahrain.edu.iq

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Abstract- V2X (Vehicle- to- Everything) evolution over cellular networks has been an excelling topic with the advances of high throughput and low latency LTE networks, and the introduction of 5G networks. According to recent researches, obtaining acceptable End-to-End (E2E) delay has been a challenging design process since data travels through several steps from the originating source to the data center and vice versa. C- V2X (Cellular- V2X) latency comprises mainly of three levels: source processing, cellular network, and data center processing. Delay reduction can be achieved on the three levels. However, many conventional solutions have not reached the required and acceptable range of latency to enable V2X communication over cellular networks. In this paper, a general review of challenges to make V2X feasible on cellular network has been discussed, and the proposed solutions in the literature has been introduced. As a conclusion, a various types of aiding tools to design and test V2X tools are given, so that a right path should be taken to consider challenges and improving design metrics.

I. INTRODUCTION

The vehicle to everything (V2X) model uses cutting- edge technologies of information and telecommunication to implement vehicle to vehicle (V2V), vehicle to pedestrian (V2P), vehicle to infrastructure (V2I), and vehicle to network/cloud (V2N/ V2C) [1]. This method combines the different components of transportation, such as vehicles, pedestrians, roads, and cloud technologies. The basis of V2X is not only constrained to improve driving safety and technology but also to engage with smart transport systems that mitigate condensed urban traffic [2]. In short, the importance of V2X availability is to reduce congested traffic, pollution, accidents, and greenhouse gas emission [3], and to enhance transportation systems [4]. In literature, two communication technologies are used to implement V2X: Long Term Evolution (LTE), which is the main topic for this review paper, and Dedicated Short Range Communication (DSRC) [5]. The latter, uses IEEE 802.11p protocol [6], which is a standard for V2V communication and designed so that vehicles can communicate with each other instantaneously within same vicinity. On the other hand, LTE based V2X is defined as a wireless telecommunication technology that adopts superior data rate and managed QoS for V2X [7], [8]. LTE technology defines two cellular communication interfaces for this purpose: Uu and PC5 [9]- [12]. Uu interface uses LTE's uplink and downlink to implement vehicle- to- vehicle communication, while PC5 (direct communication) interface uses a similar method that of DSRC which enables direct connection among vehicles. Fig. 1 shows the difference between the two interfaces [13], [14]. Several enhancements have been added into PC5 to keep up with quick changes of the dynamic information such as location, vehicle speed, directions, etc., in addition to some advanced V2X services such as smart vehicles, platooning, sensor data aggregation, etc. [15]. Many applications can be harnessed with the use of C- V2X, including: auto-driving mode, intelligent transportation, vehicle platooning [16]. The diversity of the application is based on the requirements variety, some of these requirements are delay, throughput, vehicle density, reliability, safety and traffic rules of the C- V2X setting [17]. For example, to assure safe auto driving, very low latency and reliable network setting are required [18], [19]. Security of the network is

becoming one of the most important requirements to achieve reliable and accident free automated driving. For examples, false messages by attackers may lead to unwanted outcomes especially when vehicles are spending most of the time driving in high speed. Attackers also can sniff private information of around vehicles, such as vehicle location, identity, and driving destination [20]. C- V2X if implemented, it will pave the way to many other applications and services, such as national security [21], economical blooming, and significant impact on future road and traffic planning. Many conventional network simulators can be used to adopt C- V2X simulations. Simulation process of such implementation is crucial. Accurate and reliable simulation tools are required to build C- V2X modules and test its feasibility within congested and condensed areas, since precise results is not easily predictable from such system that comprises of many entities and huge changing parameters [22]. Since, there is no stable simulator specified for C- V2X, and most current simulators that is being used to achieve experimental tests through modifying and adding new modules to the original software, it is thought that is still early to make a comprehensive review of simulators that is proper for C- V2X applications and left as future work. Several challenges have to be overcome to make the solution of C- V2X applicable, these challenges vary based upon the implementable environment, condensed users, and technologies used. Challenges may persist and escalate if not proper solution is figured out to cease it from interfering with system operation. In this paper, main challenges are reviewed such as: reliability, latency constraints, and security threats. To overcome these challenges, further steps should be taken and can greatly affect E2E magnitude. The structure of this paper is as follows: Section 2 explores the different application types of V2X. Section 3 explains several design paradigms to mitigate E2E delay in V2X implementation. Section 4 show how is cellular V2X network is designed. Section 5 discusses the main challenges of V2X implementation over cellular networks such as latency, security, and reliability. The paper ends with a conclusion section that summarizes the whole paper findings.

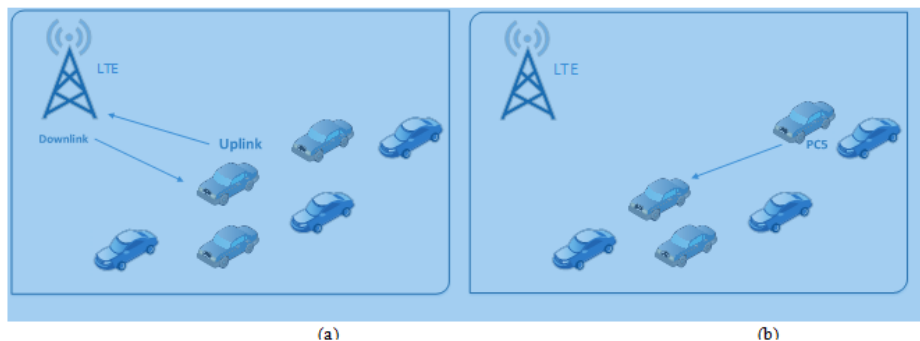


Figure 1: LTE-V2X communication interfaces (a) Uu mode (b) PC5 mode

II. V2X APPLICATIONS

Cellular V2X embodies the relation among automobiles, safety, telecommunication, intelligent transportation, and cloud computing. Many companies have put lots of effort to develop applications in this direction especially ones that connects to information systems and business uses [23]. The future of computation is data, and C- V2X can be harnessed to

obtain huge amount of useful data, that if it is put into better use, it will open numerous paths of designing many other useful applications. The most prominent applications of C- V2X is safety applications, which refers to the driver's and passenger's safety, this can be achieved through alerting systems that forwards warnings, traffic hazards, road blockages, inclement weather conditions, traffic congestions, etc. The other type of C- V2X applications is efficiency applications, this implemented through providing guidance to the driver by choosing the most efficient road till the destination. Although many devices and applications has been used for this purpose, none of these provides universal solution to all drivers at once, here comes the powerful role of C- V2X, in which all vehicles are guided to prevent the occurrence of traffic congestion. One of the data-related applications is the information services applications, which provides drivers with their vehicles information to enhance their driving practice, for example, route directions, parking assist information electronic traffic call information etc. V2X applications will greatly pave the way to the automatic driving systems and smart vehicle development, through the use of advance communication systems such as cellular networks. As a matter of fact, 3GPP presents many types of new applications, which can significantly be implemented using cellular networks, such as Advance Driving, Remote Driving, Vehicle Platooning, and Extended Sensors [18]. These applications emerged with the development of V2X industry, and the fast progress of Cellular networks. 3GPP has also set the new requirements for various V2X applications. The top two priority requirements are safety and latency with reliability [19]. Fig. 2 shows the four types of applications according to their Security and latency/ reliability. The y- axis represents the security requirement, the higher the value the higher the security requirement level is considered. On the other hand, the x-axis represents the latency/ reliability requirement the higher the value the lower latency is required and higher reliability should be considered.

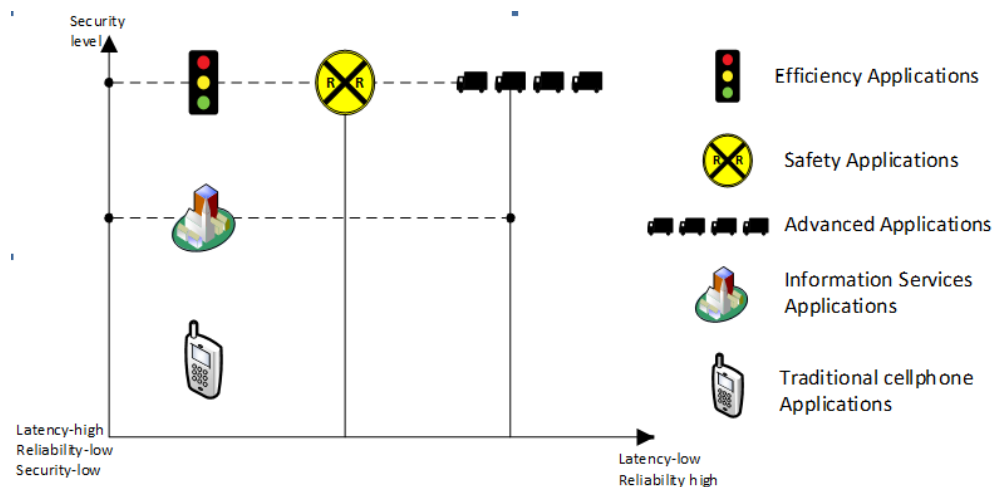


Figure 2: V2X applications with respect to security and latency/reliability requirements

III. LITERATURE SURVEY

Many techniques and methodologies has been utilized to implement Cellular V2X to be harmonious with 5G, in this section, various methods and design paradigms are discussed concerning the development of C- V2X. These methods

can be classified into two main categories: new transmission schemes, and infrastructure utilization. The following two subsections describe the methods according to the two categories.

A. *New transmission schemes*

These methods refer to modifications to the current technologies being used in cellular networks to either comply with the increasing data rate requirements of cellular nodes, or avoiding already congested traffic.

1) *Cellular- V2X in unlicensed spectrum*

In [24], they proposed using the unlicensed spectrum of cellular networks to cope with the high data rate requirements of V2X applications. The spectrum is becoming more and more overused, therefore to accommodate the new 5G high data rates requirements, one way is to expand the spectrum used for mobile communication [49], [50]. In this research, they designed a new scheme to measure the energy of the unlicensed spectrum so it can be sharable among users. This will allow users to reduce transmission collisions between cellular VANET and C- V2X users. To make it work with maximum performance, they have formulated both resource and schedule allocations with a bi-sided M-to-M match among peers. They also introduced a new algorithm of dynamic vehicle- resource matching (DV-RMA) and showed the results in both computing complexity and timing convergence, which outperformed other used techniques in terms of C- V2X performance.

2) *Evaluation of IEEE 802.11ad for mmWave V2V communications*

In [25], they have usher the use of mmWave communication to provide larger bandwidths than of obtained by the current ITS- G5/ DSRC standard. Larger bandwidths are required to cope with the enormous data generated by autonomous vehicles sensors, which are keeping to be increased after each production. The research introduces performance evaluation of the IEEE 802.11ad MAC and beamforming technique for mmWave vehicular communications. Their study shows existing prospects and limitations that should escort the progress of mmWave [51], [52] communications for vehicular communications.

3) *V2X Meets NOMA: Non-Orthogonal Multiple Access for 5G enabled vehicular networks*

In [27], they exploit the use of non-orthogonal multiple access (NOMA) [53], [54] to cope with the orthogonal access efficiency degradation due to congestion in OFDM- based LTE infrastructure. NOMA can play a great role in the future 5G networks, especially in providing massive connectivity and broad communication bandwidth. Their work investigated the viability of using NOMA to support C- V2X applications and services to accommodate low delay and reliable traffic. They proposed a new scheme of NOMA to mitigate the high spectral efficiency and to allocate better resource and scheduling schemes that can greatly benefits C- V2X in many aspects.

4) *Use cases, requirements, and design considerations for 5G V2X*

In [28], they investigate various cases in which it can help C- V2X to thrive in 5G network [55]. They made a compare and contrast between conventional communication systems and the new techniques that possibly be implemented in the future. They also discussed a complete scheme for 5g C- V2X radio access method that involves a wide range of communication technologies such as mmWave and cmWave, IEEE 802.11p [56], and visible light vehicular

communication. They also spot the light of how future C- V2X will enable variety of services that will achieve many benefits to vehicular systems.

B. Infrastructure utilization

These methods utilize cellular network infrastructure through either reconfiguring transmission standards or adding radio assistant nodes to enhance performance of the current used cellular network interfaces.

1) Multi- RATs support to improve V2X communication

In [26], their research targets two key metrics: ultra- high reliability and end to end latency (E2E), which are the main requirements of C- V2X applications. Their work inspects the performance of the system by using LTE- Uu and PC5 lines in V2X Communication. By using LTE-Uu, single V2X packet will be forwarded from end- to- end of the whole network, while in PC5 line direct V2X communication will be handled without the involvement of Cellular Network user-plane infrastructure. As a matter of fact, using single interface for the whole transmission defies the definition of reliability, so for this reason, they have proposed multi radio access technologies (multi- RATs) [57], [58] where packets will flow in both lines: LTE- Uu and PC5, so that a diversity advantage can be attained. To ensure the results are effective they have developed a simple simulator to test the system level performance.

2) MEC- assisted End- to- End latency evaluations for C- V2X communications

In [29], they used VRUs (Vulnerable Road users) to assist in information collecting about road environments, and tell the vehicles about this information and then send it using cellular network. As a result, depending on MEC (Multi- access Edge Computing) [59] bases instead of cloud based cellular infrastructure, they can lower the end- to- end latency significantly compared to conventional methods. They proved their results using extensive simulation comparison.

3) Feasibility study of enabling V2X communications by LTE- Uu radio interface

In [30], knowing that future Cellular networks targets several services with broad range of QoS measures, beginning with streaming HD videos to using low data rate services plus accommodating limited latency requirements, this research aims to study the use of LTE- Uu Radio interface [60], [61] to achieve feasible implementation of C- V2X that has limited E2E delay and high reliability communication. To achieve this study, simulations are carried out by including E2E latency in the key performance indicators (KPI) with various scenarios of V2X to test LTE- Uu air interface to perform URLLC service type.

4) Cellular- V2X communications for platooning: design and evaluation

In [31], they exploit platooning [62], [63], when many vehicles travel at the same lane with the same speed and destination, these vehicles can share its sensors data together; such that only one vehicle can send the data for all vehicles within same vicinity. The aim of this work is to test platooning application through making various choices and considering many factors. They have used two modes for their implementation: sequential and simultaneous mode. The evaluation process has been accomplished though using system- level simulations.

C. New transmission schemes vs. infrastructure utilization

In the previous subsections many techniques and methods are described, in which all, somehow contributes to latency reduction. The first category revolutionizes to use new transmission schemes to achieve such goal and to comply with 5G network, while the second category reconfigures the already used infrastructure to comply with C- V2X through adding additional steps that is mainly concerns C- V2X applications and services. Both categories outcome is feasible and depends upon on the matter of cost, regulation, and security to achieve all. Through reviewing the details of the above researches we mostly biased to the second category for research and development, since the first category solutions are prominent and some of it are already being implemented within the umbrella of 5G networks. So that, reconfiguring or updating the already existed infrastructures to maintain C- V2X applications and services is less costly solution despite it may not achieve latency reduction one hundred percent.

IV. C-V2X NETWORK DESIGN

In this section, basic design methodology is drawn that generalizes most V2X systems which operates on cellular networks. The design considers various network metrics that should be taken care of to implement V2X applications. This section shows how to calculate the E2E delay for the various steps of data travelling from source to destination and vice versa. To have a sense of how long should it take, the maximum and minimum requirements, the paper reviews some specific details about delays and its correspondent applications. The following subsection shows the requirement of E2E delay for each service.

A. Latency requirement for vehicle- related services

The V2X services can be categorized into three groups:

- 1) safety- related services.
- 2) non- safety- related services.
- 3) automated driving- related services.

Safety- related services are concerned with real- time safety messages, such as warning messages (e.g. , abrupt brake warning message) to reduce the risk of car accidents. In these types of services, timeliness and reliability are considered to be key requirements. On the other hand, non- safety- related services are intended to optimize the traffic flow on the road so that travel time is reduced. Thus, these services enable a more efficient and comfortable driving experience with no stringent requirements in terms of latency and reliability. For the safety- related services, if the frequency of periodic messages is considered (e. g., from 1 to 10 messages/s) and the reaction time of most drivers (e. g. , from 0.6 s to 1.4 s), then the maximum allowable end- to- end latency must not exceed 100ms [44]. In fact, depending on the service type, the latency requirement may even be less than 100ms, (e. g. , 20ms for a pre- crash sensing warning). In addition to these kinds of services, automated driving- related services are now being developed as key transformations begin to occur in the automotive industry. These automated driving- related services require more rigorous latency, data rate, and positioning accuracy requirements. Therefore, the latency requirements for automated driving- related services are more

stringent than those required for safety-related services. For example, automated overtaking or high density platooning services have a 10ms requirement. Since the scope of this paper is the latency issue in C- V2X communications, it focuses on the safety-related and automated driving-related services. Table I lists the V2X service use cases and the corresponding latency requirements [45], [46].

TABLE I
V2X SERVICE USE CASES AND LATENCY REQUIREMENTS

Service type	Use cases	Latency requirement
Safety-related services	Forward collision warning (FCW)	100 ms
	Control loss warning (CLW)	100 ms
	Emergency warning	100 ms
	Emergency Stop	100 ms
	Queue warning	100 ms
	Road safety services	100 ms
	Pre- crash sensing warning	20 ms
Automated driving- related services	Automated overtake	10 ms
	Cooperative collision avoidance	100 ms
	High density platooning	10 ms
	See- through	50 ms

B. Latency modelling

The objective of this work is to investigate the E2E latency through Cellular networks. Towards accomplishing this aim, in this section, various latency components are modeled relating to transmission, routing and processing. Regarding the conventional cellular network architecture approach, the one- way messaging latency is modeled as:

$$T_{one-way} = T_{UL} + T_{BH} + T_{TN} + T_{CN} + T_{Exc} \quad (1)$$

where:

T_{UL} is the radio UL transmission latency.

T_{BH} is the Backhaul (BH) network latency.

T_{TN} is the TN latency, T_{CN} is the CN latency .

T_{Exc} is the processing latency.

Consequently, the E2E latency, is expressed as [47]:

$$T_{E2E} = T_{UL} + \underbrace{2(T_{BH} + T_{TN} + T_{CN})}_{\text{Network Latency}} + T_{Exc} + T_{DL} \quad (2)$$

where:

T_{DL} represents the DL transmission latency.

C. Network modeling

As for network modelling, queuing theory approach is used to facilitate the top view of C- V2X system. The main components are: source nodes that generates data traffic in a constant rate, Back- hole nodes that forwards the traffic to the data sink, and the main data sink that process the data and give back relevant feedback to the generating traffic nodes in different and intermittent data rate. Fig. 3 shows the queuing model for such system [48].

V. V2X CHALLENGES

Challenges can be divided into two segments: Latency/ Reliability challenges, and Security threats. The first one limits the feasibility of implementing specific types of V2X applications as timing requirements are hard limits, while the latter considers the continuity of the application operability in terms of intentional sabotaging to deteriorate V2X operation, as a result to compel it, it is required additional steps that may increase E2E latency. The following two subsections describes the challenges in details.

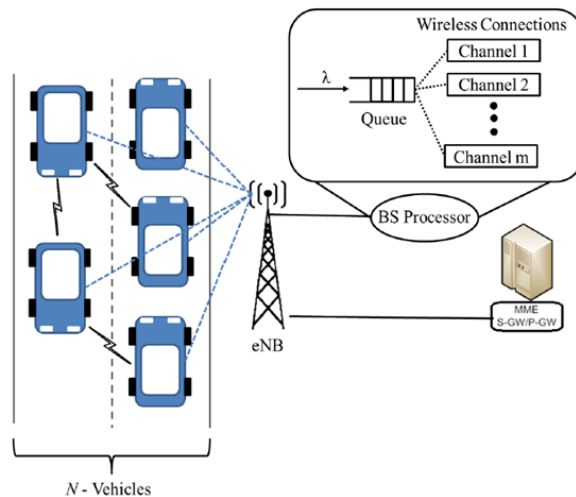


Figure 3: Basic mobile network queueing system model for C- V2X

A. Latency/ reliability Challenges

The performance of the network is most important for applications which require low latency and high reliability. DSRC uses CSMA/ CA to achieve collision avoidance and the ability for multi- user access. With fewer vehicles, DSRC has lower latency and higher reliability, but its performance is opposite in a dense vehicle environment. The latency of LTE-V2X is relatively stable, and the communication delay based on the PC5 interface, which can provide predictable delay and less interference is lower than 100 ms [33]. In the future, 5G networks will provide a communication delay of less than 1 ms while providing a stability of 99.999%, so they will be able support automatic- driving- oriented V2X services. V2X applications performs better as long as having lower latency and higher reliability. Ordinary wireless MAC sharing medium (CSMA/ CA) performs good job in small groups of vehicles. In larger groups, this technology will struggle and the whole network performance will be degraded, which directly impacts the operation of V2X applications. Using C-V2X with LTE and above cellular technologies, the network should be more stable and the E2E delay will be guaranteed to be lower than 100 ms [33]. Through utilizing 5G networks the delay should be dropped as less as 1ms, while keeping high stability of the network even in crowded areas. The V2X network faces many kinds of attacks which could lead to reduced performance. Denial of service (DoS) or distributed DoS (DDoS) refer to intensive use denial attacks by internal or external attackers on target nodes, resulting in the exhaustion of network resources and service resources [34]. They

can cause serious problems, such as high latency of communication networks, network unavailability, and unavailability of node services. Jamming attacks and greedy behavior attacks, are examples of DoS attacks [35]. A jamming attack is an attack on the physical layer. The attacker jams the wireless channel through electromagnetic interference, which increases the latency of the V2X communication and reduces the network's reliability [36]. A greedy behavior attack refers to a network node that violates the rules of channel access and occupies too many channel resources, thereby reducing the performance of other nodes and causing network congestion [37].

B. V2X security threats

The network security is an important part of V2X technology and the threats faced by V2X are divided into four aspects: mobile terminal security threats, V2X service platform security threats, V2X communication security threats, vehicle network data and privacy threats [38]. The combination of mobile smart terminals such as mobile phones and V2X can not only provide information and entertainment services for car owners, but also provides the function of remotely controlling vehicles. Mobile smart terminals typically connect to wireless networks such as in- vehicle Wi- Fi networks or Bluetooth, which provides malicious attackers with a springboard to the in-vehicle network. Moreover, applications on the mobile terminal are vulnerable to hackers because of its low threshold of development and easy accessibility. The cloud service platform not only faces the problems of traditional network cloud platforms, but also has a weak identity authentication problem caused by the principle of mutual trust in V2X communications [38]. Whether the data in the cloud will be leaked is a major problem [39]. Moreover, the V2X cloud platform contains data about vehicles, roads, and pedestrians. If these data are leaked, they could cause significant losses. Owing to the high-speed mobility of vehicles, identity authentication and establishing a trusted connection with the cloud is a difficult problem. How to identify false data uploaded by an attacker and how to uniformly manage different types of data uploaded by different vehicles are also challenges faced by the cloud platform [40]. Because of its wireless transmission properties, the V2X network is particularly vulnerable to attacks. Therefore, communication security is very important. The security attributes include authentication, availability, data integrity, confidentiality, non-repudiation, real- time constraints, and attacks against these security attributes are as follows [30], [36]- [39]:

- Authentication: Sybil attack, GPS spoofing/ position faking attack, Node impersonation attack, etc.
- Availability: DoS attack, DDoS attack, Jamming attack, black hole attack, etc.
- Data Integrity: Masquerading attack, Replay attack, etc.
- Confidentiality: Eavesdropping attack, Traffic analysis attack, etc.
- Non-repudiation: Loss of events traceability, etc.
- Real-time constraints: Timing attack, etc.

According to the attacker's network location, attackers can be divided into insiders and outsiders. Insiders can communicate directly with other vehicles, but outsiders cannot. According to the purpose of attackers, they can be divided into malicious attackers and rational attackers. Malicious attackers destroy the network, not considering personal interests, while rational attackers do so to achieve personal benefits. According to the attack mode, attackers can be divided into active attackers

and passive attackers. Active attackers actively send packets, but passive attackers only monitor a network. According to the scope of activities, attackers can be divided into local attackers and extended attackers. Local attackers only act within a limited range of activities, while extended attackers expand their range of activities by controlling other nodes [41], [42]. Compared with the traditional network, the data on the V2X network is more open, so it is easier to expose more privacy data. Attackers can passively intercept user data or actively invade vehicles or cloud service platforms to steal information. In addition, mobile terminals such as smart phones also have the risk of privacy exposure. User privacy data such as the owner's name, plate number, vehicle speed, and driving route should be prevented from being acquired by others. However, some user privacy data must be open to trusted third parties such as police and accident rescue to ensure timely handling of emergencies such as accidents while being able to detect and track malicious attackers [43]. At present, V2X is in the initial stage of development. The data management and privacy protection systems are still in the process of being perfected. It is necessary to discuss and refine key issues such as which data can be collected, how data is used, and whether it can be shared with third parties [38].

VI. CONCLUSIONS

In this paper, a comprehensive review is made about the main features of C- V2X in terms of applications, solutions, challenges, and methodologies of designing such systems on a computer hardware to mitigate final E2E delay. The outcome of this paper is mainly to demonstrate the main aspects and technologies used in the literature to reduce network latency by using various methods, so that C- V2X will be feasible for different applications and services. The paper has discussed eight modern methods to deal with latency reduction of C- V2X by several means, most of the methods are inherited from using 5G technologies, since both has the same problem to resolve, which is reducing network latency. This research has categories these eight methods into two categories: developing new transmission scheme and infrastructure utilization, however we think heading to the second category is more fruitful and cost effective. The paper described a simple analysis of how E2E latency can be modeled, as well as how network modeling process can be achieved to endorse different types of V2X services and Applications. Two main security threats are discussed that needed to be considered in the modeling of C- V2X, otherwise, the given services will not be reliable and available while using such systems. As for C- V2X simulation tools, it has left for future work, since no dedicated simulator modules has been built for this task. Finally, as a survey paper, this paper covers mostly the main promising topics that benefits future researchers through providing the bright picture of how to design new techniques to improve performance of C-V2X applications and services, plus avoiding the persisting challenges by taking the rightmost path.

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