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TECHNICAL CHALLENGES IN ACHIEVING ULTRA-RELIABLE & LOW LATENCY COMMUNICATION IN 5G CELLULAR- V2X SYSTEMS

Zia Ur Rehman Zia[1], Dr. Hameed Ur Rahman[2], Mubashir Hussain Malik[3], Adnan Jahngir[4]
[1]Department of Computer Science / IT Institute of Southern Punjab, Multan, Pakistan, ziaurrehmanzia@isp.edu.pk
[2]Department of Computer Science / IT Institute of Southern Punjab, Multan, Pakistan, hameedur.rahman@isp.edu.pk

ABSTRACT—Fifth-generation (5G) has been classified as an ultra-reliable low latency communication (URLLC) by International Telecommunication Union (ITU) to meet the varied market and industrial needs. Future cellular networks aim to fulfil the requirements to achieve seamless Ultra-Reliable & Low Latency Communication (URLLC) in delay sensitive applications also. Cellular-based Vehicle-To-Everything (C-V2X) services and its use cases are selected and reviewed. 5th generation (5G) cellular communication can provide a promising solution by ensuring reliable and fast connectivity with low latency. This work has reviewed the challenges to achieve the URLLC in C-V2X communication. It can benefit by providing traffic safety and delay-sensitive services. Conclusion and future research directions are also discussed in the end.

Keywords—C-V2X services, 5G, 5G-NR, URLLC, *VANET, V2V, V2P, V2N, V2I, mMTC.*

I. INTRODUCTION

Advancement in wireless communication is possible with the help of emerging wireless technologies. Path which was started from1G to 4Gis now reached on 5G with100-1000Mbps data rate as compared to 10Mbps in case of 4G, 2-5 times increment in spectrum efficiency as compared to 4G, 500km/h Mobility which is 400km/h in 4G, latency of 1ms as compared to 10ms in 4G, Connection density of 10^6 as compared to 10^5 in 4G, 10 times better Network Energy Efficiency and Area Traffic capacity than 4G but still there is some improvement needed with the passage of time and requirement of the users. VANET's is emerging research domain now days and getting attention to solve the problems of automotive industry. V2V,V2P, V2N and V2I makes a group known as Vehicle to Everything (V2X) and is very useful to provide the services like accident reduction, road safety and automatic driving, infotainment. It is possible when these entities share the information with each other to make better traffic management and reduce the loss (S. Chen et al., 2017).V2X services are time critical but with the help of 5G properties like reliability and QoS, these services could be used easily with this cellular system.

The biggest challenge to achieve the Cellular based V2X(C-V2X) communication system is URLLC. Fig. 1 depicts the envisioned 5G C-V2X communication system. The safety considerations in 5G C-V2X systems emphasizes on importance of achieving low latency communication rather than high system throughput when compared to the conventional cellular systems. The reasons for the aforementioned aspect are as follows: First, the safety level of the 5G C-V2X systems decreases if the reception of safety information is prone to delay. While a few milliseconds delay in infotainment system data might cause the multimedia applications to be paused momentarily, a small delay in safety related information could result in severe traffic congestion, accidents and fatality. Also, the size of safety information data to be transmitted using 5G C-V2X communications is considerably smaller as compared to general cellular system (Boban et al., 2017). 5G C-V2X link employs small packets to transmit safety information and notifications, therefore data transmission speed is less significant while considering the traffic safety in 5G C-V2X systems.

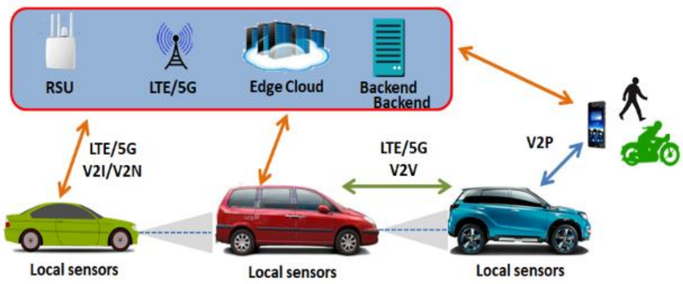

Figure 1. Envisioned 5G V2X Communication systems

Envisioned 5 G V2X communication system is shown in fig.1 in which communication between vehicle to infrastructure, vehicle to vehicle and vehicle to pedestrian on a highway is explained. In such communication system, local sensors will be installed in vehicles which will be connected through wireless link to the telecommunication system.

The 3GPP proposed various 5G C-V2X use cases within Rel. 15 specifications (*22886-100*, n.d.). These use cases are further characterized for different traffic profiles: From low-capacity and low-latency traffic, ensuring traffic safety, intelligent control and mission-critical services, to high- throughput and latency-tolerant traffic, providing the infotainment services. In this paper, our focus is to review the technology advances to achieve the URLLC in 5G C-V2X systems for the former category of the use cases.

The remaining paper is structured in the following manner. Section II defines the 5G C-V2X use cases and their URLLC requirements. The recent technical challenges to meet the URLLC requirements and conclusion and future work are presented in Section III and IV respectively.

II. 5G C-V2X Use Cases & Requirements

5G C-V2X use cases about the safety issue and traffic efficiency are presented in this section. Main functional and performance requirements for traffic safety are defined by the ITS (ETSI, 2009), ETSI, the US Department of Transportation, and several other research groups (5G American, 2018; Amoozadeh et al., 2019; Boban et al., 2017; GSMA, 2017). The formulated use cases proposed the mechanism for warning and amassed the environmental awareness based on periodic broadcast messages such as Cooperative Awareness Message (CAM) or event driven broadcast messages such as Decentralized Environmental Notification Message (DENM). The use cases demanding low latency (max tolerable latency 100ms) and high message reception reliability (above 95%) are presented in the 3GPP Rel. 15 standards (*22886-100*, n.d.). The use cases which expect the enhancement from 5G C-V2X are:

- Platooning/Cooperative Adaptive Cruise Control
- Collision waring and avoiding (Cooperative braking)
- Cooperative intersection Control
- Lane (or road) merging
- Autonomous driving
- Connected Automated Parking
- Pedestrian safety

The benefits that 5G C-V2X offers in terms of the above-mentioned use cases when compared to traditional solutions are multiple. In terms of vehicle platooning, when many vehicles moving towards the same destination then there will be a specific distance among all vehicles in a platoon so except leading vehicle remaining driver can take a rest for a while by following the leading vehicle. This convoy of vehicles will save space and fuel and maximum 3 vehicles could be added in a platoon. Platoon is possible only on the motorway if any vehicle leaves the motorway then platoon will leave that vehicle. In 5G more than 3 vehicles could be added in a platoon (GSMA, 2017). Cooperative Adoptive Cruise Control and lane merging, the 5G C-V2X benefits from pre-emptive communication of vehicles speed, location and travelling direction, resulting in reduced time and space for performing a manoeuvre. Collision warning and avoiding is obvious from its name that it will warn the driver for upcoming threat or congestion to slow down the speed and even if driver does not perceive then automated braking system will be activated to avoid collision. For Connected automated parking, 5G C-V2X enables centralized planning and control and efficient use of parking space. It will save time and decrease mental stress of the drivers. Similarly, cooperative intersection control enables efficient intersection operation by communication the traffic signals information to dynamically adjust the speed, and ensuring traffic flow by choosing appropriate route in case of traffic congestion and will avoid bottleneck. Priority traffic could be managed in an efficient way. Ambulance or any other critical state level security agency vans are priority traffic. Pedestrian and cyclists are vulnerable to traffic so the pedestrian safety can also be ensured by coordinating the precise location of the pedestrians on the road and their trajectory to avoid any accident. Fig. 2 shows each use case which can benefit from the 5G C-V2X communication systems in terms of traffic safety.

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Automated driving is very delicate matter in terms of communication reliability and latency with respect to safety requirements. Above-mentioned use cases are anticipated to eventually lead towards realizing the fully automated vehicles enabled by the 5G C-V2X systems.

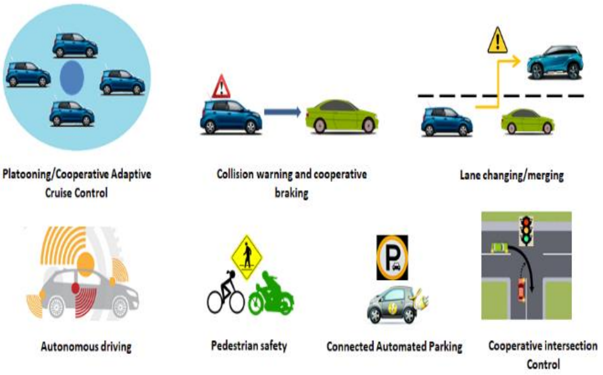

Figure 2 Proposed use cases to be facilitated by 5G V2X support

Many current papers focused on the Mode 4 algorithm by adopting several allocation schemes. In Cooperative awareness use cases, periodic messages range from 60 to 1500 Bytes are used and broadcasted in between 1 and10 Hz of transmission rate which is also affected by the road and traffic conditions (ETSI, 2009). Cooperative sensing, data about objects is sensed and shared to make a better perception. Cooperative manoeuvre includes different use cases like Platooning, Cooperative adaptive cruise control, Lane merging and Intersection control. Coordination of different vehicles and about trajectories is needed in this manoeuvre. Vulnerable road users are pedestrian and cyclists and information about the roadside problem is sent on user's mobile. In traffic efficiency, a message of 1500 bytes is uploaded after few seconds on the traffic management server with the information of vehicle location, status and Map information (ETSI, 2009). Teleoperated Driving means that remote user is controlling the vehicles and a single remote user can control many vehicles at a time and it requires high speed uplink and downlink. It is too much delay sensitive and 5G cellular systems will handle it (Boban et al., 2017).

Above discussed use cases and their types and requirements like reliability, communication latency, & communication mode are given in tabular form in Table.1

III. TECHNICAL CHALLENGES TO ACHIEVE URLLC 5G C-V2X

Recent advances in achieving URLLC for 5G C-V2X are presented in this section. As suggested in the title, our focus in this paper is to consider the schemes for achieving low latency and improving the reliability. The 3GPP Rel. 15 standard includes development of various schemes to reduce latency, including shortening of transmission time intervals (TTI) and designing of autonomous sub frames. In (Ji et al., 2018) the authors proposed design principles of 5G C-V2X system by suggesting shortened TTI using one OFDM symbol, whereas satisfying the requirements for radio resource control connection. This scheme can ensure low latency, in particular for the use cases with latency requirement to be below 20ms. TTI is further divided into two categories one is TTI-Proportional Latency (PL) and other is TTI-Independent latency (IL). Some elements are proportional to Transmission time Interval like while in data transmission there is control signalling, retransmission of packets and scheduling configuration all these take one transmission time interval (TTI) so these are proportional while other factors like backhaul transmission, wireless configuration process and network transmission time are latency factors but are not proportion so these are known as Independent Latency (IL). Author has also discussed different operating modes of V2X and latency of each element of V2X.

In order to provision of classical Vehicle-to-Everything (V2X) services, for example the delivery of CAM besides DENM and LTE MBMS has been proven its legitimacy (*Calabuig2014.Pdf*, n.d.). Cooperative awareness (CA) generates some messages known as CAM, having information about the presence, location and status of the vehicle. CAM is periodic message and is generated after few seconds (*Calabuig2014.Pdf*, n.d.). CAM format is introduced by ETSI and its status message has 4 portions. i) Basic, ii) High-frequency, iii) special vehicle container and iv)low frequency. First and second parts are compulsory while third and fourth parts are optional. Message size with basic and High-frequency is of 50 Bytes. Road Hazard Warnings (RHWs) is also introduced by ETSI and it generates DENM's messages on specific event, purpose of these messages is to avoid any undesired situation and this message is sent to all the vehicles on the network on a specific frequency (*Calabuig2014.Pdf*, n.d.). DENM's has also 4 portions.1) Management, 2) Situation, 3) Location, 4) la carte. Management portion is compulsory and remaining three is optional. Payload size of DENM's is 45 Byte with compulsory portion and by adding the optional portions its size could be from 250 Bytes to 1500 Bytes (*Calabuig2014.Pdf*, n.d.). However, with the current specification, the challenging requirements for latency and link reliability demanded by 5G V2X services cannot be ensured using MBMS.

Low latency communication achieved by shifting of MBMS and V2X servers' utilities in the base station from remote location (Palacios et al., 2018). LTE MBMS was not specifically designed for V2X services but it produces good results with some latency. The reason behind this latency was that V2X server was placed in remote location and connected to the core network, This V2x server broadcast the messages to the other RSU's. MBMS core network has BM-SC, Mobility Management Entity and MBMS Gateway. Standardization organizations, such as 3GPP and ETSI, have localized the V2X servers and its functions as a solution of latency. V2X servers are installed locally on Road Side Units (RSU) and which is near to the user equipment. Still there is a challenge that how messages will be passed among RSU's. Simulations built by using SCPTM transmission while considering end-to-end latency; shows that localization of functions at base stations can significantly reduce the conventional MBMS latency. Such localization of servers can also guarantee the precise procedure for more thought-provoking 5G V2X services like cooperative collision avoidance. Focusing on end-to-end latency in V2X communication, results for multicast messages have shown that the localization of functions can achieve latencies below 25ms in some cases.

Therefore, by localizing of roles in base stations is helpful to satisfy the requirements of 5G C-V2X independent driving applications. To ensure low latency communication for critical information exchange between vehicles and infrastructure in dense traffic load scenarios, a dynamic traffic management scheme over Downlink/uplink (Uu) and PC5 interfaces for V2X communications are proposed in (Palacios et al., 2018). In VANET when vehicles communicate with other elements is divided into two types of interfaces one is Uu interface and other is PC5 interface. Uu interface is LTE air interface that allows communication between vehicles and Base station of network and PC5 interface enables side links (SLs), these are installed between Road Side Units (RSU's). Both interfaces are used in V2X but during selection of interface different parameters are assessed for optimization and delay sensitive traffic. Interface that shows the minimum delay and maximum reliability is chosen for transmission (Palacios et al., 2018). 3GPP has also defined some scenarios for V2X communication which are "Only PC5 interface will be available", "Only Uu interface will be available" and last scenario is that "Both PC5 and Uu interfaces are available" In all these scenarios Side links (SL), UL (Uplink), DL (Downlink), UE (user Equipment) and evolved Node B (eNB) are the components to communicate in well-defined manner. In (Palacios et al., 2018) an algorithm is designed to dynamically select the suitable interface for critical information exchange. For this to achieve, cost function, defined on basis of sets of different metrics, are evaluated to realize the Uu interface, macro cells are employed while access points of IEEE 802.11n run an estimate for the PC5 interface. A delay optimized communication link for steering perilous information data packets is formulated using the above-mentioned scheme, ensuring low latency for traffic safety applications in 5G C-V2X services.

Considering a dense V2X communication network for broadcasting latency-sensitive safety related information, a scheme based on a NOMA is presented in (Di et al., 2017). V2X communication stringently requires low latency but LTE based vehicular network uses Orthogonal Multiple Access (OMA) and due to this, spectrum is not used in an optimized fashion which also causes congestion in dense environment (Pham et al., 2020). To avoid severe congestion and access latency NOMA is proposed in which code domain and chain domain multiplexing is offered which helps users and is allowed to choose the channel non-orthogonally (Di et al., 2017). It will also help in transmission of traffic concurrently which will use the channel in an efficient way and data

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retransmission will also reduce because of less congestion (Laya et al., 2014). Such scheme can be implemented by employing semi-persistent scheduling while the resource allocation is done in a non-orthogonal manner accompanied by distributed power control schemes performed by the vehicles autonomously.

Regarding the control channel design aspects to efficiently accommodate URLLC support, (*Mvt-Shariatmadari-2814378-x.Pdf*, n.d.), analyses some of the features and presents new improvements for crafting the control channels. Some transmission links having one-to-one, one-to-many and many-to many transmission modes is enabled by URLLC because some use cases are mission critical and needed one-to-one and some use cases needs many-to-many transmission mode. LTE based V2X systems are already available and now 5G is also providing the platform with better reliability and better support for URLLC.3GPP has introduced new techniques like sTTI and reduced processing time to reduce the latency at user end. In conventional LTE base system, scheduling request (SR) is sent by User Equipment to occupy resources for transmission of data but in New Radio (NR) fast uplink access reserves the radio resource for user equipment and whenever user want to send data channel is available it reduces latency because user don't need to send SR request to occupy any resource. Short transmission time interval (sTTI) is also used for reducing latency (Lafler & Corporation, n.d.). LTE based systems defines sub frame which consists of 14 symbols and these symbols could be reduced to 2 to 7 symbols using mini slot. Latency is further reduced by shortened processing time because HARQ can send response after four sub frames from receiving data time (*Mvt-Shariatmadari-2814378-x.Pdf*, n.d.). Flexible slot structure is the solution of control information delivery failure on starting step and it will also ensure that accurate control information is retransmitted.

CellularV2X communication is getting more promising future with advent of 5G. Many sensors are embedded in vehicles, generates plethora of traffic and this amount of traffic should be handled with reliability and with low delay (Alhilal et al., 2020). At the intersection of critical and massive machine-type communications (mMTC), some use cases of cellular V2X are located (*Improving Initial Access Reliability of...n Massive V2X Communications Scenarios.Pdf*, n.d.). Dense traffic generated by sensors is difficult to be handled by conventional cellular system due to less radio resource. Concerning the radio link reliability for 5G C-V2X systems, (*Improving Initial Access Reliability of...n Massive V2X Communications Scenarios.Pdf*, n.d.), proposed to introduce transmission redundancy in order to send several replicas of the random-access channel (RACH) preamble whenever an mMTC device in the idle mode attempts to connect to the network. This analysis has also included the 28GHz frequencies which are operated by 5G mmWave system. It is proved by the analysis that when redundancy is introduced in the random-access procedure then significant enhancements in reliability of directional contention-based initial access is observed in comparison of updated RACH schemes (Motlagh et al., 2016).

Table 1 Comparison of use cases

Cooperative Awareness	**Cooperative Sensing**	**Cooperative Maneuver**	**Vulnerable Road User**	**Traffic Efficiency**
In this use case V2X mode is V2V or V2I.	This use case uses V2V or V2I V2X mode	This use case uses V2Vor V2I V2X mode.	In this use case V2P V2X mode is used.	Traffic Efficiency uses V2N or V2I as a V2X mode.
End-to-End Latency in Cooperativ e awareness is from 100ms-1sec	In Cooperative Sensing Use case, End-to-End Latency is from 3ms-1sec	In this use case End-to-end latency is <3ms-100ms	In Vulnerable Road User, End-to-End Latency is 100ms-1sec	In Traffic efficiency use case, End-to-End Latency is >1sec
In this use case reliability is 90-95%	In this use case reliability is >95%	In this use case reliability is >99%	In this use case reliability is 95%	In this use case reliability is <90%
Data transfer rate per vehicle in kbps is 5-96	Data transfer rate per vehicle in kbps is 5-25000	Data transfer rate per vehicle in kbps is 10-5000	Data transfer rate per vehicle in kbps is 5-10	Data Transfer rate per vehicle in kbps is 10-2000
In this use case communica tion range is Short to medium	In this use case communicati on range is Short	In this use case communicati on range is Short to medium	In this use case communica tion range is Short	This is long range communica tion case

Communication latency, expected data rate per vehicle and reliability are performance requirements of the V2X use case categories and these use cases are given comparatively in table 1 (Naik et al., 2019). Some specific subset of operations which are required by automated and cooperative vehicles are identified in use case types (Regnell et al., 1995).

In Cooperative awareness case, warning and increase awareness about the environment are used, examples are Emergency electronic brake light, emergency Vehicle Warning (Festag, 2014), etc. Cooperative sensing is about to increase the environmental perception of vehicles sensor when data is exchanged (Q. Chen et al., 2019). In Cooperative manoeuvre use case, trajectories among vehicles are coordinated for example, platooning, lane change, cooperative intersection control and CACC. In Vulnerable Road User (VRU) use case, pedestrians and cyclists are notified (Boban et al., 2018). Traffic efficiency use case indicate Digital maps are updated dynamically and routes are updated for example, GLOSA, SPAT/MAP etc. (Festag, 2014)

IV. CONCLUSION AND FUTURE WORK

C-V2X communication is get attention and 5G is looking excellent to overcome the problems of LTE based C-V2X systems. We have discussed and reviewed many use cases of C-V2X system like platooning/CACC, lane merging, autonomous driving, connected automatic parking and pedestrian safety.CAM and DENM's are useful to share the information of the vehicle and many challenges to achieve the URLLC and proposed solutions like Transmission time intervals (TTI), shortened messages, choosing localization of function and localization of V2X servers in MBMS, Uu and PC5 interfaces are also discussed along with control channel design and Non-Orthogonal Multiple Access (NOMA), reliability and security is also discussed and in the end a comparative table summarizes all the use cases.

In (5G American, 2018; Boban et al., 2017; Lien et al., 2017), future research directions for employing 5G New Radio (NR) to support 5G C-V2X services and applications are discussed.5G NR represents the prospective to ensure the URLLC requirements for 5G C-V2X services, as it accompanies the advantage of nontrivial enhancements to the existing communication modes. For future enhancements in the 5G C-V2X services, 5G NR can be a promising candidate. In (*Mvt-Shariatmadari-2814378-x.Pdf*, n.d.), Multiplexing of different services is satisfying their communication requirements but it generates a dense traffic and all resources are occupied by this dense traffic there should be some recovery mechanism. Security issues are also affecting the reliability latency but safety and security of connected vehicles in C-V2X communication is very important as discussed in (Lien et al., 2017) and specifically about the selection of security features, Safety messages should be broadcasted in an optimal way, and the interaction among security, safety and QoS which is another research domain.

BIOGRAPHY

Zia Ur Rehman Zia received his M.Sc (Telecommunication Systems) and MS (Information Technology) degrees from Bahauddin Zakariya University Multan Pakistan. His research area includes Wireless communication and security, Mobile Cloud Computing and Cryptography.
Email; ziaurrehmanzia@isp.edu.pk

Dr. Hameed Ur Rahman is Assistant Professor and his area of research is Aritificial Intelligence, Machine learning and Medical Imaging.

Mubashir Hussain Malik is a Phd scholar from Islamia University Bahawalpur Pakistan.

Adnan Jahangir received M.phil CS degree from Department of Computer Science and Information Technology Institute of Southern Punjab Multan Pakistan.

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