The Road to 5G V2X: Ultra-High Reliable Communications

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Abstract — For the success of real-time Vehicular-to-Everything (V2X) communications it is paramount that 5G mobile networks be resilient, highly reliable, and secure in the delivery and reception of information to and from the vehicle. There are several concerted efforts underway in 3GPP and oneM2M to enhance the end-to-end transmission and forwarding of data packets through the 5G System for assuring a successful deployment and provisioning of IoT/M2M real-time vertical services. This paper provides an analysis of the 3GPP work in this area and its timescales, with focus on V2X. In addition, standards activities in oneM2M to enable interworking V2X services between 3GPP and IoT/M2M service layer are introduced providing a comprehensive overview.

Index Terms – 3GPP, oneM2M, 5GS, NR, URLLC, V2X, MEC, IoT, M2M, 5GAA

I. Introduction

To achieve reliable road safety and enable critical communication services in usage of mobile networks for vehicle-to-everything (V2X) communications, there are still many challenges that need to be addressed. There is considerable effort underway in the 3rd Generation Partnership Project (3GPP) to enhance V2X communications in the 5G System (5GS) over and above on what has been developed so far for 4G/LTE in Release 14. The time when vehicles will drive autonomously with absolute reliability has not yet arrived however, 3GPP is fully devoted to make the 5G mobile system (5GS) V2X ready by 2020 [1], which will be used as one of the key technologies in vehicle safety. In addition, 5G Automotive Association (5GAA [1]), a global, cross-industry organisation of companies from the automotive, technology, and telecommunications industries (ICT), have ear marked 3GPP C-V2X technology solutions for future mobility and transportation services by 2020.

Based on the definition in 3GPP, the V2X consists of Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), Vehicle-to-(roadway)-Infrastructure (V2I), and Vehicle-to-Network (V2N) communications. For V2V, the short-range radio communication technologies like IEEE Dedicated Short Range Communications (DSRC) or 3GPP LTE-V (also known as PC5 or *sidelink* at the physical layer) standards can be used. The short-range technologies are well developed and are continually being enhanced. For V2P, the PC5 interface can be used, while V2I and V2N rely on Cellular, i.e., C-V2X, to enable the vehicle to communicate with the roadside equipment (Road Side Units – RSU, traffic lights, etc.). The cellular network can also facilitate vehicular connectivity with a remote application server.

Cellular V2X (C-V2X) is the technology developed in 3GPP and is designed to operate in two modes as follows [2], [3]:

- Device-to-device: This is a V2V, V2I and V2P direct communication without necessarily relying on the network involvement for scheduling. This is based on the 3GPP Release 12/13 ProSe (Proximity Services) device-to-device (D2D) interface. This will help in providing ultra-low latency communication and in transferring large amounts of data reliably among neighboring vehicles.
- Device-to-network: This is for V2N communication, which uses the traditional cellular links to enable cloud services to be part of the end-to-end solution by means of 5G network slicing architecture for vertical industries.

The work done in [4] considers the physical layer design, key technology enablers and channel modeling aspects for V2X service provisioning using 5G / New Radio. The use of adaptive beamforming for enabling reliable and efficient 5G V2X networks is presented in [5], based on evaluations done using LTE system assumptions. Broadcast is one of the key requirements of 5G V2X, mainly for system alert and emergency messages. High-reliability, low-latency broadcast for V2X using non-orthogonal multiple access is presented in

[1] http://5gaa.org/

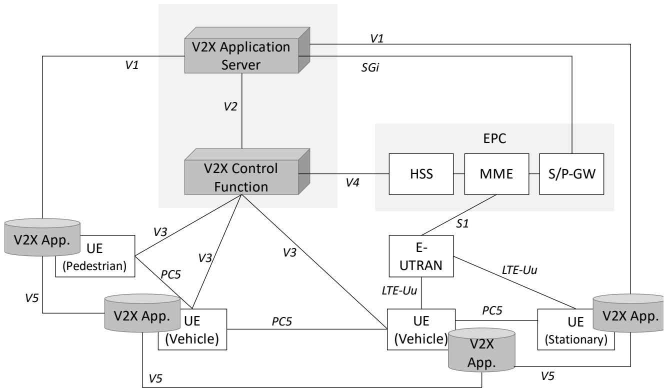

Figure 1: Non-Roaming V2X Architecture

[6]. The usage of network slicing [7], [10], one of the key technology enablers for dynamic service provisioning to new verticals such as vehicular communication, to enable V2X services is studied in detail in [8]. In addition, IoT standards bodies such as oneM2M are also standardizing IoT service layer platforms supporting V2X in particular for enabling interworking V2X services between 3GPP and IoT/M2M service layer. While V2X has received significant attention from industry and academia in terms of the research challenges, there is a limited amount work available discussing the challenges from a 3GPP perspective, which is the main focus of this work.

The rest of the paper is structured as follows. In Section II, we introduce the background of V2X in 4G. Then in Section III, the V2X enhancements for 5G are presented, which leverage the work of URLLC underway in 3GPP radio access network (RAN) and system architecture (SA) working groups. In Section IV, additional details of Ultra-Reliable Low Latency Communications (URLLC) are provided considering the application layer. Finally, we conclude in Section V providing also a brief discussion on the future outlook.

II. V2X IN 4G

The 3GPP TS 23.285 [2] for V2X specification was created in the 3GPP Rel-14 and is covering the basic functions and scenarios for V2V, V2P, V2I, and V2N. For the V2X communication, two basic reference points are used as follows:

- `PC5` reference point: this is a reused reference point for device-to-device (D2D) communication from the former work on Proximity Services (ProSe, 3GPP TS 23.303 [21]).
- `LTE-Uu` reference point: the air interface between UE and eNB.

Besides the already specified Evolved Packet Core (EPC) entities such as MME (Mobility Management Entity), HSS (Home Subscriber Server) and S/P-GW (Serving/Packet-Gateway), 3GPP introduces a V2X architecture with two new functional elements, the V2X Control Function and the V2X Application Server.

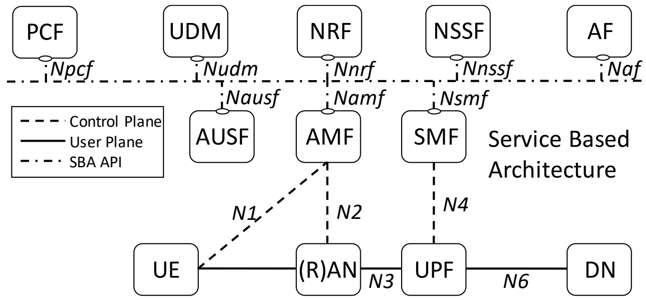

Figure 2: 5G Non-Roaming Architecture

The V2X Control Function is a logical function per PLMN and is used for PLMN specific parameter provisioning to the UE for enabling V2X in the PLMN, especially when the UE is not served by E-UTRAN. It is discovered with Domain Name Service (DNS) and a fully qualified domain name (F-QDN) of the HPLMN V2X Control Function, which could be made available in the UE by different means (pre-provisioned, self-constructed, derived from other information etc.). The V2X Application Server is communicating with the V2X application in the UE via V1 reference point. It further takes care of the multicast transmission and configuration of the Multimedia Broadcast/Multicast Service (MBMS) entities [9] for the appropriate MBMS area. Additionally, multicast could be provided by a geographic localized platform similar to Mobile Edge Computing (MEC) [11], [12], for better performance. The non-roaming architecture of V2X for the EPC is shown in Fig. 1.

III. V2X ENHANCEMENTS FOR 5G

This section introduces how V2X features are enhanced in 3GPP 5G specifications.

A. 5G Architecture

5G V2X is envisioned for 3GPP Release 16, which is already Phase 2 of 5G specifications and builds on top of the architecture of Phase 1. The 5G Phase 1 non-roaming architecture is depicted in Fig. 2 and described in 3GPP TS 23.501 [13]. The Service Based Architecture (SBA) representation differs from the traditional reference point representation with network functions (NF) connected to each other via a service bus and can subscribe to certain events, i.e. a NF becomes a service producer and another one a service consumer. These concepts are already established in the internet world and now transferred to the mobile network infrastructure.

The following NFs in Fig. 2 are defined: The Authentication Server Function (AUSF) is now a separate function but could be collocated with the Unified Data Management (UDM), the successor of the HSS. The MME is now split into the Access and Mobility Management Function (AMF) as Non-Access Stratum (NAS) signaling termination point and the Session Management Function (SMF). The Network Repository Function (NRF) stores the NF instances and is used for NF discovery. The Network Slice Selection Function (NSSF) assists to select the set of Network Slice instances for a UE.

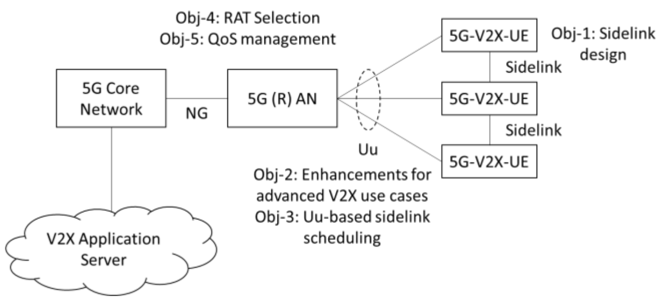

Figure 3: Main Objectives for NR-RAN Study for V2X

The Policy Control Function (PCF) has a wider scope now and can store different types of policies. The Application Function (AF) provides service specific information and the User Equipment (UE) that connects to the (Radio) Access Network ((R)AN) to the Data Network (DN), e.g., Internet, via the User Plane Function (UPF), which is the successor of the user plane part of the S/P-GW.

B. 5G V2X Services

The current study in 3GPP TR 23.786 [14] is looking how to fulfill the requirements of 3GPP TS 22.186 [15] for the new services and enhancements. The following five Categories of Requirements (CoR) were identified for 5G V2X:

1) *General Aspects*: interworking, communication-related requirements valid for all V2X scenarios.
2) *Vehicles Platooning*: vehicles travel together with extremely small distance in between them.
3) *Advanced Driving*: semi-automated or fully automated driving.
4) *Extended Sensors*: information exchange of all V2X enabled devices and network elements.
5) *Remote Driving*: remote driving on behalf of passengers or of vehicles in dangerous environments.

Further five different levels of automation (LoA) are defined:

- 0 – No Automation,
- 1 – Driver Assistance,
- 2 – Partial Automation,
- 3 – Conditional Automation,
- 4 – High Automation,
- 5 – Full Automation

The requirements on the communication differ depending on the scenario and type of communication but they can also relate with e.g., the requirements to support Extended Sensors in case of sensor information sharing between UEs supporting V2X application (to a maximum end-to-end latency of 3ms, 99.999% reliability, 50 MBps data rate and a minimum required communication range of 200m). The requirement tables for different use cases and scenarios can be found in TS 22.186 [15].

Current TR 23.786 [14] is looking at those requirements from an architectural perspective and identified a list of twelve key issues that needs to be solved for a full solution as follows:

1) Support of eV2X Group Communication: discusses the awareness of the 3GPP system of the V2X application layer grouping.
2) 3GPP PC5 RAT selection for a V2X application: PC5 can be based on LTE or NR, how and when should the UE select the RAT.
3) QoS Support for eV2X over `Uu` interface: ensure the support of the eV2X scenarios in 5GS according to requirements specified in TS 22.186 [15], including all CoRs and LoAs (incl. URLLC).
4) Support of PC5 QoS framework enhancement for eV2X: addresses whether the ProSe Per-Packet Priority (PPPP) is sufficient to support eV2X QoS requirements.
5) Service Authorization and Provisioning to UE for eV2X communications over PC5 reference point.
6) Service Authorization to NG-RAN for eV2X communications over PC5 reference point.
7) Network Slicing for eV2X Services: studies which eV2X features require enhancements to the 5GS architecture.
8) Support of edge computing: studies whether existing mechanisms specified in TS 23.501 [13] can be reused for V2X purposes or require enhancements.
9) Support of unicast/multicast for sensor sharing over PC5: what information is exchanged and what V2X layer signalling is required.
10) eV2X message transmission and reception: captures impact on the eV2X message transmission.
11) Service Authorization and Provisioning to UE over the `NG-Uu` reference point.
12) System migration and interworking for eV2X: studies how 5GS eV2X system interworks with the EPC based V2X system.

At the time of this paper, already some solutions were discussed and documented in the TR, but the final outcome of the study is expected at the end of 2018.

C. 5G RAN for V2X

Currently, there are extensive discussions ongoing related to the definition of the study item for V2X in 5G/NR [20]. Some of the widely agreed objectives being discussed are summarized in Fig. 3. One of the main objective of the study is to design the *sidelink* (also known as PC5 reference point) – between V2X UEs. The key requirements on *sidelink* include support for unicast, groupcast and broadcast. The *sidelink* physical layer procedures and protocol structure needs to be defined, along with synchronization mechanisms, resource allocation mechanisms including configuration and management using both LTE and NR `Uu` interfaces.

The LTE and NR `Uu` interface enhancements for enabling *sidelink* scheduling (including cross-technology LTE and NR *sidelinks*) would be studied. V2X system enhancements for radio access technology (RAT) selection between LTE and 5G, in order to provide reliable service for the end users. The QoS management for V2X services over the `Uu` and *sidelink* interfaces, based on the parameters received from the 5GS, would be a key enabler for features that require high data

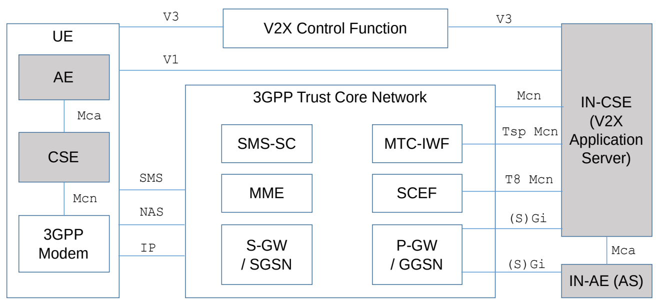

Figure 4: 3GPP-oneM2M V2X Interworking Architecture

rates, low-latency and high-reliability. The study will also focus on the support for *sidelink* in unlicensed and licensed bands below 10 GHz.

Some of the objectives related to coexistence between LTE and NR *sidelinks*, along with possible non-cellular RATs require further discussions before reaching an agreement. The evaluation of feasibility and enhancement mechanisms for V2X positioning accuracy improvement including ranging requires further study. Solutions for range extension including UE-to-UE and UE-to-network relaying is also one of the objectives that require further study. The usage of millimeter wave frequency bands (for e.g., 63-65 GHz) for *sidelink* is also one of the topics that could be included for future study.

IV. URLLC FOR V2X

This section provides an introduction to URLLC for V2X to show how V2X 3GPP 5GS is collaborating with IoT application and service layers. In order to improve the performance and the reliability of the V2X communication, it is recommended to apply network enhancements like mobile edge computing and slicing [11][12]. In the following, we concentrate on the application layer enhancements to support URLLC for V2X.

A. Interworking with V2X IoT Application Server

The V2X Application Server defined in the 3GPP V2X architecture can be instantiated via an Application Server defined in 3rd party standards organization such as oneM2M. From V2X service perspective, an end to end V2X service can deliver benefits to the vehicular industry. Therefore, oneM2M has initiated the development of specifications for IoT/M2M service layer platform focusing on standardizing a solution between UE and V2X Application Server. As part of key IoT services, oneM2M is already involved in the vehicular domain collecting various vehicular use cases. The standards work in oneM2M proposes a solution between UE and V2X Application, which can provide an end-to-end V2X standards ecosystem.

The objective of ‘Interworking with 3GPP V2X’ in oneM2M [22] is initially focusing on the creation of a technical report describing interworking solutions between oneM2M IoT service layer and 3GPP V2X service architecture. oneM2M intends to propose potential solution on how an IoT service layer platform can support a V2X service for the benefit of V2X IoT applications. The set of items addressed by the oneM2M TR include the following:

- Development of 3GPP V2X interworking architecture in oneM2M system to support end-to-end V2X IoT services.
- Analysis of role mapping of Control Function and V2X Application Server.
- Definition of functional mapping of the V1, V2 and V3 interfaces in 3GPP with the Common Service Functions (in particular, Group Management, Device Management and Location) in oneM2M system.
- Development of mechanisms to support PC5 and LTE-Uu interfaces in oneM2M system.
- Introduction to new V2X APIs to support end-to -end V2X applications.

As observed in the aforementioned items, oneM2M V2X interworking activities analyse the interworking with 3GPP V2X architecture. There exist several common network functions that are used in general 3GPP IoT interworking services, for example MBMS and IoT device triggering. This work intends to investigate opportunities for service providers and operators to introduce more integrated 3GPP V2X applications by leveraging the oneM2M IoT service capabilities.

Currently, 3GPP and oneM2M have established a direct liaison relationship to discuss interworking issues including V2X Application Server. In the future, based on findings, joint activities (e.g., joint workshop and interoperability events) between two standards bodies can be expected as interoperability is an important issue.

Although efforts on interworking are developed in both oneM2M and 3GPP, a potential standardized interworking architecture can be suggested as shown in Fig. 4 based on the current 3GPP-oneM2M interworking architecture.

B. V2X-centric Application-layer Functional Model

One of the challenges in critical C-V2X communications is how to enable the interaction between the communication and application domain in order to ensure that the performance requirements are met for both critical and non-critical V2X services. Due to the different stakeholders involved in V2X, the V2X APP-to-Communication Protocols direct interface is limited and cannot capture the required dynamic interactions for the network-level (QoS / resource conditions and availability) or application-level (change of Level of Automation) adaptations. In LTE-V the application handles very basic services, whereas much more sophisticated services are expected as vehicular automation increases [15]. This will require much overhead at the application side to gather all information from communication part. Also, the application needs to translate the context information into actions which will be decided at the vehicle Artificial Intelligence or by the end user.

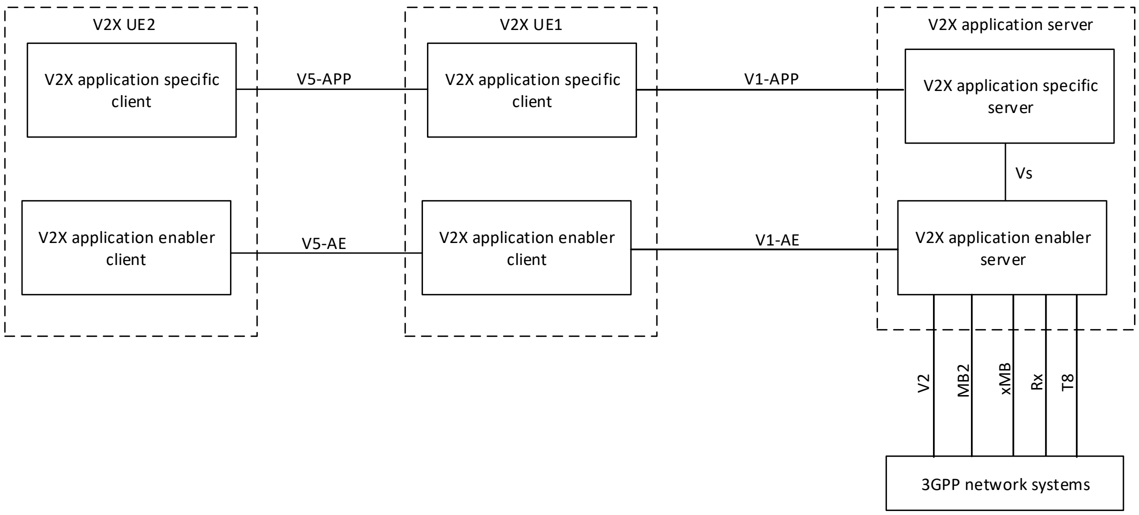

Figure 5: V2X application layer functional model [16]

In this direction, 3GPP SA6 initiated a WI [16] on application layer support for V2X services. This study aims to initially analyse Stage 1 specifications to determine which requirements have potential application level impact. Thereafter, it aims to investigate V2X application layer standards in Society of Automotive Engineers (SAE) [17], and ETSI Intelligent Transportation Systems (ITS) [18], to determine their use and impact in the context of 3GPP system support for V2X services and identify the Stage 2 V2X application layer support gaps. Based on the identified gaps, the main objective will be to develop key issues, corresponding architecture requirements and solution recommendations to enable the application layer support for V2X services over 3GPP systems.

The ongoing WI in SA6 has identified key issues and solutions [19], which require the introduction of a new application layer functional model to be used as reference for both LTE-V and 5G-V2X architectures. In particular, a new middleware entity, namely V2X Application Enabler (VAE) server was introduced to support some enhanced functionalities between the application server and the communication network. These functionalities include enhanced network/QoS monitoring and control, group management for critical communications as well as the translation of application requests to network requirements and vice versa. VAE can be deployed in various ways, as PLMN-owned application function (AF) or as part of the V2X application server. The application-layer functional model is illustrated as provided in Fig. 5.

V. Conclusions and Outlook

The paper introduced the different activities of V2X in 3GPP under consideration of the evolution of the mobile network to the new 5G technology with URLLC support. There is ongoing study on 5G URLLC (TR 23.724), which will be useful for delivering enhanced reliability for V2X UEs. We described the services and use cases that require ultra-low latency as well as ultra-reliability in order to prevent accidents due to the high level of automation within the vehicles. In addition, we explained the application related interactions with oneM2M and the new studies of the V2X application layer functional model, which will be developed in the new 3GPP Release 16. This new Release 16 will bring additional features related to V2X and 5G but those studies are currently ongoing and normative work is expected to start earliest at the end of 2018.

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