Local End-to-End Paths for Low Latency Vehicular Communication

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Abstract—**Automated Driving is expected to contribute to various factors that affect our daily life, while bringing new business and technological challenges for various stakeholders involved. The 5G cellular networks need to be redesigned by optimizing time consuming functions both at the control and the user plane to support the demanding performance requirements that automated driving sets for the communication layer. This paper proposes the evolution of the Radio Access Network, taking into account the localised nature of the vehicular traffic. The concept of local end-to-end data paths over the cellular (Uu) interface is described, while new methods and signaling are introduced at the base station by avoiding the involvement of core network entities. The end-to-end latency for the exchange of data traffic among vehicles is reduced by 45% for unicast communication and 52% for multicast communication due to the proposed localized cellular communication. A substantial reduction of the control plane latency, for radio bearers' establishment and radio paths' formation, in the order of 22.5 ms is also achieved.**

Keywords— vehicular communications; localised traffic; wireless networks; cellular networks; low latency;5G

I. INTRODUCTION

With the advent of automated driving functions, especially with the broad availability of vehicles that will be capable of supporting higher automation levels, the need for synchronization and coordination among vehicles becomes increasingly necessary. Vehicles will communicate directly with each other to extend their perception beyond the capabilities and the range offered by their integrated sensors. Cooperative lane change, cooperative collision avoidance, and platooning are typical examples of vehicle-to anything (V2X) services, where connected automated vehicles participate and the performance requirements of the communication layer are more stringent, with certain use cases requiring very reliable communication links (>99.99%), with much lower maximum end-to-end (e2e) latency (3-10 ms), and high data rate [1], [2].

The exchange of information among vehicles (V2V) is in many cases localized, without the need to access a remote server (e.g., Intelligent Transport Systems (ITS) cloud server), while in the context of the same service multiple transmission modes (unicast, broadcast, multicast) might be required. For this type of communication either the cellular interface (i.e., when the end-devices communicate via the radio network infrastructure) or the sidelink interface (i.e. when the end-devices are directly connected via the radio interface) could be used. Through the sidelink interface, the e2e latency can be reduced substantially, when devices are located in close proximity, while increasing the spectral efficiency of the transmission. On the other hand, the cellular interface (using uplink (UL) and downlink(DL) resources) does not suffer from the half-duplex constraint, as happens with the sidelink communication, and a larger geographical area could be supported [3].

However, many user plane and control plane procedures of the cellular interface have been designed taking into account the Quality of Service (QoS) requirements of traditional services e.g., voice, voice over IP (VoIP), video and web data services. The low latency at the control plane (i.e. connection establishment, or new bearer establishment) was not a key requirement for traditional services and the existing systems have not been designed with the specific performance requirement. In addition, due to the nature of these services (i.e., a remote server or user participates) the core network entities are always involved for the setup of new bearers and for the data transmission, which increases the required communication and processing delay.

In this paper the focus is on the evolution of the 5G cellular interface (Uu) for the support of V2X services that set more challenging QoS requirements, by taking into account their key feature of more localised data traffic. The formation of local e2e radio data paths via Base Stations (BS) is proposed to enable the fast and guaranteed transmission of localized data traffic among the involved vehicles, supporting different communication modes (unicast, multicast, broadcast) without the need to interact with other entities such as Multimedia Broadcast/Multicast Service (MBMS). A routing table in the BS maps and connects the UL and DL radio bearers for the formation of the local radio paths and consequently the faster forwarding of localized V2X traffic (user plane latency reduction). New functions and schemes are added at the BS to support the establishment and management of local e2e paths satisfying the QoS needs of the V2X services. In addition, time consuming Radio Resource Control (RRC) functions that are involved in the bearer (or connection) establishment are modified, by reducing also the involvement of the core network entities. This addresses the problem of the slow establishment of radio bearers and reduces also the control plane latency for the support of V2X services.

The remainder of the paper is organized as follows: Section II presents relevant research and standardization efforts, while section III highlights the proposed modifications in the Radio Access Network (RAN) for the support of localised V2X services. The signaling for the fast establishment of radio bearers and the formation of the e2e paths are described in section IV. Section V presents the required modification in the BS for the support of the e2e local radio paths. Section VI presents the benefits of the proposed solutions and section VII concludes the paper.

II. BACKGROUND

The state-of-the-art proposals and the existing procedures for establishing and managing radio bearers have been designed taking into account mainly the requirements of traditional services e.g., voice, VoIP, video and web data services. Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) are two potential solutions for the efficient handling of the localized data traffic. LIPA is an offloading technique allowing a direct connection between the user equipment (UE) and the local IP network using a femtocell (HeNB) with a co-located or a standalone Local Gateway (L-GW). The L-GW must support limited Packet data network Gateway (PGW) as well as Serving Gateway (SGW) functionalities such as interconnecting with the external IP networks. LIPA is only intended to allow the UEs to access their own Private Local Access Network via a femtocell. SIPTO is similar to the LIPA technology with the main difference that SIPTO can be used in both macrocells and femtocells. LIPTA or SIPTO are mainly used for traffic offloading from the mobile core network to allow a direct access to the public IP network via the fixed network. Both do not include any procedure for fast session establishment and fast transmission and there are no guarantees for QoS features, especially for demanding V2X Services. MME (or DNS) is involved for any control plane procedure [4], [5]. In addition, Single-cell Point-to-Multipoint (SC-PTM) is a complementary bearer type of eMBMS [6]. It is suitable for scenarios where broadcast/multicast service is expected to be delivered to a limited number of cells, to a group of UEs over shared PDSCH channel. The network architecture is the same as in MBSFN but the SC-PTM provides more efficient allocation of resources comparing to the eMBMS. On the other hand SC-PTM, as happens also with eMBMS has a slow session establishment for a new service that is triggered by the involved devices with the involvement of the application server and focuses only on the downlink transmissions.

In the existing communication systems the control plane latency for establishing a new bearer is significantly larger compared to the requirements of many V2X use cases [2], since core network entities are involved in the establishment of bearers, which increases the required communication and processing delay. More than 130 ms (control plane latency) are needed for the establishment of required bearers for a group of vehicles that participate in the same V2X service, when the vehicles are not connected to a BS (RRC IDLE state) [7]. If the vehicles are connected to the same BS (i.e., can directly ask for resources) the control plane latency is higher than 80ms [8]. Thus, these large control plane latency values are not the appropriate for many V2X use cases. The introduction of new state models for the Radio Access Networks (RAN), called "connected inactive", where both the user equipment and the network maintain context information, enabling the quick and lightweight transition from inactive to active data transmission, could support the fast connection establishment problem [9]. The proposed "connected inactive" could contribute to the reduction of the total control plane latency, but, it is not enough since the delay for adding new bearers, especially for services, where a group of devices participate, remains high (i.e., more than 80ms).

Based on the above analysis, it is evident that existing technical solutions are not suitable to support the challenging performance requirements that V2X services have, which includes the need for fast and guaranteed transmission of localized data traffic together with the very fast establishment of radio bearers. Taking into consideration the localised nature of the V2X data traffic, the RAN needs to be redesigned in order to satisfy the demanding V2X requirements.

III. 5G RAN EVOLUTION FOR LOCALISED V2X TRAFFIC

The more advanced V2X services, where coordination among vehicles is needed (e.g., cooperative maneuvers, cooperative perception), have the features of a more session-based service with a non-predefined number of involved vehicles, having also short session duration. Multiple session-based services could be concurrently triggered (event-based or periodic) in the same area, which number and frequency is dynamic, affected by the traffic and road conditions. As mentioned above, the fast establishment of new radio bearers for a V2X use case and the transmission of data traffic with very low latency and high reliability using the cellular interface are the two key problems of this paper.

The formation of local e2e radio data paths is proposed to enable the fast and reliable transmission of localized data traffic among the involved devices, satisfying their QoS requirements and the features of the V2X services. The "e2e" term denotes that the (user plane) radio data paths are established among the involved communicating end devices (i.e., vehicles), while the "local" term denotes that the paths are established by (and via) the BSs (i.e. the nodes of the core network do not participate in the user plane transmissions), since the data traffic is localized. Figure 1, provides an overview of the involved entities and interfaces.

New methods and signaling are also introduced at the RAN for the efficient formation and management of the local e2e radio data paths that are described in Figure 2. The Session Request is the initiating message, which is transmitted from the RRC module of a vehicle to the RRC of a BS. The scope of this message is to establish the e2e local radio paths among the group of vehicles that participate in the specific

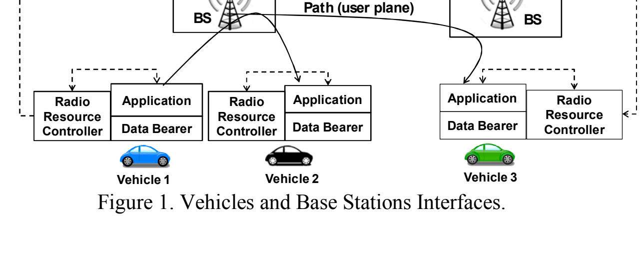

Figure 1. Vehicles and Base Stations Interfaces.

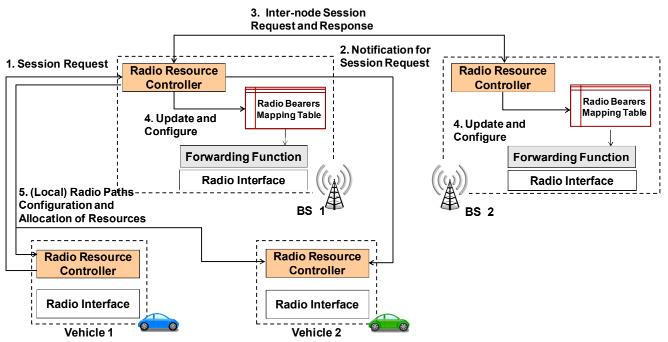

Figure 2. RAN components and Signaling.

application-layer V2X service (e.g., cooperative collision avoidance), considering the required communication modes (unicast, multicast, broadcast) and performance requirements. The RRC entity of the vehicle receives this request from the application layer, based on the triggered events or services. A Session Request message that is transmitted by an individual vehicle triggers directly the establishment of the radio bearers and the configuration of the radio paths for all the vehicles that are involved in the specific V2X service. More details are provided in section IV.

The Radio Bearers Mapping Table (RBMT) is introduced at the BS and it is updated based on the received Session Requests messages for the formation of local e2e radio data paths. These end points of the radio paths could belong to a single cell or at different neighboring cells (multi-cell radio data path). In the case that multiple cells are involved then an inter-cell coordination is needed, as presented in section IV.B. The RBMT of the BS maps and connects the uplink and downlink radio bearers to enable fast and reliable transmission of localized data traffic for different transmission modes (unicast, multicast, broadcast). An example of the mapping is presented in Figure 3. The UL radio bearer could be linked with DL radio bearers, either unicast (Figure 3, case 1) or multicast e.g., SC-PTM radio bearer (Figure 3, case 2). The RBMT of the BS does not require IP addresses and there is no need for the MBMS to support the multicast/broadcast traffic, with the direct benefit of lower latency.

IV. Fast Formation of Local End-to-End Radio Paths

The extension of the existing bearer establishment messages as well as the modification of the corresponding

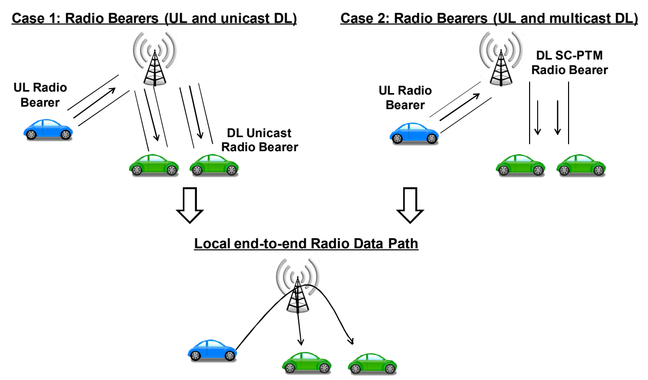

Figure 3. Example configuration of the Local end-to-end Radio Paths.

time consuming functions support the fast formation of local e2e radio paths. The bearer establishment (control plane) delay is initially minimized by avoiding the involvement of the core network or any MBMS entity. All functions for establishing and configuring new bearers that are required for the services, are located at the RAN side (e.g., BS) together with the necessary service or network information (e.g., group of involved vehicles, position of the vehicles etc). This information is available at the BS by the dedicated messages that are proposed in the paper and presented below for the establishment of a new bearer, contributing further to reduction of the control plane delay.

Some features of autonomous vehicles that have been taken into consideration for the evolution of the bearer management. Firstly, the self-driving vehicles have a local map with information about neighboring vehicles and their location, which is built and maintained using messages that are periodically broadcasted. This map and its information are also used for the acceleration of the bearers' establishment in session-based services. Secondly, the vehicles do not have energy constraints, as happens with smart phones; hence vehicles could remain more time in the connected mode during their operation. This means that the vehicles can have access to signaling resources either immediately or with very low delay (e.g., in LTE RRC assignment of SRB1, without the need to repeat context retrieval or security activation process) contributing to the control plane latency reduction.

The proposed signaling and methods for the fast establishment of the radio bearers and the local e2e path for a V2X Service are described in this section, considering both the case that the involved vehicles are located at same and at neighboring cells.

A. *Single Cell*

When a V2X service is to be offered or triggered (e.g., lane merging, cooperative collision avoidance), the initiating vehicle sends an RRC Session Request message to the BS. The introduced RRC signaling between the vehicles and the BS is presented in Figure 4. The BS performs the following tasks: a) check the availability of resources for the specific V2X service, b) establish the radio bearers, c) form the local e2e radio data paths among the involved vehicles (through the configuration of the RBMT of the BS), d) reserve the user plane radio resources that are required for the first transmissions, according to the application layer signaling and performance requirements of the specific V2X service. The content of the Session Request message includes:

- The identifier (*InitiatingVehicle-ID*) and the location (*InitiatingVehicle-Position*) of the initiating vehicle.
- The service type (*V2XServiceType*), which provides to the BS the required QoS information (e.g., multicast/unicast, user plane delay and reliability requirements). The *V2XServiceType* (e.g., Cooperative Collision Avoidance)is a key indicator for the required QoS features, the expected resources and the required radio bearers that will be established and how they will be configured.

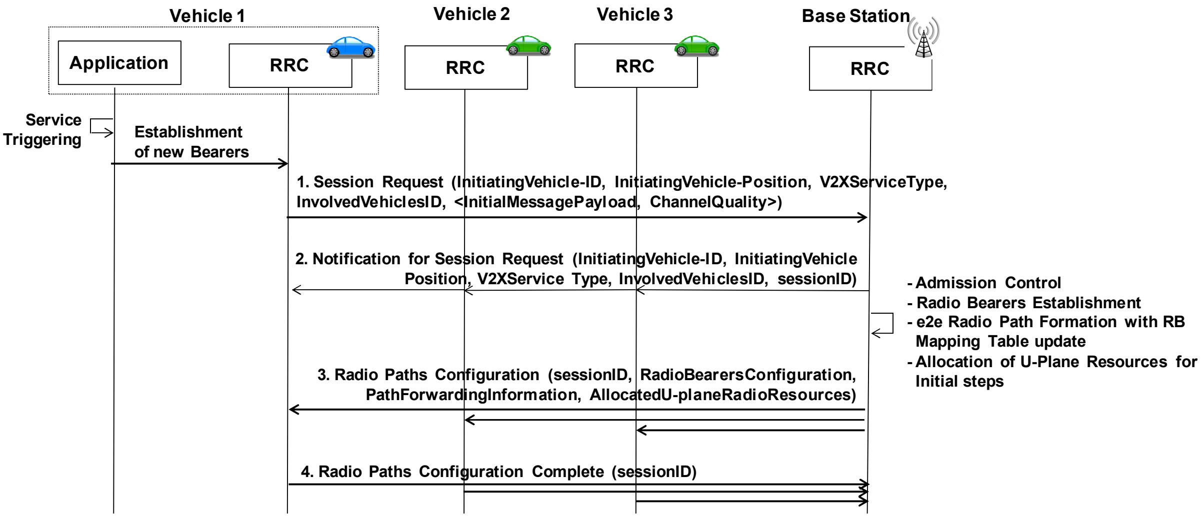

Figure 4. Signaling for Single cell Fast Bearers Establishment and end-to-end Paths Formation.

- The identifiers (IDs) of other involved vehicles in the specific V2X service (*InvolvedVehiclesID*), which are useful for the calculation of expected resources and the identification of the radio bearers that are required for the session establishment of the specific V2X service. The initiating vehicle by making use of the local map (e.g., LDM) is aware about the neighboring vehicles that are involved in the specific service. Hence, this information can be reported to the BS.
- The *InitialMessagePayload* and *ChannelQuality* provide information to the BS required for the (quick) allocation of data plane resources for the first message(s) that will be transmitted. This is very useful in the case of an urgent service (e.g., emergent trajectories alignment). The payload of (initial) transmitted data packet and the signal quality information of the initiating vehicle (e.g., RSRP or other channel quality indicators could be used) together with other information of the Session Request are used for the calculation of the required user plane resources for the initial steps of the data traffic.

With the reception of the Session Request the BS (RRC) sends a Notification for Session Request message in order to notify the vehicles in the same geographical area (e.g., cell area) about the already transmitted Session Request and thus to avoid the transmission of multiple Session Request messages for the same reason/event by the different involved vehicles. This message includes all this information that is required in order to identify the V2Xservice (i.e., information also included in the initial Session Request message). This step is important, because it contributes to the reduction of the required signaling by avoiding the transmission of multiple Session Request messages by the various involved vehicles in the same V2X Service.

The RRC at the BS based on the information received by the Session Request (Service Type, number or involved vehicles) and the locally available undertakes to execute the following steps in order to support the V2X service:

a) Initially, a *SessionID* is generated, at the BS for each served V2X service. The *SessionID* is a unique identifier that is used by the RRC layer to group the different radio bearers that will be created for the corresponding V2X service.

b) Then, the BS checks whether it has the required cellular resources to support the requested service, accordion to the performance requirements (latency, reliability, data rate etc) and the features of the V2X service (Admission Control phase).

   In the case that the needed radio resources are available, then the appropriate UL and DL radio bearers are established, which are then linked to create the different local e2e radio paths. The RBMT, used for the management of the local traffic flow, is configured and updated appropriately. The RBMT creates the e2e radio paths for fast user plane transmission (multicast and unicast).

c) The next step includes the reservation of the resources for the initial application-layer transmissions. These resources are reserved and transmitted to the involved vehicles together with other information that is needed for the configuration of the radio bearers, the local e2e radio paths and the communication modules of the vehicles. UL (and DL) resources allocated for (user plane) transmission only for the first steps of the service to provide the capability for initial fast user plane transmission. This is an important feature, especially for emergency situations (e.g., V2X collision avoidance).

The Radio Paths Configuration message is transmitted to each involved vehicle, as a response to the above procedures and to the Session Request message sent by the initiating vehicle. This message includes the following fields: a) The *SessionID*, which uniquely identifies the specific session, b) the *RadioBearersConfiguration* information for the establishment of radio bearers and (updated) configuration of the different layers (e.g., Physical Layer, Medium Access

Layer) of the radio interface in order to support the specific service, according to the fields that have been specified in the RRC-Reconfiguration message [7], c) the *PathForwardingInformation*, which includes the identifiers from the RBMT that are useful for the transmission of (unicast or multicast) data traffic over the local radio data paths (e.g., identifiers for group of vehicles, or individual vehicles), d) the allocated user plane radio resources (*AllocatedU-planeRadioResources*) that have been scheduled for the initial steps of the V2X service and e) the control plane resources for the transmission of the completion message (i.e., Radio Paths Configuration Complete).

The involved vehicles confirm the successful establishment and configuration of the radio bearers with the Radio Paths Configuration Complete message. Then, the involved vehicles can exchange their data plane traffic, according to the QoS requirements of the V2X service.

B. *Multi-Cell*

In the case that the involved vehicles for the corresponding V2X service are located/attached at different cells, then the direct interaction among the neighboring BSs is needed for the creation and the update of the RBMT and the formation of the local paths (Inter-node Session Request and Response, in Figure 2). The Source BS (i.e., BS where the initiating vehicle is located) sends to the neighboring BS (Target BS) the information that describes the triggered session and are included in the Session Request message (e.g., initiating vehicle ID, service information, list of involved vehicles, communication layer info, etc). The Target BS, based on the availability of the user plane resources to support the QoS requirements, sends the Inter-node Session Response message to trigger the configuration of the radio bearers among neighboring cells and the multi-cell radio paths. Through these messages the BSs exchange configuration parameters (e.g., radio bearers IDs) for the update of the individual RBMTs.

V. TRAAFIC FORWARDING OVER LOCAL END-TO-END RADIO PATHS

The BS creates and maintains the RBMT that maps/links the UL and DL bearers for the formation of the local radio paths and consequently the faster forwarding of localized V2X traffic. The different dedicated radio bearers that are formed for all involved vehicles for the specific service are grouped under the same Session ID, to facilitate the management and the updates of the specific V2X session (e.g., add new vehicle in the context of the same session). The dedicated UL and DL radio bearers of different vehicles that are created in the context of the same Service (i.e., same session ID) are linked at the BS level to create the local data paths, and support the faster forwarding/routing of the data packets from the source vehicle to the destination vehicle(s), based on the transmission type (e.g., unicast, multicast) and QoS features.

Each Dedicated Radio Bearer (DRB) is described by an identifier (DRB ID), the QoS Class Identifier (QCI) that defines the QoS features of the radio bearer (e.g., supported latency, data rate, reliability KPIs etc), the source node and the destination node of the DRB (e.g., for the UL DRB the source

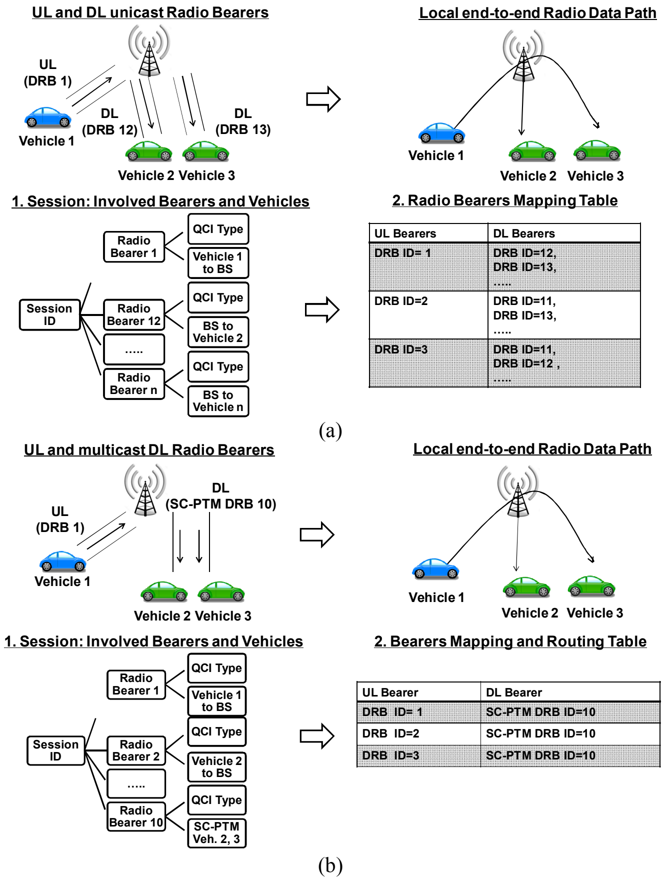

Figure 5. Structure of the Radio Bearers Mapping Table (a) UL and unicast DL DRB, (b) UL and multicast DL DRB.

has the ID of the vehicle and the destination has the ID of the BS, while for the DL DRB the source has the ID of the BS, and the destination the ID of the vehicle). Figure 5(a) and Figure 5(b) present two examples of the structure of the RBMT that is located at the BS in order to build the e2e data paths to support vehicles' data traffic.

In Figure 5(a) for each vehicle that is involved in the specific service an UL RB and a DL RB are created, based on the QoS requirements of the respective service. In the RBMT the UL radio bearer of the each vehicle is mapped with the DL Bearers of other involved vehicle (e.g., vehicle 2, 3,…n) to support the e2e multicast and/or unicast transmissions. Hence, each row of the RBMT includes the RB of the source node/vehicle of a local radio path and the RBs of the Destination vehicle. On the other hand, in Figure 5(b) a SC-PTM radio bearer is created by the BS for the DL multicast transmissions. In this case the RBMT connects the UL DRBs of each involved vehicle with the SC-PTM radio bearer (i.e., Group Bearer). The SC-PTM RB provides the benefit of the more efficient utilization of resources, comparing to the case that multiple unicast DL RBs are used in the e2e paths. On the other hand, each unicast RB facilitates the targeted retransmission, while the configuration of the DL RB based on the radio channel conditions is easier and more flexible. In the case that multiple cells are involved, then each local radio path is extended to the neighboring BSs. The RBMT includes in the

DL Bearers column the ID(s) of the DL DRB of neighboring BS together with its identifier/address.

VI. PERFOMANCE ANALYSIS

A performance analysis is provided in this section using numerical methods to present the benefits of the proposed local e2e path solution for both the control and user plane latency, comparing to baseline technologies. Taking into consideration the operation of existing LTE schemes, the overall e2e latency for the transmission of a unicast data packet via the cellular interface, from a source to a destination vehicle, includes the following latency components, depending always on the Scheduling Requests (SR) period and the Block Error Rate (BLER): a) *L-RAN_UL*: the time duration from the time the vehicle has a V2X message to send over UL to the time the BS successfully receives the V2X message (i.e., 17.5ms+SR period+(1+8*Target BLER %/100) in the case that dynamic scheduling with a separate Buffer Status Report (BSR) is used [10]), b) *L-CN*: the time duration the V2V message is travelling from BS, then passing through the S-GW/P-GW, the ITS server, and is back to the BS for unicast DL transmission (in the order of 20ms, [11]), c) *L-RAN_DL*: the time duration from the time BS has V2X message to send and to the time the vehicle receives the V2X message via unicast DL (4ms+8*Target BLER(%)/100, [10]).

Firstly, we assume that the source and destination vehicles are located at the same BS and dynamic scheduling with a separate BSR is used. For a SR period=1ms and a BLER=10% the total e2e latency for a unicast communication, using the existing LTE scheme through the P-GW (*L-RAN_UL+ L-CN+ L-RAN_DL*) is larger than 45ms (Figure 6). Using the local e2e radio data paths the latency that is introduced by the core network entities (e.g., MBMS, S-GW) is avoided and the user plane latency for the exchange of unicast V2V packets is in the order of 25ms, showing an improvement of 45%.

In the case that a packet should be sent from a source vehicle to a group of vehicles (multicast communication) then there are two baseline technologies that could be used: a) MBMS and b) SC-PTM. On both cases the *L-RAN_UL* and the *L-CN* latency components are also involved. The *L-CN* includes the network latency for the V2V message from the BS of the source vehicle to the BS of the destination vehicles with passing through the Broadcast Multicast Service Center (BM-SC), which is estimated around 20ms [11]. The difference between MBMS and SC-PTM lies in the time from when a V2V message arrives at the BS (of the destination vehicles) to the time when the vehicles successfully receive the V2V message. In the case of MBMS *(L-RAN_MBMS-DL)* the total latency includes the waiting time for the Multicast Traffic Channel (MTCH) opportunity for transmission, the DL transmission and the UE processing time. The *L-RAN_MBMS-DL* includes the latency due to buffering packets at the BS waiting for next MCH Scheduling Period (MSP) (that varies from MSP to 1ms) and the time to wait for the MTCH transmission opportunity (equal to 3.5+MSP/2+ upper layer processing, [10]). In the case of SCPTM *(L-RAN_SCPTM-DL)* the latency depends on the SC-PTM Scheduling Period (SSP) (equal to 2.5+max(SSP/2+1,2)+upper layer processing, [10]), which is shorter comparing to the MSP.

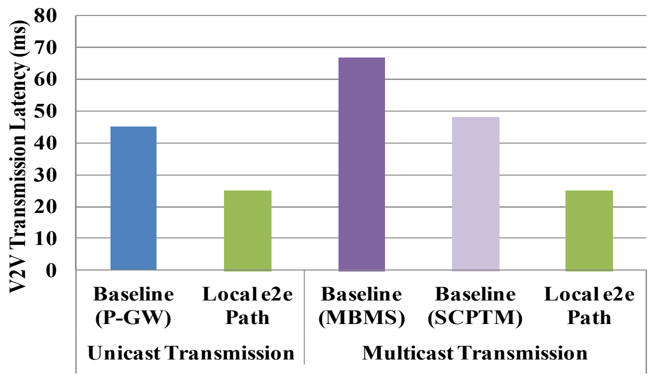

Figure 6. Local e2e Path User plane Latency - Single Cell.

Figure 6 also presents the e2e latency for a multicast communication, comparing the baseline multicast schemes (with MSP=40ms and SSP=1ms) with the proposed local e2e paths scheme. Due to the larger MSP the average e2e latency of MBMS is 67ms, while using SC-PTM the average e2e latency is 48ms. The e2e latency of the proposed local e2e path is the same as the corresponding latency for unicast transmission (25ms), and it is better comparing to the baseline multicast schemes (52% improvement comparing to the SC-PTM scheme and 73% comparing to the MBMS scheme). The proposed scheme treats both unicast and multicast data packets with the same manner. The introduction of the RBMT at the BS provides the benefit of the faster user plane transmission of the localized V2X data traffic, without the need of IP protocol procedures and without any interaction with the MBMS entities for multicast transmissions.

In the case that the source and destination vehicles are located at the neighboring BSs (multi-cell case) the latency that is introduced by the inter-BS interface should be added for both the unicast and multicast communication over the local e2e radio data paths (e.g., 7ms according to [11]). However, even in this multi-cell scenario there is substantial improvement comparing to the baseline LTE-based schemes.

The control plane latency for the connection establishment in an LTE network is analyzed in Table I. According to [7], the latency required for state transition from RRC IDLE to RRC CONNECTED and the data bearer setup is *47.5 + 2*Ts1c ms*, where *Ts1c* denotes the delay for a packet to traverse the S1-interface that interconnects the BS with the core network. The *Ts1c* value ranges from 2ms to 15 ms. For a session-based V2X service the overall latency is larger than 130ms and consists of: a) the latency for the connection establishment of the initiating vehicle, b) the latency required for reception of paging message (that is affected by the paging cycle) together with the notification of other involved vehicles, as well as c) the latency for the connection establishment of other vehicles in the V2X service. In the case that all the vehicles are in the RRC CONNECTED state, then the expected overall latency is reduced, since there is no need to perform steps 1-4 described in Table I; but again the required overall latency for the creation of new bearers is more than 80ms and is considered large for urgent services.

Table II presents the expected delay to establish local e2e paths using the solution proposed in section IV. There is a

TABLE I. LATENCY OF LTE CONNECTION ESTABLISHMENT

Step	***Description***	***Duration(ms)***
1	RACH scheduling period	5
2	RACH Preamble	1
3	Preamble detection, and transmission of RA response	5
4	UE Processing	2.5
5	TTI for transmission of RRC Connection Request	1
6	HARQ Retransmission (@ 30%)	0.3 *5
7	Processing delay in eNB (Uu –> S1-C)	4
8	S1-C Transfer delay	Ts1c(2-15ms)
9	MME Processing Delay (including UE context retrieval of 10ms)	15ms
10	S1-C Transfer delay	Ts1c
11	Processing delay in eNB (S1-C –> Uu)	4ms
12	TTI for transmission of RRC Connection Setup (+Average alignment)	1.5
13	HARQ Retransmission (@ 30%)	0.3*5ms
14	Processing delay in UE	3
15	TTI for transmission of L3 RRC Connection Complete	1
16	HARQ Retransmission (@ 30%)	0.3 *5ms
	Total LTE IDLE à ACTIVE delay (C-plane establishment)	*47.5ms + 2 * Ts1c*

TABLE II. LATENCY OF PROPOSED SCHEME FOR LOCAL END-TO-END PATH ESTABLISHMENT (CONTROL PLANE)

Step	***Description***	***Duration(ms)***
1	Transmission of RRC Session Request (Maximum Delay)	10
2	HARQ Retransmission (@ 30%)	0.3 *5ms
3	Admission Control, Establishment of Bearers and Allocation of Resources	5
4	Transmission of RRC Reconfiguration	1
5	HARQ Retransmission (@ 30%)	0.3 *5ms
6	UE Processing Delay	2.5
7	Transmission of RRC Connection Reconfiguration Complete	1
	Control Plane Latency	*22.5*

substantial reduction of the control plane latency to establish the required radio bearers for all the involved devices, which is estimated at 22.5ms in a single cell case, together with the respective reduction of the signaling overhead. This is due to the reduction of the interactions with the core network entities, the provision of service-layer information in the Session Request message from the initiating device that allow the faster establishment of radio bearers for all involved vehicles and the more time that vehicles can remain in the RRC Connected mode. Within this control plane latency all the involved devices have been informed about the triggered V2X service and all the required radio bearers and radio paths have been established. Moreover, user plane radio resources could be reserved and allocated to the corresponding vehicles for very fast initial user plane transmissions that are useful for emergency V2X services. In addition, the signaling overhead is reduced, due to the SR and grants that are not exchanged between involved vehicles and the BS.

It should be also noted that at the above examples an LTE configuration has been considered (e.g., 1 ms TTI) in order to have a fair comparison with an LTE system. For 5G communication systems, the achieved user plane latency will be much lower, using 5G New Radio (NR) numerology and configuration schemes (e.g., smaller TTI, faster *Xn* interface).

VII. CONCLUSIONS

In this paper, we have proposed the redesign of the 5G RAN in order to enable fast and guaranteed transmission of data traffic together with the very fast establishment of radio bearers for the localized V2X services that have low latency requirements, without the involvement of the core network or any MBMS entity. New methods and signaling have been introduced at the BS for the formation of local e2e radio data paths. With the proposed solution there is a substantial reduction of the control plane latency to establish the required radio bearers for all the involved devices, while the transmission of the data packets over the local radio data paths enables the fast and reliable transmission of localized data traffic among the involved vehicles, by showing an improvement of more than 45% for unicast and 52% for multicast communications, comparing to LTE schemes.

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