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5G Functional Architecture and Signaling Enhancements to Support Path Management for eV2X

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ABSTRACT Enhanced vehicle-to-everything (eV2X) communication is one of the most challenging use cases that the fifth generation (5G) of cellular mobile communications must address. In particular, eV2X includes some 5G vehicular applications targeting fully autonomous driving which require ultra-high reliability. The usual approach to providing vehicular communication based on single-connectivity transmission, for instance, through the direct link between vehicles (PC5 interface), often fails at guaranteeing the required reliability. To solve such a problem, in this paper, we consider a scheme where the radio path followed by eV2X messages can be proactively and dynamically configured to either transmit through a single interface (chosen between the PC5 and the Uu interface for infrastructure-based communication) or through both interfaces simultaneously, depending on the requirements and particular situation. After describing some path management general considerations, we propose a new network function and a procedure to enhance the current capabilities of the 3GPP 5G system. Next, we propose different architectures to support our proposal following the four 5G eV2X architectural options defined by the 3GPP. For each alternative, the necessary signaling for the dynamic configuration of the radio paths is detailed. Finally, an exemplary use case of our proposal is presented in detail to illustrate the feasibility of our proposed functional architectures, and, for that use case, system-level simulation results are provided to demonstrate the benefit achieved with dynamic path management.

INDEX TERMS Multi-connectivity, V2X, sidelink, 5G core.

I. INTRODUCTION

Cellular standards are including new functionalities to support vehicular communications in fifth generation (5G) networks [1], [2]. In particular, the third generation partnership project (3GPP) has considered two communication modes: direct vehicle-to-vehicle (V2V) communications and infrastructure-based V2V communications. The direct communication mode is also known as PC5-based V2V, due to the use of a new sidelink communications interface between two user equipment (UE) referred to as PC5 interface. The infrastructure-based communication mode is known as Uu-based V2V, and is based on the so-called Uu interface, which is the conventional long-term evolution (LTE) radio interface for uplink (UL) and downlink (DL) communications between UEs and the base stations (BSs) of the radio access network (RAN).

Recently, the 3GPP has particularly defined the Enhanced support of vehicle-to-everything (V2X) communication services, known as eV2X [3], which targets essential use cases for improved traffic safety and traffic efficiency, such as vehicles platooning (grouping of vehicles travelling together), advanced driving (semi- or fully-automated driving), extended sensors, and remote driving. It is worth noting that assuring the quality-of-service (QoS) requirements of eV2X is a very demanding task, since, by its very nature,

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eV2X communications require ultra-high reliability (e.g., fully automated driving requires values of 99.99% within a range of up to 500 meters). In practice, it has been shown that fulfilling the ultra-high reliability requirement only with a single communication interface (either PC5 or Uu-based) is a challenging task [4]. Therefore, a possible solution to this problem, which is not supported by the current standard, could be to transmit eV2X messages both via the Uu and PC5 interfaces simultaneously or through a dynamic selection between both. This proposal, however, poses several challenges, some of them addressed in this paper, such as how to give indications to vehicles on where, when and how Uu cellular-based or PC5 V2V communications must be selected or combined.

The use of multi-radio access technologies (multi-RAT) to improve the V2X communication reliability is addressed in [5]. The paper evaluates different independent and coordinated transmission schemes, and shows through system level simulations the effectiveness of combining more than one transmission path to enhance reliability. However, the actual implementation of that scheme in the 5G network architecture is not given, leaving room for the definition of different functional architectures and the corresponding signaling. Other previous works dealt with the problem of radio path selection, such as [6], where a path selection method is proposed focused on receiving path indication information and selecting a transmission path between Uu-based and/or sidelink, according to such path indication information. However, the work only focuses on initial selection and, thus, there is no dynamic switching or proactive behavior at all involved in such decisions. The work in [7] also develops a selection method of a service transmission path, but only focusing on defining the radio resource control (RRC) signaling needed to determine if the PC5 switching path is selected or not. The latter work neither considers any kind of proactive approach to dynamically decide between Uu and PC5-based communication.

The key goal of our proposal is to provide the necessary functional architecture and the corresponding signaling to support a dynamic and proactive path management for vehicular communications in 5G networks. The proposal relies on multiple information sources providing insights about the QoS performance of the network, e.g. cell status, sidelink resource pools, actual problematic cell regions, past aggregated experience of users in the area, and, optionally, UE specific information, such as selected reports from UEs enduring actual problems. With this information, decisions are made on the independent or combined use of the PC5 and Uu interfaces. Those decisions can differentiate services and sessions for each user. In addition, the decisions can be common for a specific geographical zone or particular for each user. Overall, the main contributions of this work are:

- Examples of path management, where either the best interface for single-path communication in an area is proactively selected, or the use of two-path communication is exploited for throughput increase (different information through each interface), or for QoS enhancement through information redundancy.
- Support of a simple regional-based path management in which the decisions on the path usage are driven by the location of the users.
- Generic functional architecture for path management. A novel network function for path management is proposed, to receive inputs from other available network functions in the 5G architecture and to interact with the logical function used for network-related actions required for V2X defined by the 3GPP. A procedure for path management based on five subprocesses is introduced.
- Implementation proposal over the four 3GPP architecture alternatives for V2X.
- Signaling for each implementation proposal. The necessary signaling to carry out the proposed path management scheme over the different V2X architecture options is developed.

The remainder of this paper is structured as follows. Section II describes some general considerations and use cases of the proposed path management scheme. In Section III, an overview of the 5G architecture with focus on the functional entities necessary to implement our proposal is provided. Section IV proposes a new network function and a procedure for path management. Section V details the implementation of the new procedure over the four 3GPP architecture alternatives for V2X and the signaling exchange among the involved control functions in each architecture alternative to carry out the proposed path management scheme. Finally, Section VI presents an exemplary use case of our proposal to illustrate its feasibility, and, for that use case, system level simulation results are provided to demonstrate the benefit achieved with a dynamic path management.

II. PATH MANAGEMENT GENERAL CONSIDERATIONS

In this section, we present some general considerations and requirements concerning the path management, useful to introduce the proposals presented in subsequent sections. We also propose some use cases in which the dynamic path management can enhance the communication or make it possible in some critical situations.

A. PATH USAGE TYPES

Figure 1 shows an overview of three categories of path usage that we envision in case of availability of both Uu and PC5 interfaces. In Figure 1 (a) a single interface communication scenario is shown, in which only one interface is selected to conduct the communication according to a certain criterium, for instance, selecting the path providing the highest QoS to the user. Figure 1 (b) considers the simultaneous use of PC5 and Uu paths with different data being transmitted through each interface. This approach can be used, for instance, to perform load balancing or to increase the capacity of the communication. Finally, in Figure 1 (c), dual-path

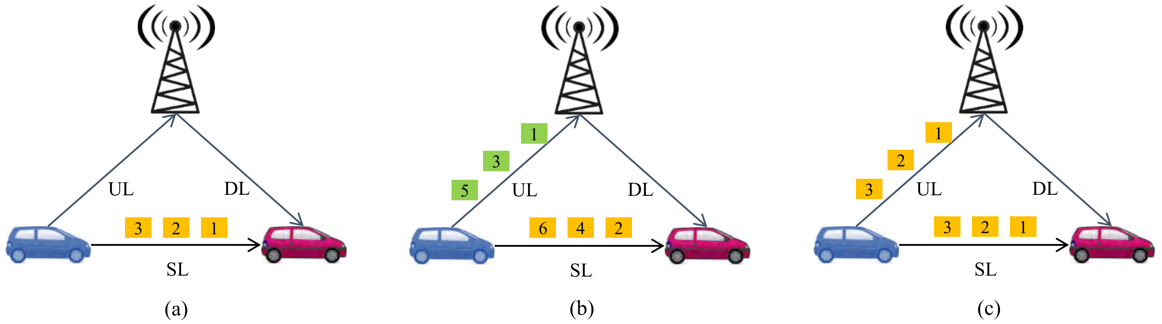


FIGURE 1. Overview of path usage categories. (a) Single interface operation. (b) Dual interface operation without redundancy. (c) Dual interface operation with redundancy.

communication is used to transmit redundant information through the different paths, either transmitting exactly the same data, or different versions using some kind of incremental redundancy scheme, with the aim of increasing the reliability of the communication. Incremental redundancy may be accomplished by using a different set of coded bits at each transmission, using different redundancy versions generated by puncturing the encoder output, so as to, upon the reception of a coded data block, being able to gain extra information about another coded data block, thus increasing the likelihood of correctly decoding a combination.

Our proposal should allow the configuration of the path usage according to the three identified categories depending on aspects such as the service/vehicle/mobile network operator (MNO) requirements and QoS experience. Note also that the path usage can be decided on a per-UE basis but it also may be decided on lower levels such as per-service or per-session.

B. REGIONAL-BASED PATH MANAGEMENT

Although the path usage decisions can be made independently for each UE, it is also possible to make decisions associated to geographical regions. This option is reasonable given that the QoS experienced by the users is typically spatially correlated. In fact, this option may be the best one in some cases, for instance, when the data available from specific UEs to make decisions is scarce but, at least, its position is known.

A possible approach to make such decisions is to divide an area into geographical zones according to the QoS perceived for the different available paths (QoS zones) and associate each zone with a specific decision suitable to satisfy a given QoS requirement. In Figure 2, an exemplary urban scenario is divided into several geographical regions according to the perceived QoS of the PC5 and Uu interfaces, each of them shown in a different color.

Provided that the network is able to keep track of the UE positions, it can detect that a UE is changing the QoS zone in which it is located, and then notify a change of recommended path selection (when applicable).

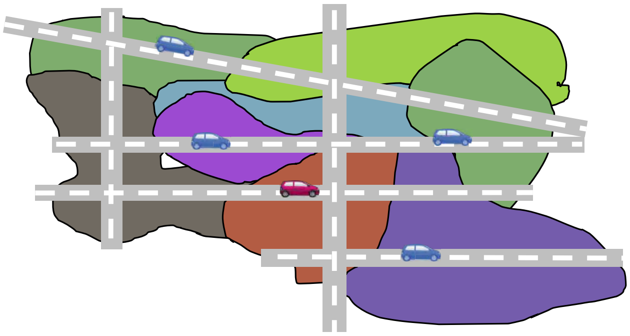
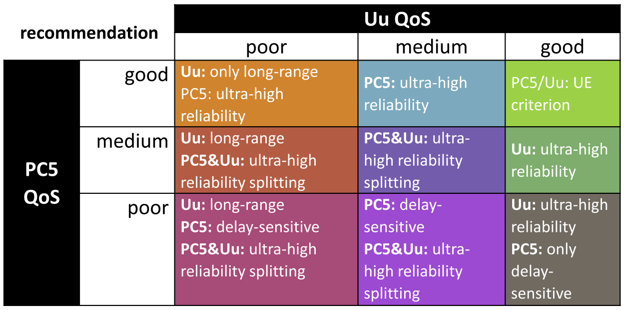


FIGURE 2. Possible geographical division of an urban scenario according to the QoS of the PC5 and Uu interfaces.

Figure 3 presents an example of path usage decisions for PC5 and Uu considering the regions in Figure 2. In this example, we consider that, in case of good QoS for both interfaces, PC5 could be used for latency-sensitive use cases, (e.g. providing current location, speed, orientation, safety warnings), while Uu could be of use for long-range sensitive use cases (e.g. remote alerts, reaching vehicles far away), for the sake of balancing the load of both interfaces. According to this rationale, when both PC5 and Uu interface QoS are perceived as good (bright green), the network gives the UEs freedom of choice between the interfaces, whereas when the Uu QoS is poor and the PC5 QoS is good (bright orange), the network recommends using the Uu interface only for communications that require eminent traits of this interface (e.g. being able to reach a distant receiver), and the network recommends to resort to PC5 interface for those applications constrained by ultra-high reliability restrictions. Furthermore, the specific QoS status of each interface in a certain geographical zone (e.g. Figure 2) might prompt different recommendations from the network. For example, when the Uu interface has medium QoS and the PC5 has good QoS, the overall status is optimistic enough to discard redundancy to favor a load balancing approach; however, when the Uu interface QoS is poor and the PC5 QoS is medium, the network may anticipate the recommendation of using redundancy for any communication requiring ultra-high reliability.

Finally, note that the regional-based path management allows to implement a proactive path management in the sense that it is possible to associate the path management



recommendation		Uu QoS		
		poor	medium	good
PC5 QoS	good	**Uu:** only long-range PC5: ultra-high reliability	**PC5:** ultra-high reliability	PC5/Uu: UE criterion
	medium	**Uu:** long-range **PC5&Uu:** ultra-high reliability splitting	**PC5&Uu:** ultra-high reliability splitting	**Uu:** ultra-high reliability
	poor	**Uu:** long-range **PC5:** delay-sensitive **PC5&Uu:** ultra-high reliability splitting	**PC5:** delay-sensitive **PC5&Uu:** ultra-high reliability splitting	**Uu:** ultra-high reliability **PC5:** only delay-sensitive

FIGURE 3. Possible network recommendations for path selection based on current QoS.

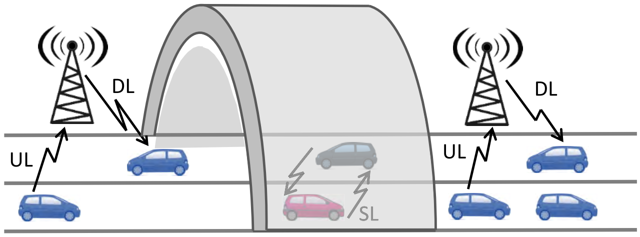


FIGURE 4. Path selection in an exemplary static scenario: tunnel without coverage.

decisions to the QoS that a UE will experience in a geographical area before it actually experiences such QoS, i.e. before the UE enters that area. Therefore, it allows, for instance, the UEs to change its path usage before the experienced QoS degrades below some threshold.

C. USE CASES

In order to illustrate the usefulness of the path management, and specifically of the regional-based path management, we present some use cases.

Figure 4 shows a tunnel without Uu coverage. Upon entering the tunnel, a UE using the Uu interface may benefit from a Uu to PC5 switch network recommendation, thus allowing the vehicles approaching the tunnel to be prepared to commute to sidelink before losing its signal, thanks to the definition of the QoS zones. A similar situation would arise in an area where a BS is down. Again, upon entering the defined zone, the network should recommend the UEs to be prepared to switch to sidelink temporarily because of the BS failure and out-of-coverage approaching conditions.

The switching of the interface would be also very useful in case of a network attack where, e.g., the PC5 interface is compromised in a certain geographical zone. With the present proposal, the network could force the UEs to communicate only through the Uu interface in the zone where the attack is being carried out, thus protecting the overall security and road safety.

III. 5G ARCHITECTURE

Another contribution of this paper is focused on the necessary enhancements to the 5G system architecture in order to support path management. To this end, we first introduce the main characteristics of the standardized 5G architecture with special emphasis on those most relevant for our proposal.

TABLE 1. Description of network functions acronyms.

5GC NF	Description
AF	Application Function
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
NEF	Network Exposure Function
NRF	Network Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
SMF	Session Management Function
SMSF	SMS (Short Message Service) Function
UDM	User Data Management
UPF	User Plane Function

The 3GPP has defined both a new radio access network, NG-RAN, with a new radio interface protocol architecture called New Radio (NR), as well as a new 5G core network (5GC) [8]. The NG-RAN is composed of two types of NG-RAN nodes: gNBs, providing NR protocol terminations towards the UE, and ng-eNBs, providing E-UTRA protocol terminations towards the UE. The NG-RAN nodes can be interconnected with each other via Xn interfaces and with the 5GC via NG interfaces.

In contrast to the 4G traditional evolved packet core (EPC), the 5GC does no longer consider network elements but network functions, which can be virtualized and hosted in a cloud environment. As a result, the physical deployment of well-known EPC network elements such as the Mobility Management Entity (MME), Serving Gateway (SGW) and Packet Data Network Gateway (PGW) are now replaced by virtualization and software, thus increasing core network flexibility to meet the 5G requirements [9]. Figure 5 shows an overview of the 5G system architecture and network functions [10] and Table 1 expands the related acronyms.

The 5G system architecture contains also several reference points connecting the different network functions, referred to as Nx in Figure 5. For instance, the N1 and N2 are the reference points connecting the AMF with the UE and RAN, respectively.

NF service producers expose services (an action or information) to NF service consumers. A consumer and a producer may interact following a request-response mechanism or a subscribe-notify mechanism. In the former, the consumer requests a service from the producer in a specific time and expects a response within a certain time span. In the latter, the consumer subscribes to the service offered by the producer which will send notifications of the service result to the consumer either periodically or triggered through events.

The most relevant network functions for this paper are: the Application Function (AF), the Access and Mobility Management Function (AMF), the Policy Control Function (PCF), the Session Management function (SMF) and the V2X Control Function (V2XCF). In the following we describe their main functionalities.

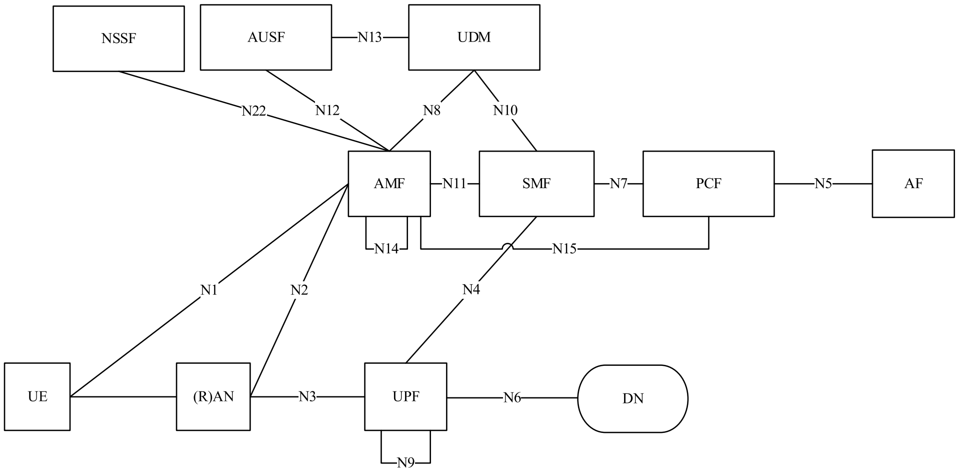


FIGURE 5. Overview of 5GC network architecture and reference points [10].

The role of the AF is to interact with the 5GC in order to provide services, for example, to support the following: application influence on traffic routing, accessing Network Exposure Function (NEF), and interacting with the Policy framework for policy control.

The AMF is in charge of important tasks such as registration, connection, reachability and mobility management, access authentication and authorization, UE mobility event notification, termination of RAN control plane interface through N2, and termination of Non-Access-Stratum (NAS) through N1.

The PCF includes the following functionality: supporting unified policy framework to govern network behavior, providing policy rules to control plane functions to enforce them, and accessing subscription information relevant for policy decisions in a Unified Data Repository (UDR).

The SMF is in charge of session management tasks, e.g., session establishment, modify and release, including tunnel maintain between User Plane Function (UPF) and Access Network (AN) node. Another key functionality is the UE IP address allocation and management.

Another relevant functional entity is the V2XCF, which is the logical function that is used for network related actions required for V2X. It is used to provision the UEs with specific parameters that allow the UE to use V2X in a specific network. According to 3GPP [11], the role of the V2XCF must be assumed by either an existing 5GC NF or by a MNO proprietary V2XCF. In particular, as stated in [12], the service authorization and provisioning function for V2X may be done according to the following alternatives regarding the 5GC architecture:

1) Alternative 1: The tasks of the V2XCF are performed by the PCF.
2) Alternative 2: Keeps the Release 14 approach by reusing the evolved packet system (EPS) V2X architecture defined in [10] and V2X architecture reference model in [13].
3) Alternative 3: The tasks of the V2XCF are performed by a new CF in the 5GC.
4) Alternative 4: The tasks of the V2XCF are performed by an AF.

In alternative 2, the provisioning of V2X policy/parameters is via user plane (U-plane), whereas in the rest of alternatives, the provisioning is via control plane (C-plane). In the latter case, the provisioning via C-plane sends the configuration to the AMF, which in turn sends it via N1 to the UE.

IV. PROPOSED NETWORK FUNCTION AND PROCEDURE FOR PATH MANAGEMENT

In order to support the path management, we propose the definition of a novel network function with path management specific functionalities: the path management function (PMF). The PMF would be in charge of a new procedure to support path management, depicted in Figure 6, which involves also other existing functions and entities of the 5G system. The proposed procedure allows to make path management decisions based on a plurality of possible inputs and to update the UEs with those decisions. Five subprocesses are considered for the proposed path management procedure, which may be executed in sequential order or concurrently:

1) PROVIDING INFORMATION TO PMF

In this subprocess, the PMF receives multiple up-to-date information from different sources via a new information element (IE) called *InformationForPathManagement*. In particular, the PMF is informed about the QoS performance of the network thanks to the periodical update of this IE by the NG-RAN. In this case, the *InformationForPathManagement* comprises essential information and optional information. Essential information may be the comprehensive global statistics of every cell controlled by a BS (e.g. average SINR), as well as their potential status (down, hacked), and sidelink resource pools; additionally, the reports on current cell regions identified as problematic, and also some

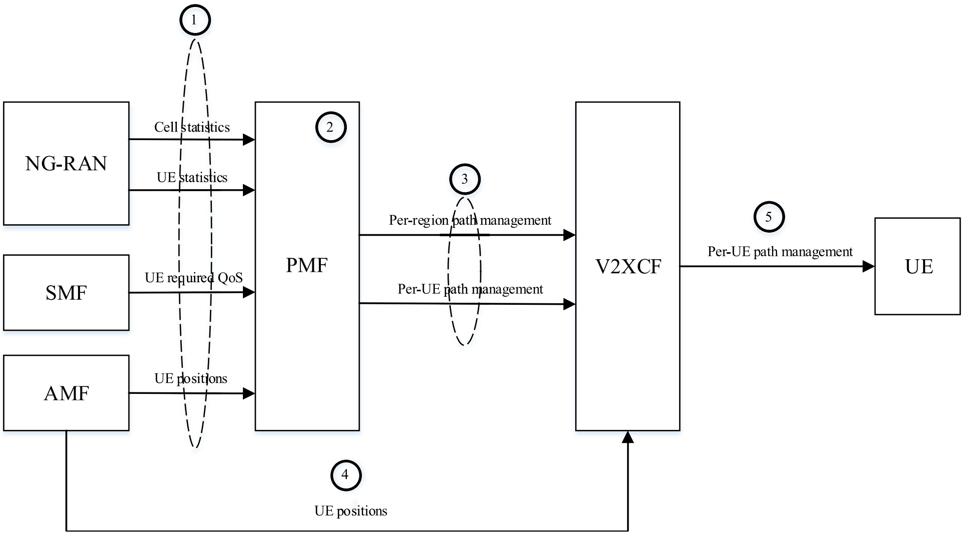


FIGURE 6. Overview of the proposed functional architecture and process stages.

historical information (e.g. the past aggregated experience of users in certain areas). Essential information may be also SINR (or other signal-related indicators) maps, and geographical definitions about the zones where the SINR is below a certain threshold. Optionally, certain UE specific information could be also included, such as the QoS required by the UEs or selected reports from UEs enduring actual problems.

Regarding the comprehensive statistics from every cell controlled by a BS, these must include the following information:

- mobility-related parameters: speed, direction, UE location,
- admission control related, radio bearer control related,
- handover-related: radio-link-failures, excessively frequent, too-early, too-late, ping-pong, and wrong-cell handovers,
- reporting the status of the network resource pools (using the same definition used today for sidelink reporting), IE SL-CommResourcePoolV2X-r14 reported from BS to UE (TS 36.331 V15.2.2) must be extended with new fields to report the QoS key performance indicator (KPI) status of the network resource pools,
- radio quality measurements: timing advance, channel baseband power, etc.,
- user plane QoS and quality of experience (QoE),
- scheduler related: physical resource block (PRB) usage (UL/DL, total/per traffic class, dedicated/common/ random access control channels), random preambles, active UEs, etc.,
- received signal strength indicator (RSSI), channel busy ratio (CBR), violation of CBR thresholds, PRR from users,
- control plane performance counters and delay measurements (common performance counters for accessibility, retainability, and mobility KPIs).

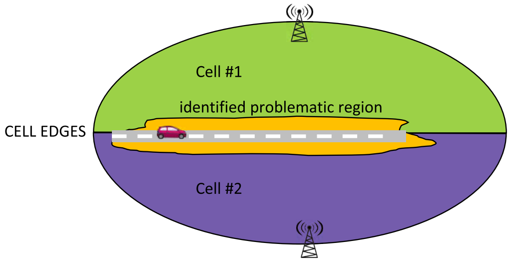


FIGURE 7. Situation with NG-RAN identifying a zone as problematic.

Concerning the reports on current cell regions identified as problematic, it must be noted that the NG-RAN does not compute the QoS zones (this is the role of the PMF) but informs the PMF of cell regions currently identified as problematic. Instead of reporting the UE specific QoS performance, the gNB should report a currently-diagnosed problem (what causes the problem), as well as the specific cell region the problem is limited to.

For example, Figure 7 shows a road located between two cells (at the cell edges), where the cell average QoS may be good but a significant amount of users experience degraded communication along the road. Under those conditions, the NG-RAN identifies a problematic region where the road meets the cell edges.

Regarding the question of how to provide user plane QoS and QoE to the PMF, it must be noted that one of the attributes of the SMF is managing every QoS flow, by deriving their QoS parameters from information provided by the PCF. Therefore, the SMF has been chosen as the function with the task of providing the PMF with the QoS profile containing the QoS parameters of a QoS flow from a specific UE.

Finally, note that because of its inherent mobility-related tasks, the AMF should be the function selected for the provision of the PMF with essential and up-to-date UE location information. The location updates can be periodical or event-triggered. In an event-triggered approach, we propose that the AMF can be informed by the PMF of a list of geographical zones (we call them GeoZones) and requested to notify the identity of the UE and its new GeoZone (that we will refer to as currentGeoZone) whenever a UE changes from a GeoZone to a different one.

2) PMF DECISION MAKING

With the inputs provided in subprocess 1, the PMF is in charge of deciding the PC5/Uu path usage of the UEs. Note that the algorithmic logic guiding the computation of such decisions is out of the scope of the present paper, instead, the focus is on setting the basis to allow the implementation of multiple decision-making approaches.

In any case, there are some characteristics of the PMF decision making process that may fit many implementations. First, the PMF has to process all the updates of the *InformationForPathManagement* IE with new information. These updates can be used to feed internal data structures which may represent a model of the network. Second, the PMF may assess potential configurations with respect to previously-trained models (via machine learning, and based on occurrences of that past-behavior of the network) in terms of QoS improvement. For example, in Figure 7 the PMF could conclude that recommending the Uu only for applications that require access to long-range communications and limit applications with ultra-high reliability constraints to PC5 is the best approach (as confirmed by past instances of this problem already witnessed by the PMF).

As mentioned in Section II, the decision-making may be regional-based. In this case, the PMF could first identify different QoS zones for each available interface and make per-region decisions based on such spatial distribution of the experienced QoS. These decisions would be formed by an indication of the path usage together with the indication of the corresponding geographical region. However, the decisions may be also tailor-made for each UE taking into account its whole specific context, thus leading to per-UE decisions.

3) PMF PROVIDES DECISIONS

Once the PMF makes a decision, either per-region or per-UE, the decision is sent to the V2XCF using a message with the management object (MO) *PathManagementDecision*. This new MO will include all the necessary elements to define the path management decision. First, it should be identified if the decision is per-region or per-user. In case of per-region decisions, the region can be indicated reusing the GeographicalArea MO which defines a polygon and already exists as defined in [14]. In case of per-user decisions, the user identity must be indicated. Also, it has to be indicated if the decision is for all services, for one specific service (stating in this case the associated service ID), or for a specific session. Finally, the decided path-usage option, i.e., the single interface communication, dual interface without redundancy or dual interface with redundancy, has to be indicated.

In summary, the structure of the *PathManagementDecision* MO would be the following:

- ○ *PathManagementDecision* MO
  - – Type: per-region/per-user
  - – Type-dependent parameters:
    - • Region [if type is per-region]: GeographicalArea MO
    - • UE identity [if type is per-user]
  - – Scope: all services/specific service/specific session
  - – Scope-dependent parameters:
    - • Service ID (if scope is specific service)
    - • Session ID (if scope is specific session)
  - – Path usage: single interface PC5, single interface Uu, dual interface without redundancy, dual interface with redundancy

4) AMF PROVIDES UE LOCATION DIRECTLY TO V2XCF

Subprocess 4 involves the monitoring of the UE mobility. This subprocess is necessary when the PMF is only providing per-region path management decisions to the V2XCF since, in this case, the location knowledge is needed to translate per-region decisions into UE-specific decisions. The AMF is the best candidate to perform UE mobility monitoring tasks, since it is the 3GPP approach to UE-based authentication, authorization, mobility management, etc., as previously introduced. Therefore, when the PMF has provided per-region path management decisions, the AMF will prompt the V2XCF to update the UE configuration due to location changes.

5) V2XCF PROVIDES RECOMMENDATION TO UE

In this last subprocess, the V2XCF informs the UE about the proposed path management decision. Provided that [14] gives the option of extending the V2X communication provisioning MO exchanged between V2XCF and UE, the *PathManagementDecision* MO is proposed to be inserted as an extension there. This MO sent to the UE can be the same MO generated by the PMF, when the PMF makes per-UE decisions, or a new MO built by the V2XCF based on per-region decisions of the PMF and UE position updates from the AMF.

V. SIGNALING MECHANISMS AND ENTITY LOCATION OPTIONS IN 5G SYSTEM ARCHITECTURE

This section examines the implementation of the present proposal in the previously introduced 5G architectural alternatives for V2X, and provides a description of the necessary signaling exchange among the involved functions. For each alternative, a key decision is where to place the PMF. Note that, in alternative 2, the position of the V2XCF needs also to be decided. Even though the simplest approach could be to locate the PMF at the same function as the V2XCF (preventing the burden of defining additional signaling), in practice, there may not be freedom of choice over this aspect due to, e.g., MNO requirements. As such, the implementation

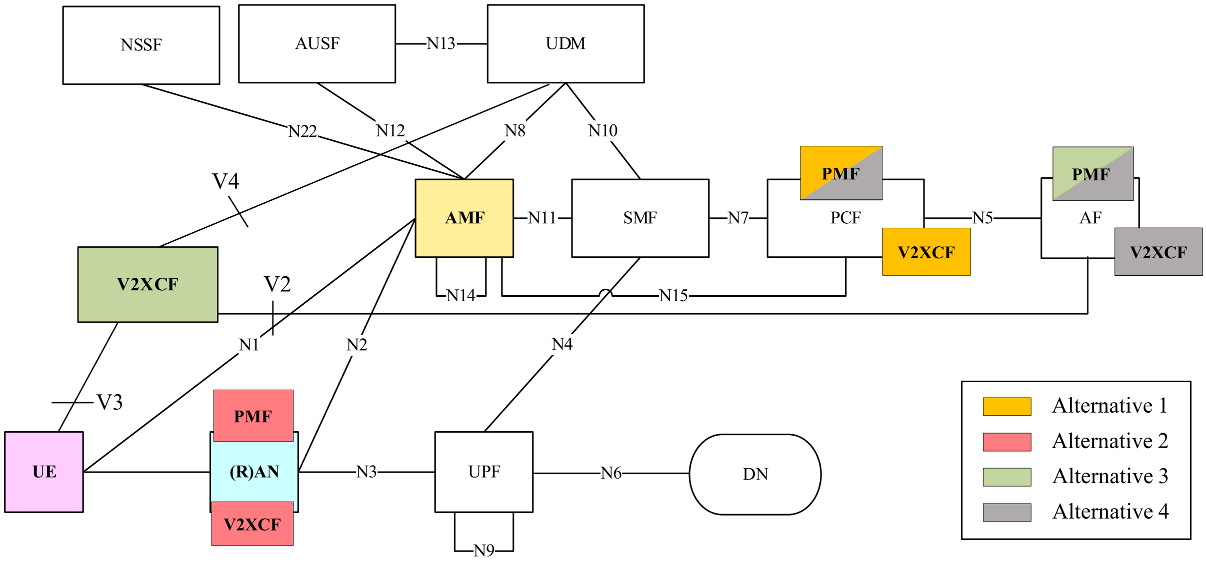


FIGURE 8. Location of V2XCF and PMF in the four architecture alternatives.

examples below try to cover a signaling overview as complete as possible by placing the PMF in reasonable alternative core functions.

A. IMPLEMENTATION OVER ALTERNATIVE 1: PCF ACTS AS V2XCF

As previously introduced, Alternative 1 uses the C-plane, where the PCF is acting as V2XCF. Our proposal is to co-locate also the PMF with the PCF. The locations of both blocks are highlighted in orange in Figure 8.

The signaling involved in the five subprocesses of our proposal for this architecture alternative is presented in the message sequence chart (MSC) of Figure 9, which has been derived following the guidelines in [15]. Before subprocess 1, the PCF is subscribed to the AMF for the delivery of information contained in a new specific N2-message (*InformationForPathManagement*), which includes the notification of NG-RAN about updated information for the computation of path management (cell and UE statistics). From this moment on, the NG-RAN and AMF will communicate with each other for path management purposes (either periodically or event-driven) using the N2 interface, allowing the AMF to subsequently deliver the *InformationForPathManagement* message towards the PCF. As shown in Figure 6, the AMF can also report UE positions, and the SMF can send information about the UE required QoS through the N7 interface as well. This information is also sent via *InformationForPathManagement* messages to the PMF after the corresponding subscription to the AMF and SMF.

The signaling in subprocess 3 from PMF to V2XCF, since the PMF and the V2XCF are located at the same network entity, is an internal communication process at the V2XCF.

In subprocess 4 (needed when the PMF is only providing per-region path management decisions), the V2XCF is subscribed to reporting from the AMF about one or more UEs moving in or out of any of the previously informed geographical zones, as described in [10]. Then, the AMF provides the requested information to the V2XCF, indicating the corresponding UE identities and their new GeoZones (currentGeoZones).

The signaling in subprocess 5 from V2XCF to UE is based on the UE Configuration Update from [15] for transparent UE Policy delivery, where the delivery of the UE policies implies the AMF providing the new *PathManagementDecision* MOs to the UE.

B. IMPLEMENTATION OVER ALTERNATIVE 2: U-PLANE-BASED

Alternative 2 uses the U-plane, where we propose both the V2XCF and PMF to be located at the NG-RAN, as shown by the red blocks in Figure 8.

The MSC in Figure 10 shows the signaling to enable our proposal for this architecture alternative. Regarding the signaling in subprocess 1, from NG-RAN to PMF, this is a process internal to the RAN because of the PMF location. The same happens in subprocess 3, since the PMF and the V2XCF are located at the same entity, the communication between both functions is an internal process at the NG-RAN.

Note that, given that this is a U-plane alternative, the control plane functions, such as the AMF and SMF, are not used. Therefore, in subprocess 1, we don't consider the signaling that involves such network functions. In the same way, subprocess 4 is not considered since AMF should be used in that subprocess.

Finally, the signaling in subprocess 5 from V2XCF to UE follows the V2X authorization update procedure through

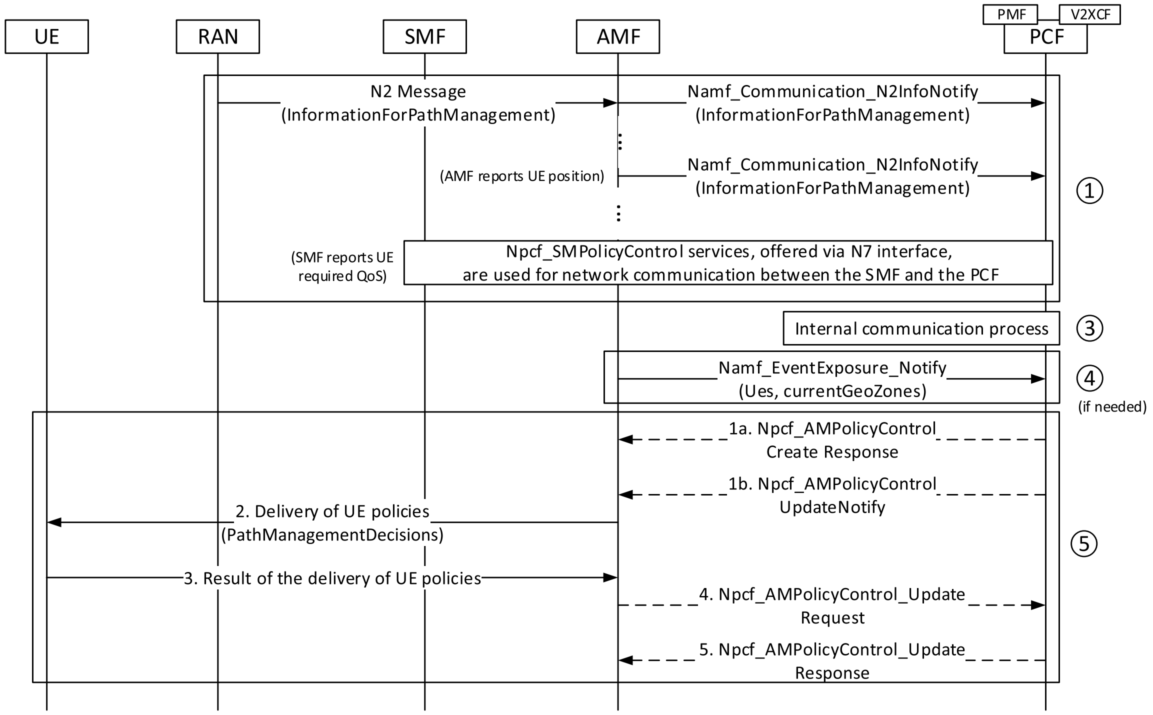


FIGURE 9. **Signaling exchange in Alternative 1.**

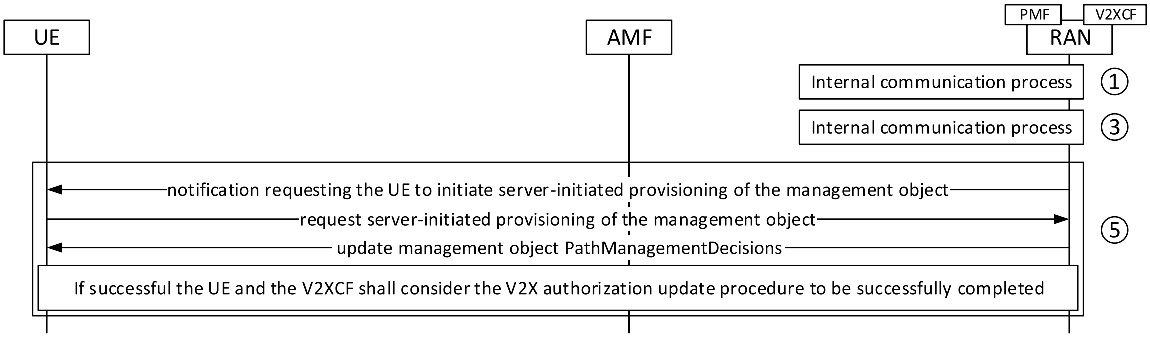


FIGURE 10. **Signaling exchange in Alternative 2.**

interface V3 in [16], introducing the update of the *PathManagementDecision* MOs as a V2XCF initiated operation, as shown in Figure 10.

C. IMPLEMENTATION OVER ALTERNATIVE 3: NEW V2XCF LOCATED AT THE 5GC

Alternative 3 uses the C-plane and considers a new V2XCF at the 5GC, connected with the AF, UE and UDM through Vx interfaces. Our proposal is to locate the PMF at the AF, able to interact with the V2XCF through the V2 interface. The particular position of the V2XCF and PMF in this alternative are shown by green blocks in Figure 8.

The signaling in subprocess 1 from NG-RAN to the PMF is shown in Figure 11. The NG-RAN provides the AMF with the *InformationForPathManagement* via a N2 message. The subscribed PCF is in turn informed via a *NamfCommunicationN2InfoNotify* message, and finally, the PCF sends the subscribed AF the *InformationForPathManagement* MO for its use at the PMF. In a complementary way, the AMF may decide to report the UE position using the *InformationForPathManagement* MO to the already subscribed PCF, which follows a similar procedure to inform the PMF located at the AF. Additionally, the SMF may inform the PCF about the QoS required by UEs with *NpcfSMPolicyControl* services, offered via N7 interface.

In subprocess 3, the AF uses the V2 interface to send the *PathManagementDecision* MO to the V2XCF. This choice seems reasonable, provided that the V2 interface is normally used by the V2X application server to provide PC5 parameters to the V2XCF.

In subprocess 4, the PCF is subscribed to the AMF, with interest on being notified when one or more UEs move in

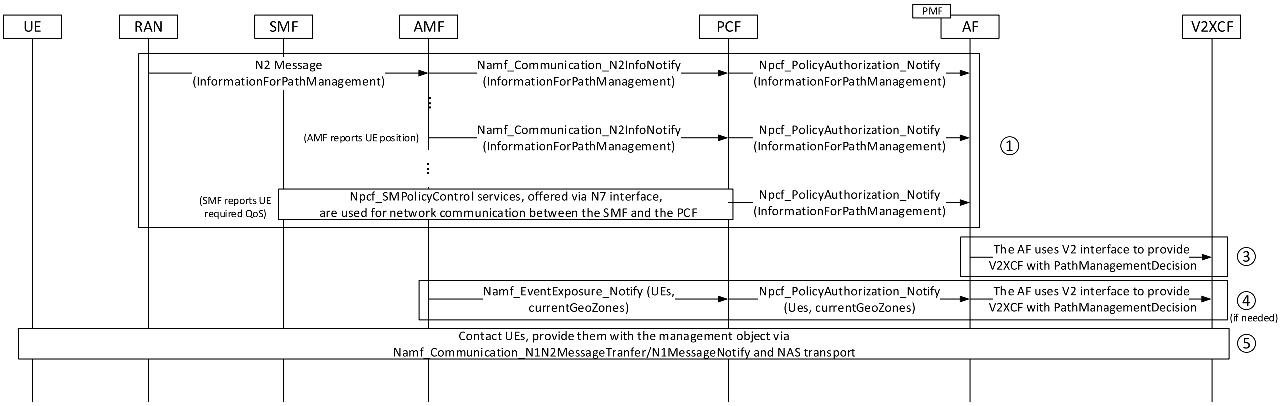


FIGURE 11. Signaling exchange in Alternative 3.

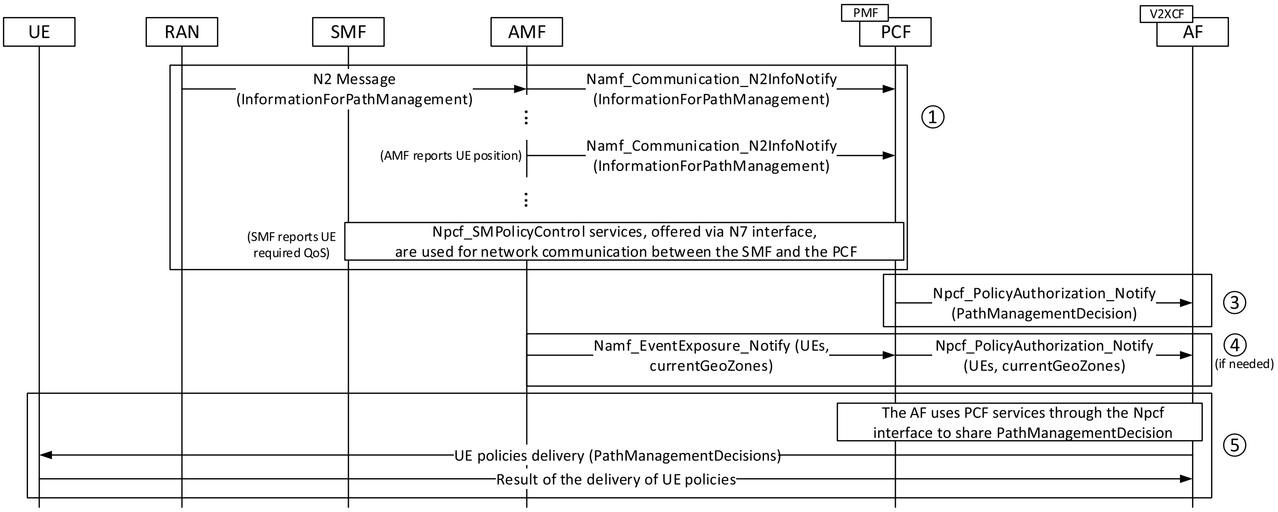


FIGURE 12. Signaling exchange in Alternative 4.

or out of a subscribed area of interest. When this happens, a *NamfEventExposureNotify* message is issued containing the information regarding the UEs and their *currentGeoZones* to the PCF. In turn, the PCF relays this information notifying the PMF in the AF via a *NpcfPolicyAuthorizationNotify* message. After this, the PMF decides the course of action and then the AF sends the calculated *PathManagementDecision* through the V2 interface to the V2XCF.

The signaling in subprocess 5 from V2XCF to UE uses a new NAS message (e.g., NAS V2X message) on top of the NAS mobility management message to contact UEs and provide them with the new MO. Note that this is because the old application layer interface between V2XCF and the UE (V3) is replaced in Release 16 by *NamfCommunicationN1N2MessageTransfer/N1MessageNotify* service of the AMF, and the NAS transport.

D. IMPLEMENTATION OVER ALTERNATIVE 4: AF ACTS AS THE V2XCF

Alternative 4 uses the C-plane, with the AF acting as V2XCF and two proposals for the PMF location: either at the PCF or at the AF. The potential locations of these functions are denoted with grey blocks in Figure 8.

When the PMF is chosen to be located at the PCF, the signaling in subprocess 1, from NG-RAN to the PMF, is identical to the one shown in Figure 9 for alternative 1. In the case of placing the PMF at the AF, this subprocess matches the one described in alternative 3.

Considering the first option (PMF at PCF), Figure 12 shows the signaling for the rest of subprocesses. Note that subprocess 3 from PMF to V2XCF is identical to subprocess 3 of alternative 3.

The signaling in subprocess 4 to communicate the V2XCF with the AMF matches the description provided in alternative 1 but between PCF and AMF. In subprocess 5, from V2XCF to UE, the AF provides V2X policy/parameters directly to the UE, as shown in Figure 12.

VI. EXEMPLARY USE CASE

In this section, we present an exemplary use case of our proposal using a simulated environment with Uu and PC5 technologies. Our aim is not to demonstrate the full potential of

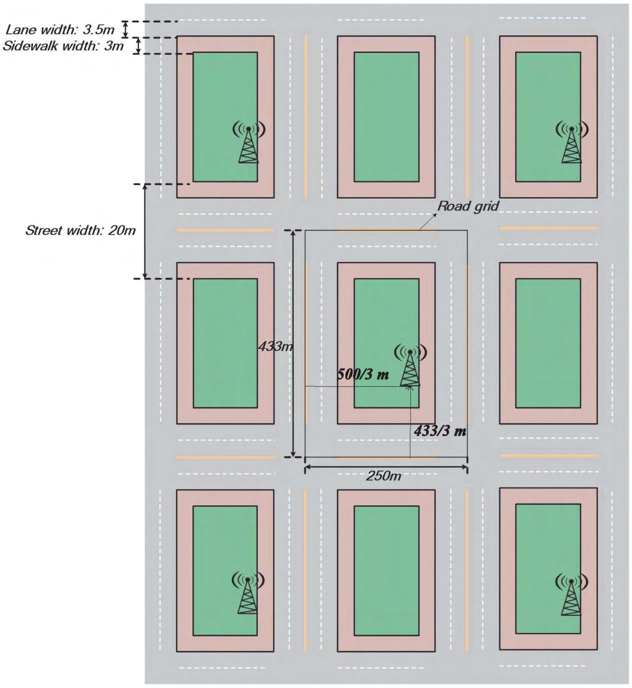


FIGURE 13. Road configuration and network deployment in the urban environment.

a proactive and dynamic path management, although we will see a clear benefit for the presented use case, but rather to check the feasibility of our proposed functional architecture, and to introduce a possible implementation of the algorithm running in the PMF to make path management decisions. Note, however, that the presented algorithm is just a particular example to clarify our proposal, but it does not preclude other possible implementations.

To conduct the simulations, we have used a proprietary C++ dynamic system-level simulation tool that was used in the framework of the WINNER+ project for 4G evaluation [17], and more recently in the METIS and METIS-II projects for the evaluation of the 5G system [18].

A. SYSTEM MODEL

1) ENVIRONMENT

We consider the Manhattan-like scenario of the 3GPP urban use case in [19] which is represented in Figure 13. In this scenario, there are four lanes in each street, two per direction, with a lane width of 3.5 m and the sidewalks width is 3 m, which leads to a street width of 20 m. The blocks of buildings have a length of 413 m and a width of 230 m. Therefore, the environment results from the repetition of a road grid of 250 m×433 m. Note that the figure is not realistically scaled, hence the streets and sidewalks appear to be bigger than they are in reality for the sake of a better visualization of the streets configuration.

2) NETWORK DEPLOYMENT

We consider macro BSs deployed with an inter-site distance of 500 m as shown in Figure 13. This deployment follows the wrap around model in [19] where the site is located 500/3 m from the left of a road grid and 433/3 m from the bottom. Each site has three sectors with azimuths equal to 0°, 120° and 240°. The height of the antenna is 25 m as specified in [19] and the antenna tilt is 102°.

TABLE 2. Radio-frequency parameters.

Parameter	Value
Carrier frequency	BS-to-vehicle: 4 GHz V2V: 6 GHz
System bandwidth	Downlink+uplink: 20 MHz Sidelink: 10 MHz
BS Tx power	39 dBm
UE Tx power	23 dBm
BS receiver NF	5 dB
UE receiver NF	9 dB
BS antenna height	25 m
UE antenna height	1.6 m
BS antenna gain	17 dB
BS cable loss	0.5 dB
UE number of antennas	Tx:1, Rx:2
UE cable loss	0.4 dB
UE implementation loss	5 dB

Table 2 presents the main radio-frequency parameters considered in this assessment.

Concerning the antenna modeling, for UEs we consider omnidirectional antennas with fixed gain, and for the BSs the model in [19].

3) TRAFFIC

We use a single type of traffic which emulates a periodic transmission of Cooperative Awareness Messages (CAMs), similar to the periodic traffic model 1 in [19]. In our simulations, we consider an inter-packet arrival time of 100 ms, packet size fixed and equal to 300 bytes (similar to the low load configuration in [19]), and a latency requirement for the End-to-End (E2E) delay of 100 ms.

The CAM messages are relevant to all the vehicles within a relevance distance or coverage range of the originator. In this assessment, the considered relevance distance is 150 m as in [20]. Note that the relevance distance is not determined in [19].

4) MOBILITY

We consider the UE dropping option A for urban grid scenarios in [19]. In this option, we use a single type of vehicle (vehicle type 2 in [19]) whose main characteristics are: length of 5 m, width of 2 m, height of 1.6 m and antenna height of 1.6 m. Also in this option, the speed is 60 km/h in all lanes. A vehicle changes its direction at the intersection as follows: it goes straight with probability 0.5, turns left with probability 0.25, and turns right with probability 0.25.

In our simulations we set a fixed amount of vehicles in the scenario. Specifically, we use 64 vehicles per road grid.

5) CHANNEL

Both the vehicle-to-vehicle and vehicle-to-BS channels are modeled in the simulations. For the vehicle-to-vehicle sidelink channel model, we follow the model included in [19] with some simplifications (for example, as vehicle blockage losses, we consider a fixed loss of 5 dB instead of a random model with that mean) and without fast fading modeling.

For the vehicle-to-BS channel modeling, the path-loss comes from the equation $128.1 + 37.6 \log(R)$ with R in kilometres, and the shadowing follows a log-normal distribution with 8 dB standard deviation and 50 m decorrelation distance. The fast fading model is a tapped delay line model according to the Extended Vehicular A power delay profile in [21].

6) RADIO ACCESS TECHNOLOGY CONSIDERATIONS

For the sidelink interface, the pool of Resouce Blocks (RBs) is divided into five subchannels, where each subchannel requires 2 control RBs. We assume that each CAM message is completely transmitted in one subchannel and in one subframe. In addition, we assume full-duplex reception. Our V2X sidelink resource manager provides a semi-persistent allocation of resources, in which one subchannel is allocated with certain periodicity. A network-controlled resource allocation is performed, in which the position of all the vehicles is assumed to be known by a central controller that maximizes the distance among the vehicles that use the same resources. The resource allocation decision is renewed when the position of the vehicles changes 200 m, which is a trade-off between accuracy in position tracking and minimization of changes. We assume that the resource manager is not aware of the exact timing of message generation and, hence, it does not aim at providing minimum latency but to maximize the capacity of the system given a maximum latency. This could be achieved using a periodicity equal to the maximum delay minus the minimum transmission delay.

Concerning the link between the BSs and the UEs, we use unicast and a single-antenna transmission with maximum ratio combining at the receiver due to its robustness for vehicular communications. In fact, we did not obtain better performance with other unicast transmission modes in this scenario. The scheduler prioritizes those users with best channel quality in each subframe to reduce the transmission latency.

B. EXEMPLARY PATH MANAGEMENT PROCESS

1) INPUTS TO PMF

As a particular case of the possible inputs to the PMF described in Section IV, we consider the following in this example:

- The RAN is sending to the PMF a map with the spatial distribution of the average packet reception ratio for the CAMs transmitted by the users with PC5 interface, an average packet reception ratio versus distance performance curve for sidelink transmission, and an indication of the coverage range considered for the packet reception ratio calculation (150 m, in this case).
- The SMF is sending to the PMF an indication of the minimum desired packet reception ratio (90% in our example).
- The AMF is sending to the PMF the UE position with high frequency so as to have a good tracking accuracy.

The average packet reception ratio for a number of packets N can be calculated as $\sum_n^N X_n / \sum_n^N Y_n$, where Y_n is the number of UEs located in the range (a, b) from the transmitter of packet n, and X_n is the number of UEs with successful reception among Y_n. This metric measures, therefore, the portion of intended receivers of a message that receive the message successfully. Note that, as inputs to the PMF we consider two kinds of packet reception ratio statistics. First, the spatial distribution of the average packet reception ratio for a range (0,150), i.e., for each location we obtain an average of the packet reception ratio of the packets generated in the vicinity and with 150 m of coverage range. Second, we provide to the PMF the packet reception ratio versus distance curve in which we obtain the packet reception ratio for all the packets in the scenario and a set of ranges between $a = i \times 5$ meters and $b = (i + 1) \times 5$ meters with $i \in \{0, 39\}$.

2) PMF PATH MANAGEMENT DECISION

With the inputs sent by the RAN to the PMF, the PMF is able to detect specific regions where the sidelink transmission is not sufficient to fulfill the minimum packet reception ratio criterion identified by the SMF. Figure 14 presents the central road grid of the simulation realistically scaled. The streets are colored according to the average packet reception ratio experienced by the users on them. Those regions with insufficient QoS are rounded with ellipses. Specifically, we can see regions with poor QoS in horizontal streets, where the packet reception ratio is around 85% in some locations. and also in vertical streets, where the minimum packet reception ratio is slightly below 90%.

One possible approach to be followed by the PMF could be to recommend all the users in all locations to use PC5 and Uu with, e.g., packet duplication of all transmitted CAMs. That is, to say, to transmit each packet via the two interfaces to increase the reliability of the communication. Given that the CAM has to reach multiple users, this means that for each CAM generated, there would be one sidelink transmission and one UL transmission followed by as many DL transmissions as users within 150 m from the message originator.

In an alternative approach, which is an example of our proposal with regional-based path management, for the sake of reducing the DL load and increasing the reliability of DL transmissions, only the UEs in poor areas would use the Uu interface to transmit their CAM messages. In addition, only the potential receivers of such messages which were also in other poor areas would be the targets of DL transmissions.

3) UE ACQUISITION OF PATH MANAGEMENT DECISIONS

In our exemplary case, the PMF sends only per-region path management decisions to the V2XCF. It does not send neither per-UE path management decisions to the V2XCF nor per-UE path management decisions to the UEs, as allowed in Figure 6.

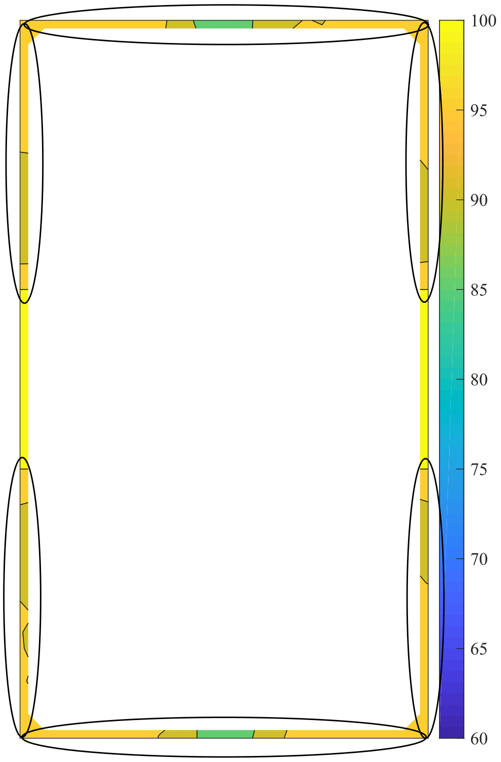


FIGURE 14. **Spatial distribution of the packet reception ratio and insufficient QoS zones identified by the PMF in the central road grid.**

The decision sent to the V2XCF is embedded in a message with a MO where the bad regions are clearly identified and the path recommendation for them is set: duplication of packets. Additionally, it is specified that for locations out of that identified regions (i.e., non-bad region case) the path recommendation is the transmission over only sidelink.

It is the V2XCF who, after receiving updates of the UE positions, sends per-UE path management decisions to the UEs whenever they enter or leave a region with a specific path management decision. Specifically, the per-region management decision stored and corresponding to the region where the UE is entering is sent to that UE.

C. PERFORMANCE EVALUATION

Focusing on the aforementioned spatial distribution of the average packet reception ratio for a range (0,150), results obtained through simulations in the scenario under study reveal that the minimum packet reception ratio for the dual-path transmission with global PC5 and Uu usage does not improve compared to the single-path usage with only PC5. Specifically, if we apply a sampling of the spatial distribution with a step of 10 m, the minimum value is around 85%, i.e., lower than the 90% requirement. On the contrary, the dual-path transmission with regional PC5 and Uu usage provides a minimum packet reception ratio slightly higher than the 90%.

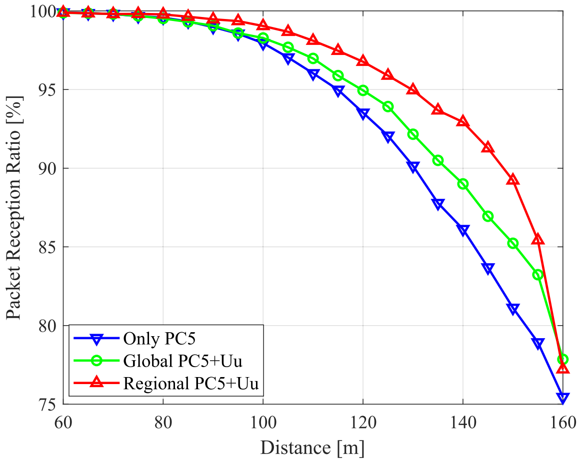


FIGURE 15. **Packet reception ratio vs distance.**

Figure 15 presents, as a complementary metric, the packet reception ratio at different distances for the following schemes: only PC5 transmission, duplication of packets using PC5 and Uu in all the locations (Global PC5+Uu), and duplication of packets only in the regions with insufficient QoS via PC5 and Uu (Regional PC5+Uu). It can be seen that the average packet reception ratio improves with the duplication of packets in all the locations, but the enhancement is even higher with the regional-based approach, thanks to the more intelligent usage of the available paths.

VII. CONCLUSION

In this work, we considered a possible solution to increase the reliability of eV2X communications through a path management approach, where the radio path for the eV2X messages can be dynamically selected or combined depending on different inputs, such as the location of the users or the network state. The proposal is first illustrated through the description of three general path-usage options, a regional-based decision making approach and several practical use cases such as the out-of-coverage situation in tunnels or the falling down of base stations.

We have detailed a proposal of new procedure for the path management compatible with the current 3GPP 5G system description. This procedure involves a new network function, the PMF, in charge of making path management decisions based on inputs received from the NG-RAN and other network functions and interacting with the UEs to configure them through the V2XCF.

Together with the new procedure and network function, we have proposed how to implement these novel elements over the existing 3GPP 5G system architecture taking into account the four 5G eV2X architectural options defined by the 3GPP. For each alternative, the necessary signaling exchange among the functions involved is also developed.

Finally, we have presented an exemplary use case, the distribution of CAM messages in an urban scenario with PC5 and Uu interfaces, which illustrates the feasibility of our proposed functional architectures. For this use case, we show what would be the specific inputs to the PMF and how the PMF would make regional-based decisions. System level simulation results have demonstrated the benefit achieved in terms of the CAM distribution reliability with our path management approach. Specifically, the duplication of messages in all the locations of the simulated scenario is not able to fulfill the reliability requirement set in our use case (90% packet reception ratio) whereas a duplication of messages only in some regions with insufficient QoS, following the proposed regional-based path management, enhances the communication to fulfill the reliability requirement.

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