Heterogeneous Vehicular Communications – Multi-Standard Solutions to Enable Interoperability

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***Abstract* — Vehicular communication is considered to be a key enabler for future automated driving applications, which is considered one of the most promising vertical sectors for mobile networks. The 5.9 GHz frequency band has been allocated for safety and non-safety critical services in various regions of the world. Two radio access technologies have being defined and are currently competing for market adoption: IEEE Wireless Access in Vehicular Environments (WAVE) / Dedicated Short-Range Communications (DSRC) based on the IEEE 802.11p and 3GPP LTE Cellular Vehicle-to-Everything (C-V2X). Standard bodies have independently specified these technologies, which rely on different channel access schemes. Consequently, three major challenges arise when the two technologies are supposed to access the spectrum in the 5.9 GHz band: Coexistence, Interoperability and Backwards Compatibility. Moreover, multi-operator interoperability is another key issue for a wide market acceptance. In this paper, we propose an innovative way to use Multi-access Edge Computing (MEC) infrastructure, preferably co-located with Coud-RAN, to enable interoperability between distinct vehicular communication systems operating in the same band at the same location. Moreover, we also show how MEC enables vehicles from multiple OEMs to communicate via multiple Mobile Network Operators (MNOs) and Intelligent Transport Systems (ITS) service providers.**

Keywords* — *3GPP LTE Cellular V2X, DSRC, MEC, Wireless Access in Vehicular Environments, Interoperability

I. Introduction

Future generations of vehicles will have support to Vehicle-to-everything (V2X) technology, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Vehicle (I2V) communications. The automotive ecosystem will experience a progressive revolution in the next twenty years, starting from driver assistance functions (Society of Automotive Engineers - SAE autonomous driving level 1) to a full-fledged autonomous driving experience (level 5) [1]. Further evolutions of corresponding ITS and related V2X connectivity will enable real-time collection of sensor data, providing predictive information to the cruise control and autonomous driving entities of the respective vehicles. This will support an improved traffic flow, e.g. reducing the risk of accidents and fuel improving efficiency.

The corresponding technology heavily depends on direct communication links (side-link) as well as communication with network and infrastructure, in particular MEC nodes, which offer specific advantages to the vehicular ecosystem [2][3]. In fact, MEC technology (introduced by ETSI) provides IT cloud capability at the edge of the network, and due to its access-agnostic nature, guarantees a smoother deployment independently on the underlying radio access network (e.g. LTE or 5G, or other non-3GPP radio access). The role of MEC is thus essential to provide fast access to information and a localized pre-processing of data, and the possibility to host ITS applications in close proximity to the devices. In addition, the MEC system is also able to expose a set of standardized interfaces to applications (through RESTful APIs), which permit developers, car OEMs and their suppliers to implement ITS services in an interoperable way, across different access networks, MNOs and vendors. Fig. 1 shows an example of heterogeneous V2X system using MEC, where cars communicate with RSUs (Road Side Units) and base stations, and MEC hosts can be co-located with these radiating elements (and/or with C-RAN aggregation points). In addition, ITS applications exploit the distributed computing environment, including terminals, edge cloud and also private/remote clouds.

While the advantages for the concerned vehicles are obvious, the actual deployment of the system and its evolution over time is challenging. Currently, mainly two competing standards exist in the field for the side-link communication: WAVE/DSRC based on the IEEE 802.11p standard and the LTE-based 3GPP feature LTE C-V2X. Thus, the presence of vehicles supporting just one of the two standards will introduce interoperability issues, or at least will need to consider how to enable C-ITS services across the two standards. Otherwise, the exchange of safety critical information may not be possible, impacting the overall safety of the passengers. A heterogeneous vehicular network and the related interoperability issue are depicted in Fig. 2.

Industry associations, such as the 5GAA (5G Automotive Association), and regulatory bodies in US and Europe are currently working together, to ensure that both systems, DSRC and LTE C-V2X, may have access to the 5.9 GHz band, which is allocated to safety- and non-safety applications. For this purpose, suitable interoperability and coexistence solutions are being defined as for example outlined in [10].

Moreover, even by considering only cellular networks, ITS services are characterized by the presence of multiple stakeholders, so the interoperability among them is a critical issue in many V2X use cases, especially when ITS operators need to provide V2X services in all possible scenarios.

In particular, from a network perspective, multi-operator interoperability should be taken into account, since from the ITS operator perspective it is essential to be able to provide ITS services in a cross-country, cross-network and cross-OEM environment.

In summary, due to the heterogeneous nature of this V2X service scenario, we need to deal with the following challenges:

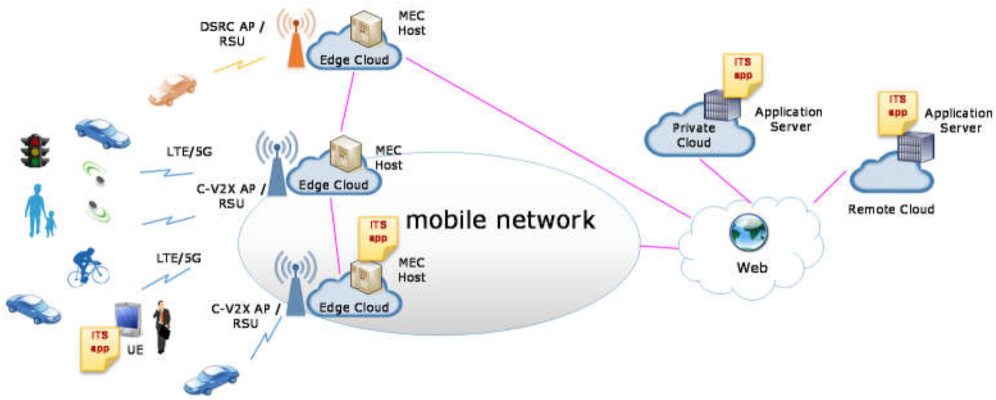

Fig. 1. Example of heterogeneous V2X system with MEC (Multi-access Edge Computing)

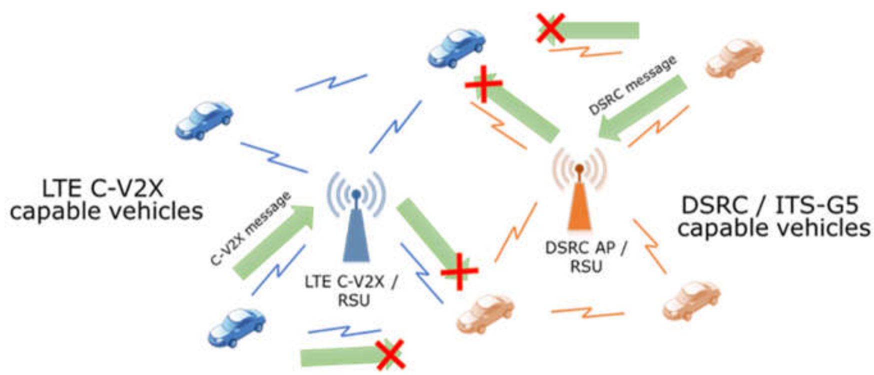

Fig. 2. Heterogeneous vehicular communication, and related interoperability issues among different technologies

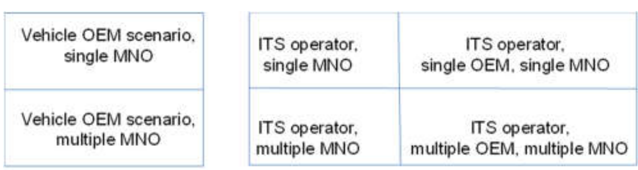

Fig. 3. Different categorization of V2X service scenarios

- **Coexistence**: How to share available ITS channels between DSRC and LTE C-V2X systems?
- **Multi-access interoperability** (i.e. between different access technologies): How to enable vehicles equipped with distinct technologies (DSRC or LTE C-V2X) to communicate with each other?
- **Multi-operator interoperability** (i.e. between different mobile operators): Even within the same access technology, how to enable the provisioning of ITS services across different network operators and different countries?
- **Backwards compatibility**: How to enable the continued usage of earlier generation technology in the presence of later generation? This last requirement is in particular relevant for 3GPP, which is working on an evolution from 3GPP LTE C-V2X Rel. 14 to Rel. 15 and 5G NR.

In this paper we propose, innovative way to use MEC infrastructure to enable interoperability between distinct vehicular communication systems operating in the same band at the same location. Moreover, we also show how MEC enable vehicles from multiple OEMs to communicate via multiple MNOs and ITS service operators.

II. Main Challenges in a Heterogeneous ITS Environment

As discussed above, the key challenges are expected to relate to coexistence, interoperability and backwards compatibility. Let us look at those items further detail below:

A. Coexistence

Some of the ITS wireless communications technologies standards have been developed independently of each other. This is in particular the case for 3GPP LTE C-V2X and DSRC technologies, following very different basic principles:

- DSRC builds on the IEEE 802.11p standard, including (non-centralized) contention based access to the spectrum resource, low-cost deployment independent of any existing (cellular) infrastructure. IEEE has been working on the basic underlying technology for about 10 years; in combination with other IEEE and SAE standards, an entire system framework is available, as illustrated in the left side of Figure 4, across all protocol stack [4]. In Europe, an equivalent system has been defined by ETSI under the name ITS-G5, but that employs the same specification as the IEEE variant for the radio access layers. In the sequel of the paper, we will only use the term DSRC.

- While the DSRC standard has already been tested in several trials, especially in North America and Europe, in September 2016, 3GPP issued the first version of its LTE C-V2X standard in Rel. 14 and is currently working on its evolution in Rel. 15. 3GPP is also currently laying the ground for further evolutions of C-V2X using the 5G NR technology in Rel. 16 and 17. 3GPP-RAN builds on the cellular protocol architecture [5] depicted in the right side of Fig. 4 and focuses on the definition of the lower radio access layers.

Thus, no provisions were made to address co-existence of the two V2X standards. When configuring two such independent system to operate in the same frequency band, at the same location and at the same time, it is likely that transmissions will overlap and interfere with each other. The result is a partial or total loss of the information in the receiver and automotive safety is compromised.

In practice, it is expected that some level of orthogonality in space, time, frequency and/or code domain needs to be introduced in order to separate such distinct systems. Table 1 below summarizes those options and outlines related decision making strategies.

For example, the 5GAA has proposed for the short term a so-called safe-harbor approach [6], where the industry may agree to configure one system to use one 10 MHz channel and another system to use a different 10 MHz channel in the 5.9 GHz band. Other channels are foreseen to be shared between technologies, based on enhanced sharing mechanisms.

3GPP RAN1 has also suggested that the different technologies should use different frequency channels [7] if deployed in the same geographical area. They also noted that a co-deployment is not likely to happen in all regions. Some standardization and/or regulators actions need to be taken in other bodies to enable the coexistence. Moreover, 3GPP RAN1 has identified the following solutions for coexistence:

- Geolocation and database;
- Time sharing between systems based on GNSS timing;
- Sensing-based vacate/switching approaches with or without transmission of a predetermined signal(s).

It is worth noting that time sharing between systems based on GNSS timing and sensing with a predetermined signal(s) would require some modifications to DSRC.

B. *Multi-access interoperability (between different access technologies)*

As stated above, standards for ITS technologies have been developed independently of each other and no effort has been made to enable an inter-system information exchange. For example, a 3GPP LTE C-V2X module will not be able to process a DSRC signal and vice-versa. In practice, it is expected that either this lack of interoperability is tolerated or additional provisions need to be introduced in order to overcome this limitation. Also based on the correspondence of higher layer protocols between WAVE/DSRC and LTE C-V2X systems (as depicted in Fig. 4), we will provide detailed solutions for the interoperability in the course of this paper, which includes part of our contribution to the ETSI ITS WI DTR/ITS-00276-2 [8] that studies different interoperability solutions. We will also provide a multi-OEM, multi-ITS operator and multi MNO, MEC-based solution for the interoperability in a wider sense.

C. *Multi-operator interoperability (between different mobile operators)*

Beyond interoperability issues between various distinct communication standards, another interoperability challenge arises for cellular ITS services as they are offered by LTE C-V2X. As anticipated, the presence of multiple stakeholders and the interoperability among them is a critical issue, and from a network perspective, multi-operator interoperability should be taken into account in order to provide ITS services in a cross-country, cross-network and cross-OEM environment. In fact, a specific service may be provided in a certain region to multiple vehicles from different OEMs. Those different vehicles may be attached to networks of different MNOs, but still the same service should be available to all the vehicles in the concerned area. Since these issues are limited to cellular services only, well known handover mechanisms may be suitably modified and employed for ensuring service continuity.

D. *Backwards Compatibility*

With the ITS wireless communications technologies evolving, e.g. 3GPP LTE C-V2X Rel. 14 and 15 transitioning to 5G NR V2X and beyond, it is essential to ensure that new technology generations are able to process signal transmissions of previous generations for safety applications; also, it is mandatory that a latest generation module is able to interact with its counterpart of an early generation.

In contrast to current mobile networks, the vehicles communicate directly with each other and there is not always central signaling capability. Basically, the data is transmitted in broadcast mode without ensuring that other vehicles can understand the standard used for transmission. Moreover, due to the low-latency requirements, in typical safety use cases no feedback channel exists, i.e. no handshaking or acknowledgment is possible. All this combined with the long lifetime of a motor vehicle leads to additional aspects necessary to be considered during the system design.

In practice, it is expected that this requirement leads to the following system design approach: Earlier generation features are maintained by later generation components; the latter, however, may provide innovative and additional services and features which are only available to recent component designs. A typical example relates to the introduction of 5G NR technology for ITS.

I. SOLUTIONS FOR INTEROPERABILITY

Interoperability needs to be addressed at different levels: different OEMs may employ different radio access technologies for the side-link and also be provided the same service via different MNOs for up- and downlink.

TABLE 1: ORTHOGONALITY SOLUTIONS AND RELATED DECISION MAKING.

	Orthogonality in Time Domain	**Orthogonality in Frequency Domain**	**Orthogonality in Space Domain**	**Orthogonality in Code Domain**
A-Priori Agreement	An A-Priori Agreement is defining how distinct technologies (including ITS-G5 and LTE C-V2X) are being configured in order to achieve orthogonality over Time, Frequency, Space and/or Code domains. Such an a-priori agreement may or may not evolve over time.			
Infrastructure based decision making	Infrastructure equipment, including Road-Side-Units (RSUs) and Cellular Infrastructure, may provide control messages indicating which orthogonality solution needs to be applied by which system for a given time, frequency (channel) and geographic location.			
Client based decision making	Client devices may detect the presence of other communication systems applying the same or different communication technologies. The client devices will take appropriate decisions in order to ensure coexistence to systems applying different communication technologies.			

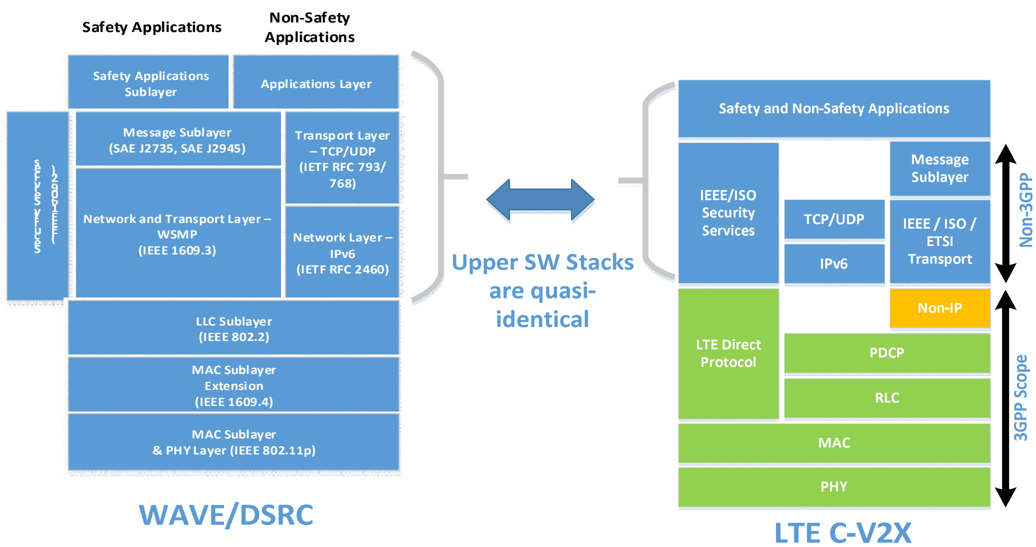

Fig. 4. Correspondence of higher layer protocols, between WAVE/DSRC and LTE C-V2X systems.

A. Solutions for multi-access interoperability

As anticipated, multi-access interoperability is a critical issue in order to enable vehicles equipped with an older communication technology, e.g. DSRC, to communicate with vehicles equipped with a newer communication technology, e.g. LTE C-V2X, and vice-versa. This feature is essential in particular for critical safety applications. A lack of interoperability may indeed lead to life threatening situations on the roads.

In order to identify a suitable solution, we observe that the higher layers protocol stack of DSRC and LTE C-V2X on top of the radio access layers are quasi-identical as illustrated in Fig. 4. It is therefore straightforward to convert a DSRC packet into a LTE C-V2X packet and vice versa (Fig. 5). We propose that an infrastructure node, for example, a mobile or fixed MEC equipped node, such as a Road Side Unit (RSU) for example, is equipped with dual-technology capabilities, i.e. supporting the lower layers of both DSRC and LTE C-V2X and, more importantly C-RAN capabilities. In fact, multiple radiating elements can be coordinated in a C-RAN architecture, and the co-location of a MEC host can be particularly suitable, not only in terms of cost-efficiency and low latency, but also exploitation of local radio processing and management of different cells for a better management of both radio and MEC mobility.

This MEC node (possibly also co-located with C-RAN aggregation point) will thus be able to perform transcoding from one technology to another and vice versa (a reference scenario is depicted in Fig. 5). This is easily achieved by connecting the radio access stack of the receiver from one technology to the one of the transmitter of the other technology, as illustrated below for transcoding from DSRC to LTE C-V2X; the same procedure can be applied for the inverse direction, i.e. transcoding from LTE C-V2X to DSRC. It is worth noting that not all higher layer protocols necessarily need to be implemented in the transcoding node, reducing hardware complexity and further delays to deliver the messages to the final destination.

The final practical set-up is illustrated in Fig. 5. Vehicles will interact with C-RAN enabled MEC nodes / RSUs which offer the transcoding feature. DSRC equipped vehicles will thus receive directly the DSRC signals transmitted by other cars. The signals transmitted by vehicles which are equipped with LTE C-V2X will first be received by RSUs which will apply transcoding and issue a DSRC signal with the same payload. The transcoding itself may occur within the local nodes or in a (remote) cloud center. This transcoded signal will then be received and processed by vehicles with DSRC capabilities. A corresponding approach is applicable for enabling LTE C-V2X equipped vehicles to access to DSRC transmissions. In this way, all vehicles are able to interoperate regardless of the available communication technology.

We should note one important drawback of the transcoding procedure based on an infrastructure node: it reduces the spectral efficiency, since the same message will need to use radio resources twice. But this is a reasonable price to be paid to achieve safety and save lives.

B. Solutions for multi-operator interoperability

Multi-operator interoperability is a critical issue for V2X use cases, especially when ITS operators need to provide V2X services in all possible scenarios. Here the presence of MEC can be relevant to achieve this goal.

In order to better understand these issues, and how these aspects are related to MEC, the figure below is providing a couple of examples of MEC deployment. In particular:

- Fig. 6(a) shows in red the data path considering the interconnection between MNOs terminated at the remote side, and causing high end-to-end (E2E) latency. In green, instead, a direct interconnection between MNOs could be envisaged in order to reduce significantly the E2E latency. This means that a standardized “interface” (API) is needed between vehicle and application in edge cloud, and also between vehicles belonging to different OEMs. This will require a proper normative work in ETSI MEC standardization, e.g. in the framework of the MEC-030 work item on “MEC V2X API” [9]
- Fig. 6(b) is related to a case where the car is temporarily out of coverage of two operators, and there is the need to provide V2X service continuity across all the territory including both areas (i.e. also moving from Op. 1 to Op. 2), without service disruption and by ensuring E2E connection. MEC can be a solution to host side-link configuration and manage multi-operator environment, especially when the vehicle is out of coverage. So, a standardized “interface” (API) is needed in order to correctly manage side-link configuration parameters, when the vehicle is out of coverage. Also this case will require a proper normative work in ETSI MEC standard (e.g. in current MEC-030 work item, but potentially also with impacts on enhancements of the reference MEC architecture, including MP3 and/or other reference points between MEC platforms, possibly belonging to different MEC systems).

II. Regulatory and Standardization Impact

In Europe the current regulation for the 5.9 GHz ITS band follows the principle of technology neutrality. However, to guarantee that multiple technologies can coexist in the ITS band, the European Commission mandated the European Regulations Administrations (through CEPT ECC) [10] together with ETSI to perform a coexistence study and propose solutions to enable coexistence. This study is ongoing and concerns both road-ITS and rail-ITS (i.e., ITS systems for railway communications) technologies. Nevertheless, a delegated act will be issued in the second half of 2018 by the European Commission mandating services, functionalities and standards for road-ITS. In the US, a similar discussion is ongoing with the objective to enable DSRC as well as LTE C-V2X to access the 5.9 GHz band. 5GAA, SAE and other organizations are working on establishing the grounds and developing studies and standards to change this regulation and allow C-V2X to also operate in the ITS spectrum.

The ETSI ITS Standards Committee is currently performing studies on coexistence and interoperability to provide a number of solutions, including those that will be submitted to CEPT ECC and later to the European Commission. Later those solutions will be incorporated in the specifications. Moreover, a number of specifications are being prepared to make the higher layer protocol stacks to be compatible with the LTE-V2X radio access layer.

Moreover, one of the solutions is expected to relate to MEC based transcoding as discussed above, as MEC nodes will ensure interoperability across distinct communication systems. This work can be carried out in ETSI MEC e.g. in the work item MEC-030 on “MEC V2X API”, based on technical requirements contained in the study on “MEC support for V2X use cases” [3], and on the most important requirements coming from automotive stakeholders. In that sense, a collaboration between ETSI MEC and 5GAA can be envisaged, as automotive stakeholders are requesting standardized interfaces, in order to overcome interoperability issues. From this perspective, ETSI MEC (as leading SDO in the space of edge computing) can play a major key role, as it can provide the needed technological solutions.

III. Conclusion

We have discussed three key challenges for a heterogeneous ITS framework: coexistence, interoperability and backwards compatibility. A specific solution is proposed for the interoperability challenge employing MEC node (such as RSU) based transcoding exploiting the identical design of upper layers in DSRC and LTE C-V2X systems. As a result, an efficient coexistence of both technologies can be achieved guaranteeing a maximum level of safety for any vehicles and its passengers irrespective of the available technology. A further urgency for such solutions is observed, because related rules are introduced on a regulatory level [9].

Moreover, we have shown how vehicles can communicate via side-link in an effective way in and out-of-coverage in a multi OEM, multi ITS and multi-MNO environment by employing MEC technology.

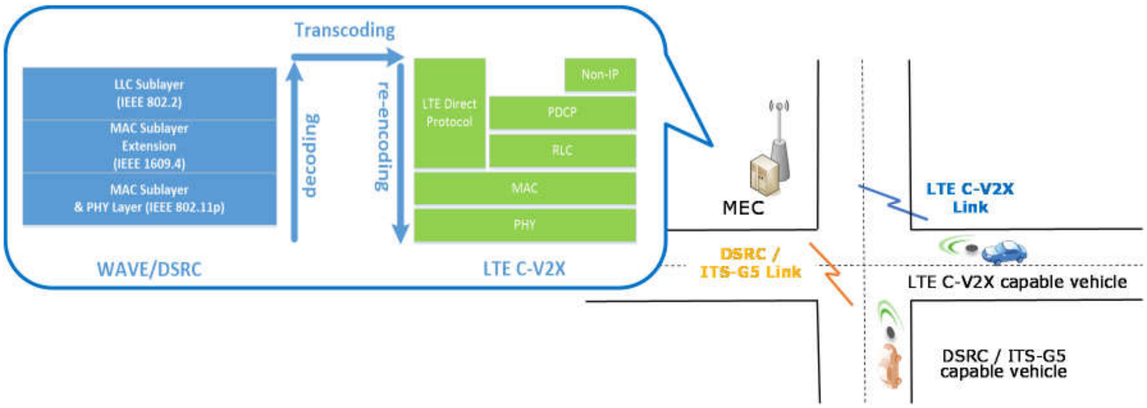

Fig. 5. MEC node providing translation services to convert DSRC / ITS-G5 to LTE C-V2X and vice-versa
(Note: in general, the actual transcoding process may occur within the local node itself or within a (remote) cloud center).

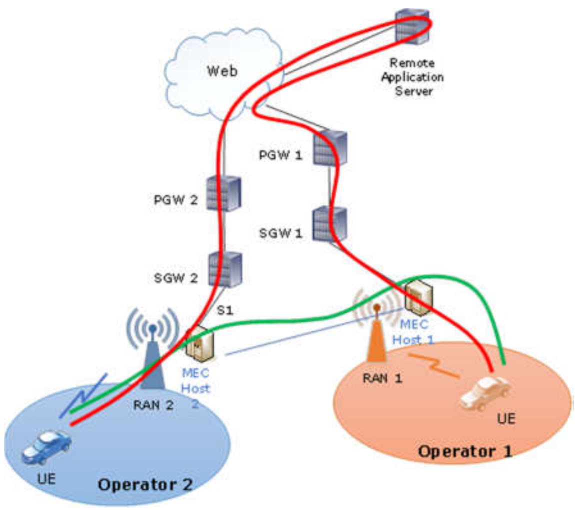

Fig. 6(a) Example of MEC deployment for V2X in multi-operator environments

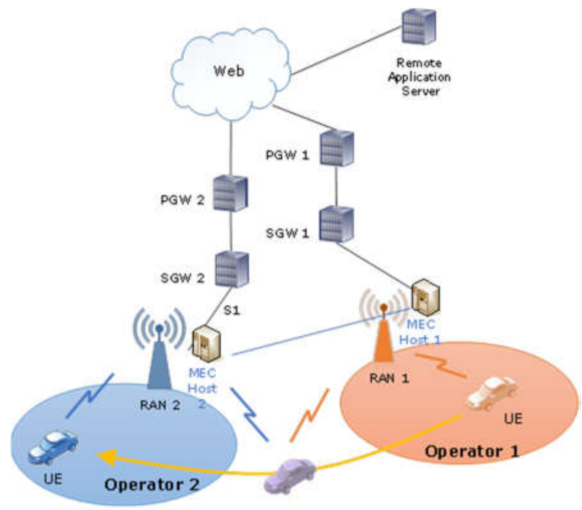

Fig. 6(b) V2X service continuity in multi-operator environments

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