Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band	)	ET Docket No. 13–49
	)	
Public Notice Seeking to Update and Refresh the Record	)	

To: The Commission

COMMENTS OF ERICSSON

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July 7, 2016

Executive Summary

Ericsson urges the Commission to implement a policy of technological neutrality that would allow for multiple approaches to unlicensed operation in the U-NII-4 band. Opening this spectrum to a variety of uses and technologies will allow DSRC licensees, as well as others, to employ this spectrum similarly to other unlicensed applications, thus expanding the opportunities for the ITS industry as well as providing room for new entrants. There is no need to distinguish non-safety ITS applications from other unlicensed operation. Other forms of unlicensed operation should be allowed to share spectrum with non-safety ITS, just as there should be technology neutrality with respect to the specific wireless technologies employed for that purpose. A technologically neutral policy approach for non-safety ITS, and allowing other systems than ITS in the non-safety ITS spectrum, will both create opportunities for new and innovative unlicensed applications and stimulate the introduction and spread of ITS technology. Such an approach can help best meet the coverage and performance and flexibility goals of non-safety ITS and provide opportunities for other types of systems.

The 3GPP has been undertaking a standardization process for LTE targeting V2X use cases since 2014 and the specification is expected to be frozen in early 2017. 3GPP has identified use cases for LTE-based ITS that include safety-related applications based on cooperative awareness, as well as safety- and commercial-related cloud-based services, as part of the Internet of Things ("IoT") ecosystem. As demonstrated in an attached Ericsson whitepaper, LTE-ITS has considerable promise in this area. Ericsson proposes that the Commission should establish a policy of technological neutrality that also permits the introduction of LTE-based ITS with a focus to facilitate harmonization with other nations, future proof capabilities, and encourage economies of scale.

ITS is expected to be one of the key services supported by 5G technology with some service requirements that can likely not be fulfilled with currently available technology. The ongoing development of 5G offers further options for radio technologies, where the core network improvements allow greater programmability for networks. Therefore, future safety and non-safety ITS networks can be designed for a richer array of services that take advantage of the ability to provision computational and storage resources closer to road traffic, thus reducing network latency to the order of a millisecond.

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Ericsson submits the following comments in response to the Commission's Public Notice seeking to update the record on potential sharing solutions between Unlicensed National Information Infrastructure ("U-NII") devices and Dedicated Short Range Communications ("DSRC") operations in the 5.850-5.925 GHz ("U-NII-4") band.[1] Ericsson urges the Commission to:

- Advance the goals identified by Congress as well as the Commission of making wider swaths of spectrum available for U-NII use through technical rule changes – including the U-NII-4 band; and

- Expand access to the U-NII band including the U-NII-4 band, on a technology-neutral basis, that encourages innovation, technological development, and investment, with access to the band open to any technology that meets the Commission's U-NII rules.

Technological neutrality will stimulate usage of non-safety Intelligent Transportation System ("ITS") spectrum and foster alternative means to meet the objectives of safety ITS.

[1] Public Notice, *The Commission Seeks to Update and Refresh the Record in the "Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band" Proceeding*, FCC 16-68 (June 1, 2016).

I. BACKGROUND

Ericsson previously filed comments in response to the NPRM[2] in this proceeding supporting the sharing of the U-NII-4 band between unlicensed devices, such as wireless backhaul equipment or mobile units, and DSRC systems, which are part of the ITS radio service, while also protecting services located in spectrum above the U-NII-4 band, specifically Fixed Satellite Service and government radar, from interference.[3] After some commenters raised concerns about potential interference to DSRC operations by unlicensed operations in this band, an IEEE "Tiger Team" was formed to examine techniques for sharing this spectrum; it submitted two potential methods: (1) "detect and avoid"; and (2) "re-channelization" that would place public safety channels at the upper end of the spectrum block.[4] Ericsson offers these comments to the Commission as it seeks to refresh the record by inviting comment on these new alternatives as well as other approaches.

II. THE COMMISSION SHOULD ADOPT RULES THAT PROMOTE TECHNOLOGICAL NEUTRALITY

While the Commission's discussion of the re-channelization and "detect and avoid" proposals largely assumes that the sharing between DSRC and unlicensed devices will be based on IEEE 802.11 protocols, the Public Notice acknowledges that "other protocols" may also be appropriate and invites comment on "other approaches that would facilitate unlicensed use of the 5.850-5.925 GHz band without causing harmful interference to DSRC operations."[5] Ericsson urges the Commission to follow an approach of technological neutrality that would allow for

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[2] *Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 13-49, *Notice of Proposed Rulemaking*, 28 FCC Rcd 1769 (2013) ("NPRM").

[3] Comments of Ericsson, ET Docket No. 13-49, at 9-12 (filed May 28, 2013) ("Ericsson Comments").

[4] Public Notice at 5-7.

[5] Public Notice at 8, 9.

multiple approaches to unlicensed operation in the U-NII-4 band without causing harmful interference to safety and non-safety-related ITS and to services above 5925 MHz. Moreover, because of the critical nature of safety-ITS, protection of the service would be facilitated with dedicated spectrum.

A technologically neutral approach here would encourage innovation, technological development, and investment. It would avoid "locking in" a given technology for the foreseeable future, allowing today's technologies to evolve over time as well as facilitating the development and introduction of alternative technologies, provided they are capable of providing the needed degree of interference protection. This would be fully consistent with the Commission's repeated invocation of technological neutrality, especially in the spectrum sharing context.[6]

A. Non-safety ITS: Technological Neutrality Will Stimulate Usage of Non-Safety ITS Spectrum and Create Multiple Use Cases for the U-NII-4 Band

Currently in the U.S., the exchange of information between vehicles and the roadside infrastructure for non-safety communication is expected to employ DSRC technology. This is inconsistent with established Commission policy in favor of technological neutrality for mobile services.

The benefits of opening non-safety ITS spectrum to shared use by a wide variety of technologies are extensive. The Commission allocated spectrum for ITS in the 5.9 GHz band in

[6] *See, e.g.*, *Commercial Operations in the 3550-3650 MHz Band*, GN Docket No. 12-354, *Order on Reconsideration and Second Report and Order*, FCC 16-55, at ¶¶ 186-87 (May 2, 2016); *Comprehensive Review of Licensing and Operating Rules for Satellite Services*, IB Docket No. 12-267, *Second Report and Order*, 30 FCC Rcd 14713, 14776 (2015); *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, GN Docket No. 14-177, *Notice of Proposed Rulemaking*, 30 FCC Rcd 11878, 11889 (2015); *Wireless Communication Services in the 2.3 GHz Band*, WT Docket No. 07-293, *Report and Order and Second Report and Order*, 25 FCC Rcd 11710, 11723 (2010).

1999.[7] The IEEE 802.11p project was not formed until 2004 with an approved amendment published in 2010. For many years, DSRC spectrum was reserved for ITS use, but there has been little use—safety-related or non-safety-related—to date. In the same period from 1999-2016, the mobile industry has continued to evolve 2G GSM/EDGE, and developed two generations of mobile broadband systems, namely 3G based on Universal Mobile Telecommunications Service ("UMTS"), and 4G based on Long Term Evolution ("LTE"). All of these systems are still in service and it is expected that LTE will continue to evolve well into the next two decades and will in turn be a strong complement to 5G. The Commercial Mobile Radio Service ("CMRS") has brought high speed mobile broadband into common use throughout America in these years, and continues to meet the needs of increasing traffic demand with improved systems. The mobile industry also has the wherewithal to handle the needs of ITS, while at the same time ensuring that the spectrum available for expansion of mobile services continues to increase.

Opening this spectrum to a variety of uses and technologies will allow DSRC licensees, as well as others, to employ this spectrum similarly and thus expand the opportunities for the ITS industry as well as provide room for new entrants. It has promise for use in machine-to-machine communications, such as supervisory control and data acquisition ("SCADA"), and can benefit from broadband access.

There is no need to distinguish non-safety ITS applications from other unlicensed services. Other forms of unlicensed use should be allowed to share spectrum with non-safety ITS, just as there should be technology neutrality with respect to the specific wireless technologies employed for that purpose. A hybrid approach utilizing different access technologies could be also considered for non-safety ITS or as a substitute depending on the

[7] *See Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz Band (5.9 GHz Band)*, Report and Order, FCC 03-324.

nature of the underlying communication needs. Ericsson expects that Day One applications for non-safety ITS will be less complex use cases like traffic warnings and alerts. These traffic notification services and use cases can be facilitated readily because any cellular smartphone or similar device that is properly enabled can receive these traffic warnings, even as car manufacturers avail themselves of a globally accessible source for radio technologies. The primary benefit of such a hybrid approach is early deployment and the benefit to vehicle to infrastructure ("V2I") is fast, reliable, wide area coverage that can be facilitated by using current network infrastructure that is already largely deployed nationwide and easily scalable. Traffic safety systems in the vehicle can communicate with these networks, with flexible QoS provisioning, to exchange critical and operational data.

Under a technologically neutral approach, this spectrum would be accessible on equal terms by: WiFi, Multefire,[8] or LTE-Unlicensed and License-Assisted Access ("LAA"), which allows unlicensed devices to work in conjunction with licensed LTE networks, or other spectrum access protocols such as unlicensed devices and 802.11p (DRSC) or LTE for non-safety ITS applications.

In short, a technologically neutral policy approach for non-safety ITS, and allowing systems other than ITS in the non-safety ITS spectrum, will both create opportunities for new and innovative unlicensed applications and stimulate the introduction and spread of ITS technology. Such an approach can help best meet the coverage and performance and flexibility goals of non-safety ITS and provide opportunities for other types of systems.

[8] Developments of LTE by the Multefire Alliance (MFA) can be deployed without the use of a licensed anchor carrier. In fact, the availability of spectrum for the Citizen's Broadband Radio Service ("CBRS") can greatly expand availability of spectrum for ITS applications as well, were municipalities so inclined to deploy their roadside infrastructure as part of the CBRS.

We view non-safety ITS applications as functionally equal to use of the spectrum for unlicensed use and advocate for a technology neutral specification for spectrum sharing. As an example, a Listen Before Talk ("LBT") procedure with a reasonable Energy Detection threshold can be a possible spectrum sharing method.

B. Safety-ITS: Technological Neutrality Will Facilitate Alternative Means of Meeting the Objectives of Safety ITS and Facilitate Global Harmonization

Currently there is extensive work underway in global standards bodies to develop methods for additional technologies to support ITS tasks, including not only vehicle to vehicle ("V2V") and V2I but also vehicle to pedestrian ("V2P") and vehicle to network ("V2N") connectivity.[9] For example, the Third Generation Partnership Project ("3GPP") has been undertaking a standardization process for LTE targeting these vehicular use cases since 2014 and the specification is expected to be frozen in early 2017, in the following pages and further described in the attached whitepaper by Ericsson researchers.[10] Specifically, there are several tools available in 3GPP standards to assure reliability for ITS applications, both safety and non-safety. The LTE network has a well thought-out approach to quality of service ("QoS") within the network that allows the selective prioritization of safety traffic above all others. Such capability is possible across many operator networks and can channel ITS traffic to the Department of Transportation's approved core network infrastructure for any local jurisdiction. LTE-ITS is designed for safety-ITS applications to be deployed on any spectrum suitable for mobile broadband up to 6 GHz, in scenarios that include multicarrier operation as well as

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[9] Collectively, these technologies are often written as "V2X."

[10] Ricardo Blasco, Hieu Do, Serveh Shalmashi, Stefano Sorrentino, Yunpeng Zang, *3GPP LTE Enhancements for V2V and Comparison to IEEE 802.11p*, Paper number EU-SP0264, at 1 (2016) (submitted as an Attachment to these Comments) ("whitepaper"); *see also* Stefano Sorrentino, *LTE for Intelligent Transport Systems*, https://www.ericsson.com/research-blog/lte/lte-intelligent-transport-systems/#more-3505 (June 9, 2016).

operation in dedicated or shared spectrum. This capability therefore includes operation in the 5.9 GHz band both in a dedicated allocation for safety purposes and in shared allocation for non-safety applications.

The development of V2X standards will enable not only mobile network operators, but other entities as well, to offer ITS services, using licensed cellular spectrum and existing networks where available, as well as "sidelink" transmissions between the vehicle, infrastructure, and pedestrians, for connectivity.[11] 3GPP has identified use cases for LTE-based ITS that include safety-related applications based on cooperative awareness, as well as safety- and commercial-related cloud-based services, as part of the Internet of Things ("IoT") ecosystem.[12] The 3GPP effort on 5G will improve latency, capacity, and efficiency of both the sidelink and the cellular interface. A sidelink using U-NII-4 spectrum would permit vehicles to have connectivity even in remote areas.

In the attached whitepaper, Ericsson has provided an overview of LTE sidelink and discusses its potential enhancements targeting ITS use cases.[13] To show the viability of LTE-ITS to meet the ITS requirements, we compare LTE and 802.11p by numerical simulation for different reference deployment scenarios. The whitepaper focuses on LTE sidelink and does not discuss LTE cellular except for those aspects that are relevant for the sidelink interface.

One of the important aspects considered in the attached whitepaper was with respect to receiver performance and specifically the ability of the receiver to estimate the quality of the channel accurately and compensate for impairments. The V2V radio channel is characterized by

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[11] *See* whitepaper at 2.

[12] *Id.* at 3, citing 3GPP TR 36.885 V0.4.0, Technical Specification Group Radio Access Network; Study on LTE-based V2X Services (Nov. 2015), http://www.3gpp.org/ftp/Specs/archive/36_series/36.885/36885-040.zip.

multipath reflections (due to scatterers between the transmitter and receiver) that spread the signal energy in time and induce frequency selectivity in the signal transfer function. Furthermore, the high relative speeds between transmitter, receiver, and signal scatterers introduce rapid stochastic variations of the radio channel, a physical phenomenon associated with Doppler spread. In addition, the misalignment between the reference frequency of the local oscillators at the transmitter and receiver distort the signal even further. These effects have a particular impact at high carrier frequencies such as 5.9 GHz, since the accuracy of oscillators is typically proportional to their nominal frequency. LTE-ITS receivers are designed to address these challenges and show good performance at typical vehicular speeds. This performance was achieved with a simple linear equalizer in the receiver model versus the more complex receiver architectures that rely on advanced turbo-equalization to compensate for the aforementioned channel degradation.

In this work Ericsson also describes the various enhancements being made to the 3GPP LTE standard in order to support ITS services.[14] Initial numerical evaluations of the proposed enhancements show that the enhanced LTE-Advanced sidelink interface is capable of delivering reliable performance under evaluation scenarios defined by 3GPP. The LTE gains can be attributed to both the gain from a more robust PHY layer signaling scheme and the gain attained by the more efficient resource allocation mechanisms. Especially the centralized resource allocation used in the simulation, although it makes use of information only relating to the geographical location of devices, can bring about significant improvements. A further advantage is the slotted resource allocation that enables better interference control in high-load scenarios.

[14] *Id.* at 2.

The Ericsson study suggests that with enhancements, the LTE-sidelink can satisfactorily fulfil the ITS requirements for safety.

ITS is expected to be one of the key services supported by 5G technology and demanding services requirements that can likely not be fulfilled with currently available technology are being developed by the 5G Infrastructure Public Private Partnership ("5GPPP").[15] The ongoing development of 5G offers further options for radio technologies, where personal devices can utilize expanded access to more bands and service features. The core network improvements planned for 5G allow greater programmability for networks, and future safety and non-safety ITS networks can be designed for a richer array of services that take advantage of the ability to provision computational and storage resources closer to road traffic, thus reducing network latency to the order of a millisecond. Improvements to the core network will integrate standards for Software-Defined-Networking ("SDN") and Network Function Virtualization ("NFV"), allowing rapid service provisioning and feature deployment for a variety of broadband services and industrial automation, including ITS. Advances such as these will allow the automotive industry to evolve to more intelligent platforms, including support infrastructure for autonomous vehicles, and network assisted inter-vehicular communication.

Safety-related communication on ITS systems is a critical service that must be fully protected from harmful interference. Technologically neutral rules, in harmony with the ongoing efforts of global standards bodies, can fully ensure that safety- ITS operations remain interference-free.

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[15] *5G Automotive Vision*. October 20, 2015. https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf

In the short term, the protected DSRC Safety channels would be the source of safety-ITS for V2V connectivity, but V2V connectivity will provide real safety benefits only if a significant number of vehicles in a fleet are so equipped and there is a means to ensure secure and reliable V2V communications.

LTE-based ITS has considerable promise in this area, because of widespread customer usage of LTE devices.[16] For instance, safety ITS can be integrated into consumer devices and link to on-board vehicular computers and ensure that services can evolve using an "app" model. The Commission should establish technology neutral policies that create such opportunities for complementing and competing alternatives.

Ericsson recognizes the need for rigorous requirements for robustness and latency for safety-ITS applications. The allocation of unlicensed devices even as a secondary service will increase the risk of interference, and thus we are of the view of allocating safety-ITS spectrum on an exclusive basis.

A policy of technological neutrality that also permits the introduction of LTE-based ITS would facilitate harmonization with other nations, future proof capabilities, and encourage economies of scale.

III. CONCLUSION

Accordingly, Ericsson urges the Commission to consider exclusive spectrum allocation for safety ITS and establish technology neutral policies that create such opportunities for complementing and competing alternatives. In addition, Ericsson proposes that establishing a technology neutral approach will also benefit the rest of the 5.9 GHz band. In this way,

[16] Over the long term, LTE and other technologies, including the widespread introduction of autonomous cars, may drive safety connectivity away from the dedicated DSRC channels.

alternative technologies and approaches, including LTE, can be implemented to support ITS and utilize unlicensed spectrum. Both unlicensed in the U-NII-4 band and non-safety ITS should be subject to the same regulatory rules with equal access to the spectrum.

Respectfully submitted,

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July 7, 2016

ATTACHMENT

Paper number EU-SP0264

3GPP LTE Enhancements for V2V and Comparison to IEEE 802.11p

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Abstract

In 2014, the 3rd Generation Partnership Project (3GPP) started the standardization process of LTE-Evolution/5G enhancements targeting vehicular use cases, with specification expected to be frozen in early 2017. Ongoing radio-level work focuses on latency, capacity, and efficiency enhancements for both the direct communication path between vehicles, known as sidelink, and the cellular radio interface for connecting network infrastructure to the vehicles.

In this work we analyze the limits of the current sidelink LTE interface and discuss some enhancements in order to fulfil long-term vehicle-to-vehicle (V2V) service requirements, in light of the ongoing standardization process in 3GPP. Further, we compare the enhanced LTE performance to that of IEEE 802.11p by numerical simulations, taking into consideration realistic implementation aspects. Results show significant range gains for the sidelink LTE interface compared to IEEE 802.11p in certain highway and urban scenarios.

Keywords:

LTE, 5G, DSRC

Introduction

The 3rd Generation Partnership Project (3GPP) is the organization developing and maintaining mobile communication standards such as 2G, 3G, and 4G (LTE). Currently, 3GPP is working on improving the Long Term Evolution (LTE) standard, sometimes referred to as “LTE-Evolution” or “LTE-Advanced Pro” [1], as well as on a new radio interface. The combination of LTE-Evolution and such new radio interface will define what is collectively called the fifth generation (5G).

LTE is a radio access technology comprising both a cellular interface between the network and user equipments (UEs) as well as a direct radio interface between user devices, usually referred to as *sidelink*, as opposed to uplink and downlink. The LTE sidelink interface was introduced in Release 12 to support Public Safety services as well as to enable commercial proximity-based services [2].

Some of the latest enhancements of LTE aim at more efficiently supporting a number of industrial applications as part of the Internet of Things (IoT) ecosystem. In particular, 3GPP identified the Intelligent Transportation Systems (ITS) as one important type of services to be supported. Work on both identifying requirements and specification started during 2015 [3]. It is expected that the specifications will be frozen as part of LTE Release 14 during the first half of 2017. This fast

standardization pace is justified by the ambitious time-plan for ITS deployment in China and in other countries where LTE is an important candidate for radio access. To efficiently fulfil the ITS requirements, it is expected that LTE will take advantage of both the cellular and sidelink interfaces. In addition, it will be able to operate even without network coverage so that vehicles in areas without LTE coverage can also make use of the ITS services.

As spectrum regulations are in constant evolution, LTE-based ITS is designed to be deployed on any LTE-compatible spectrum up to 6 GHz including multicarrier scenarios, spectrum sharing scenarios across Mobile Network Operators (MNOs) and dedicated spectrum, e.g., in the 5.9 GHz band. MNOs also have the chance to offer ITS services, using cellular or sidelink, over the same spectrum being used for other cellular services and with flexible QoS provisioning.

Another candidate technology for information exchange among vehicles and between vehicles and the roadside infrastructure is the IEEE 802.11p [4]. It specifies the Physical layer (PHY) and the Medium Access Control (MAC) layer for the Dedicated Short Range Communications (DSRC). DSRC uses 10 MHz channels in the 5.9 GHz frequency band and have standardized message sets, management procedures, and security infrastructures for ITS services [5][8]. The IEEE 802.11p standard targets standalone operation of devices (i.e., without any telecommunications network infrastructure) as well as short-range communications with roadside infrastructure. In addition, this standard is designed for use in unlicensed bands where all the peers have equal right to access the shared channel via a listen-before-talk protocol.

Both LTE and IEEE 802.11p are candidates for radio access technologies for V2V and vehicle-to-infrastructure V2I connectivity. While many factors will eventually determine the adoption of such technologies, radio performance should be one of the determining factors. In this paper, we provide an overview of LTE sidelink and discuss its potential enhancements targeting ITS use cases. We then compare LTE and 802.11p by numerical simulation for different reference deployment scenarios. This paper focuses on LTE sidelink and does not discuss LTE cellular except for those aspects that are relevant for the sidelink interface.

To the best of our knowledge this is one of the first work providing a comparison between LTE sidelink and IEEE 802.11p.

Analysis of potential sidelink enhancements for LTE-Evolution

ITS services involve communications between a vehicle and another node. This second node may be another vehicle, a pedestrian or vulnerable road user, a road-side unit part of the road infrastructure, or the network infrastructure with core access. Each of these endpoints defines a different connectivity scenario (see Figure 1): vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), or vehicle-to-network (V2N), respectively; collectively, they are often referred to as V2X communications. The different connectivity scenarios are typically associated with specific services and their corresponding requirements.

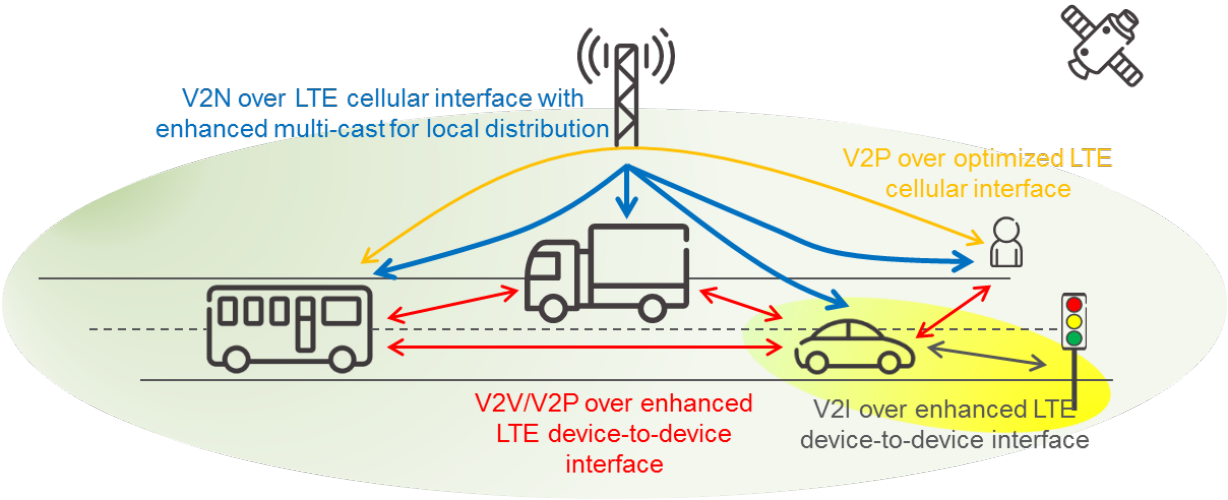

Figure 1– Summary of V2X connectivity scenarios

LTE is service-agnostic as long as the network is able to fulfil the associated service requirements. In the ITS case, a number of interesting use cases have been identified and corresponding networks requirements are being determined by 3GPP [3]. These include safety-related applications based on cooperative-awareness as well as cloud-based services for safety and commercial applications.

As discussed in the introduction, the sidelink interface was introduced in LTE Release 12 and enhanced in Release 13. However, the ITS services target specific scenarios that differ substantially from those previously envisaged for sidelink. For example, the number of ITS users is orders of magnitude beyond those of previous LTE sidelink services. Second, the users are highly mobile implying that the propagation conditions are quite unstable. At system level, this implies that the presence of a network, its topology, and the number of users will change quickly, following the distribution of the road traffic. Further, to provide global services, LTE sidelink for V2V must be operational with and without network coverage.

To meet these requirements, 3GPP has identified (among other minor enhancements) the following aspects of the LTE sidelink radio interface that need to be addressed:

- Physical Layer (L1) enhancements for high Doppler support
- Radio Resource Management for improved system efficiency
- Synchronization for high mobility with/without network coverage.

In the coming two sections we discuss the first two enhancement areas in more detail. Improvements to synchronization are not discussed in this paper due to space limitations.

Physical Layer enhancements for high Doppler support

The physical layer of LTE sidelink is similar to that of uplink cellular LTE and is based on SC-OFDM (Single Carrier OFDM). The packets are turbo-encoded and modulated (QPSK, 16QAM or 64QAM).

The transmission rate can thus be controlled by adjusting the coding rate of the turbo-encoder and by selecting the modulation order. The obtained data symbols are then spread by a DFT precoder and subsequently mapped to a subset of contiguous inputs to an IDFT (OFDM) modulator. Different carrier bandwidths are supported by adjusting the OFDM length and the sampling rate.

Sets of 14 contiguous OFDM symbols are grouped into a subframe, which is the shortest resource that can be scheduled in sidelink. The bandwidth of the subframe can be adjusted from a minimum of 180 kHz to the maximum bandwidth supported on the carrier.

After propagating through the radio channel, the signal is processed by the receiver to recover the information symbols. Coherent demodulation of the received signal is essential for decoding correctly the information. This requires accurate channel estimation and equalization (i.e., compensation for the distortions introduced by the channel). This task is challenging because the V2V radio channel is characterized by multipath reflections (due to scatterers between the transmitter and receiver) that spread the signal energy in time and induce frequency selectivity in the signal transfer function. Furthermore, the high relative speeds between transmitter, receiver and signal scatterers introduce rapid stochastic variations of the radio channel, a physical phenomenon associated to Doppler spread. In addition, the misalignment between the reference frequency of the local oscillators at the transmitter and receiver distort the signal even further. The impact of these effects is particularly visible for high carrier frequencies such as 5.9 GHz, since oscillators accuracy is typically proportional to their nominal frequency.

In order to enable the receiver to estimate the channel accurately and compensate for these impairments, 3GPP agreed to interleave 4 wideband demodulation reference signals in each subframe as shown in Figure 2. Figure 3 shows the simulated error performance of the sidelink physical layer at a carrier frequency of 5.9GHz and for relative speeds up to 280km/h. The proposed design shows good performance for the typical vehicular speeds. It is important to emphasize that the performance in Figure 3 was achieved with a simple linear equalizer in the receiver model. Other systems such as the IEEE 802.11p require more complex receiver architectures that rely on advanced turbo-equalization to compensate for aforementioned channel degradation [8].

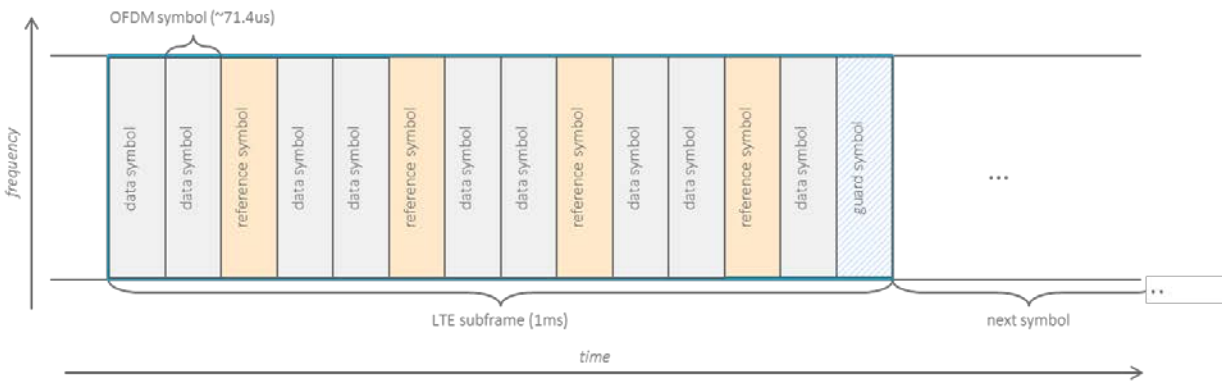

Figure 2 – Sidelink physical layer format. Four reference symbols are transmitted per subframe (1 ms) to allow the receiver to obtain accurate channel estimates.

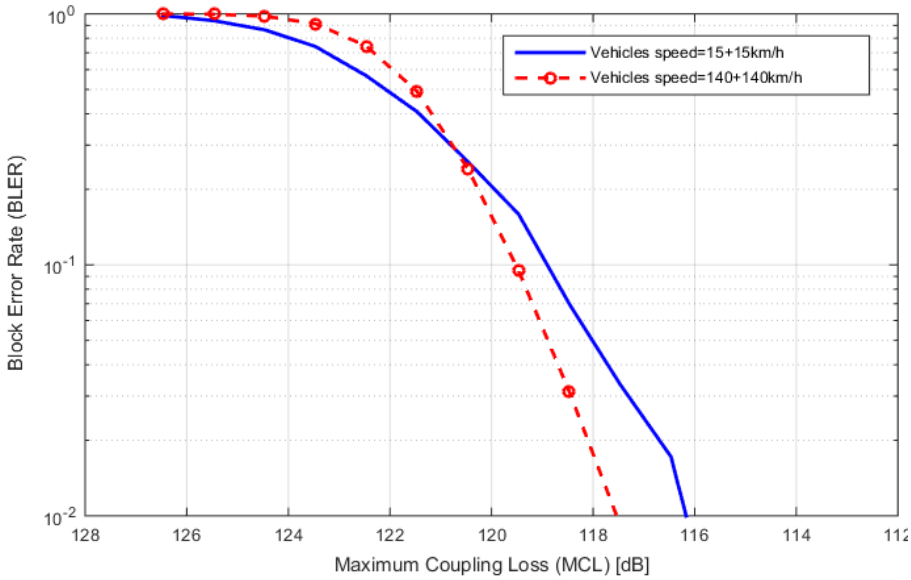

Figure 3 – Sidelink physical layer error performance for transmission of a 300-byte message using a 5 MHz channel in the 5.9 GHz band. The proposed design is robust against channel variations and it benefits from time diversity for higher speeds. The performance improvement at high speed is motivated by the enhanced time-diversity experienced by the channel within the subframe.

Enhancements to Radio Resource Management

In this section, we focus on the resource allocation and scheduling procedure for LTE sidelink, which are fundamentally different from the one specified for IEEE 802.11p.

LTE sidelink is a synchronous time-slotted system, where transmissions may only occur within time slots. A synchronization procedure that works both under-eNB-coverage and out-of-eNB-coverage is defined but not discussed here because of space limitation. The slots enable efficient resource packing and interference control in case of high system load as well as efficient multiplexing of sidelink and cellular transmissions within a common shared carrier.

LTE sidelink allows different users to share the medium using both time-division multiple access (TDMA) and frequency-division multiple access (FDMA). The combination of both multiplexing modes can be used to achieve higher spectral efficiencies than those possible with TDMA-only systems such as IEEE 802.11p.

To allow potential receivers to receive the transmissions by different users, which are possibly multiplexed in time and frequency, LTE sidelink uses two types of information packets: scheduling assignment (SA) packets and data packets. The SAs are small packets that contain all the scheduling information that is necessary for a receiver in order to decode a data transmission. SA packets are transmitted using a predefined format on specific radio resources. In contrast, the data packets have variable size and format and may be transmitted over a much larger set of radio resources. The main advantage of using SAs is that they allow for efficient receiver implementation without sacrificing

transmission format flexibility. Figure 4 illustrates an example on how scheduling and data resources on a carrier are split and the relationship between them.

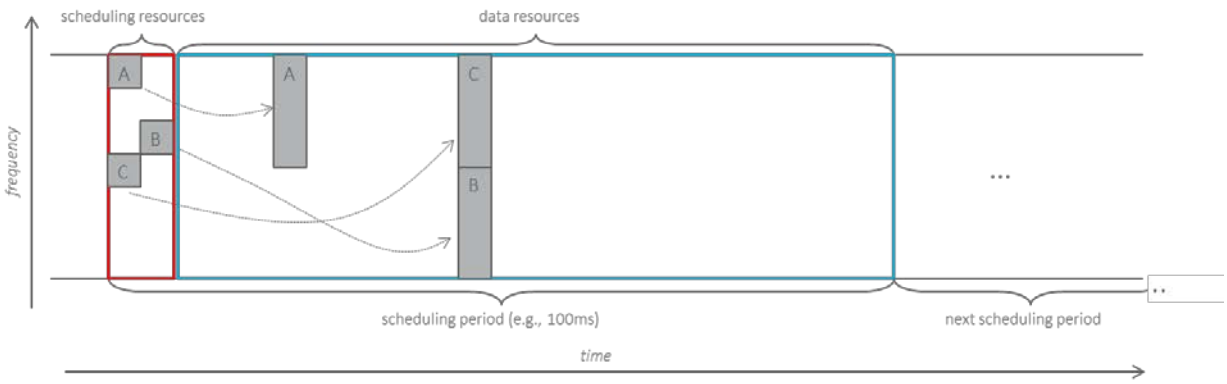

Figure 4 – Sidelink carrier resource mapping with three SA resources and three associated data resources multiplexed in time. Alternatively, the resources could be multiplexed in frequency. In addition, cellular resources could be multiplexed on the same carrier (not shown here).

In order to provide global service while ensuring that radio resources are fully utilized in the most congested areas, LTE sidelink for V2V is designed to operate with and without network coverage. This means that LTE sidelink will be fully operational even in remote areas but will also exploit the presence of network infrastructure to increase the efficiency of the system, for example by centralizing parts of the radio resource management. This implies that two different resource allocation procedures are defined for sidelink:

- Distributed resource allocation, supported both within and outside eNB coverage;
- Centralized resource allocation, supported only within eNB coverage.

These allocation procedures are discussed in more detail in the following.

Distributed Resource Allocation

When performing distributed resource allocation, each device independently decides which radio resources to use for each transmission. This applies to both the transmission of SA packets and the associated transmission of data packets. The same algorithm is used by all devices and is based on two principles: 1) sensing of transmissions by other devices; and 2) minimizing the number of radio resource reselections. The first principle means that, whenever a device is not transmitting it measures the activity (e.g., in terms of received power) in all the radio resources. In addition, a device uses its readings of the SAs transmitted to other devices to detect collisions with transmissions by nearby devices. The second principle implies that a device only reselects resources whenever it is necessary; for example, when a collision is detected. This makes the utilization of the radio resources quite stable over time, allowing the sensing algorithms to converge and letting devices infer the resource allocation use by nearby devices. To avoid consistent hidden station issues resource reselection is enforced periodically.

Centralized Resource Allocation

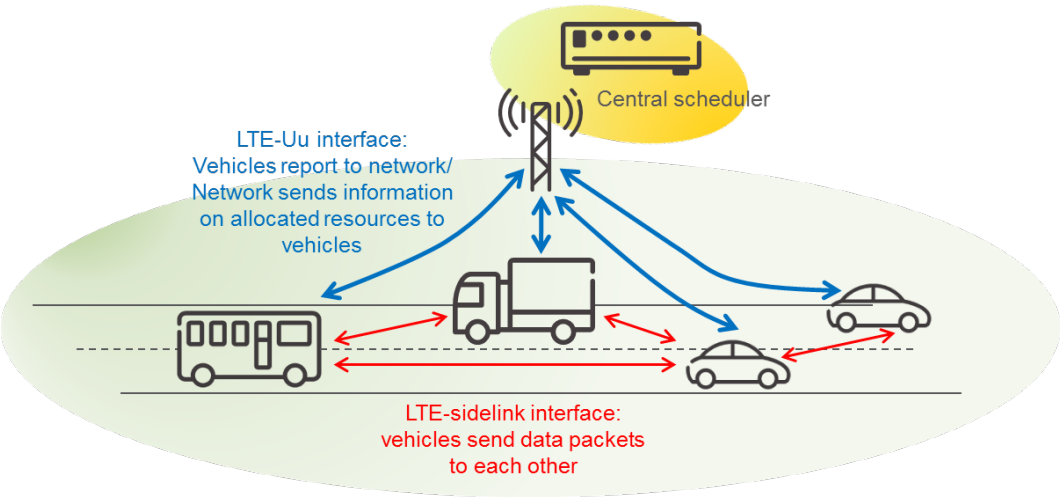

Figure 5 – Vehicular communications with centralized (network-aided) resource allocation

The communication over sidelink interface in LTE networks can be improved by leveraging the help of the network. One example of such network-assisted communication scenarios is the centralized resource allocation, illustrated in Figure 5. Therein the eNB plays the role of a central scheduler which performs scheduling algorithms and sends information about the allocated resources to each device. Devices contribute to the procedure by reporting necessary information to the eNB, e.g., information about their respective geographical location. Information exchanged between eNB and devices is performed over the LTE-Uu interface between devices and eNB, i.e. uplink and downlink, as shown in Figure 5. Resource allocation is an optimization problem which aims at maximizing the packet reception ratio, namely ensuring that the packet broadcasted by each vehicle can reach as many vehicles as possible. However, finding the globally optimal solution (if there is any) to this problem is generally computationally complex, especially when the number of devices is large. Furthermore, the solution may require information about channel state information between all vehicles, leading to undesirably heavy signaling load in the network. Therefore, in this paper we propose a heuristic solution which shows significant gain compared to non-centralized schemes.

In our algorithm the eNB updates the time-frequency resources for each device for the next scheduling period based on the assigned resources of *all* devices in the current period. The update process is done in such a way that the interference or power leakage due to using the same time and/or frequency resources is minimized. Moreover, the update can be done for all devices or only to the devices that will most benefit from the process. Currently the algorithm only uses the information of geographical location of the devices as the input, but other types of input information are possible.

Evaluation Settings and Results

In this section, we evaluate the performance of our proposed enhancements for LTE sidelink in two scenarios that have been identified by 3GPP in [3]. The first scenario, referred to as *urban slow*, models an urban deployment with 3 horizontal streets and 3 vertical streets (9 crossings) with high

density of users (2540 vehicles/km^2) travelling at low speeds (15 km/h). The second scenario, known as *highway fast*, models a 6-lane highway deployment with a reduced number of vehicles (62 vehicles/km) travelling at high speeds (140 km/h). We also considered the official V2V propagation models defined by 3GPP. A complete description of the scenarios can be found in [3].

For comparison purposes, we also present the performance of a system using the IEEE 802.11 standard release 2012 [4]. Our simulator includes an abstraction of the physical layer and MAC layer functionalities such as the listen-before-talk Enhanced Distributed Channel Access (EDCA) mechanism and the capture effect of IEEE 802.11 OFDM PHY discussed in [7]. Some relevant simulation parameters common to the LTE sidelink simulator and the 802.11p simulator are summarized in Table 1. We emphasize that we modeled a high-end 802.11p transceiver with performance reference way above the minimum requirements since we considered a receiver sensitivity of -95 dBm (as compared to the requirement of -82 dBm @6Mbps in [4]) and a Clear Channel Assessment (CCA) detection threshold of -92 dBm (as compared to the requirement of -85 dBm in [4]).

We evaluate the performance of the systems in terms of the packet reception ratio (PRR) as function of the communication range. For one transmitted packet, the PRR is defined as the ratio between the number of vehicles that successfully received the packet and the total number of vehicles that are located in the given range. We emphasize that the results presented here have been obtained for two particular models that were selected by 3GPP as representative of challenging highway and urban deployments. However, a much wider range of conditions is found in real-life situations. In this respect and considering the dependence of absolute performance on the specific channel models, we believe that it is more accurate to interpret the results presented here in relative terms (LTE vs. 802.11p performance) rather than in absolute performance terms.

Table 1 - Simulation parameters

Parameter	Value
Carrier frequency	6 GHz
Bandwidth	10 MHz
Transmit power	23 dBm
Antenna gain (transmitter and receiver)	3 dBi (each)
Packet size	A 300-byte packet followed by four 190-byte packets
Packet generation frequency	10 Hz (highway scenario), 2 Hz (urban scenario)
IEEE 802.11p mode	QPSK 1/2 (6 Mb/s)

Figure 6 compares the average PRR performance versus distance of two LTE schemes, based on centralized and distributed resource allocation respectively, with that of the IEEE 802.11p, for the *urban slow* scenario and each vehicle sends two messages per second. It can be seen, as indicated by the double arrow in the figure, that at a given distance from the transmitter, the LTE schemes achieve significantly higher PRR than the IEEE 802.11p scheme. Equivalently, if we take the PRR as a

measure of *reliability* of communication then the LTE schemes can guarantee a significantly higher reliability than the IEEE 802.11p scheme. For example, the 90% reliable communication distance of the LTE schemes is about 90 meters, which is nearly two times the reliable distance achieved with IEEE 802.11p.

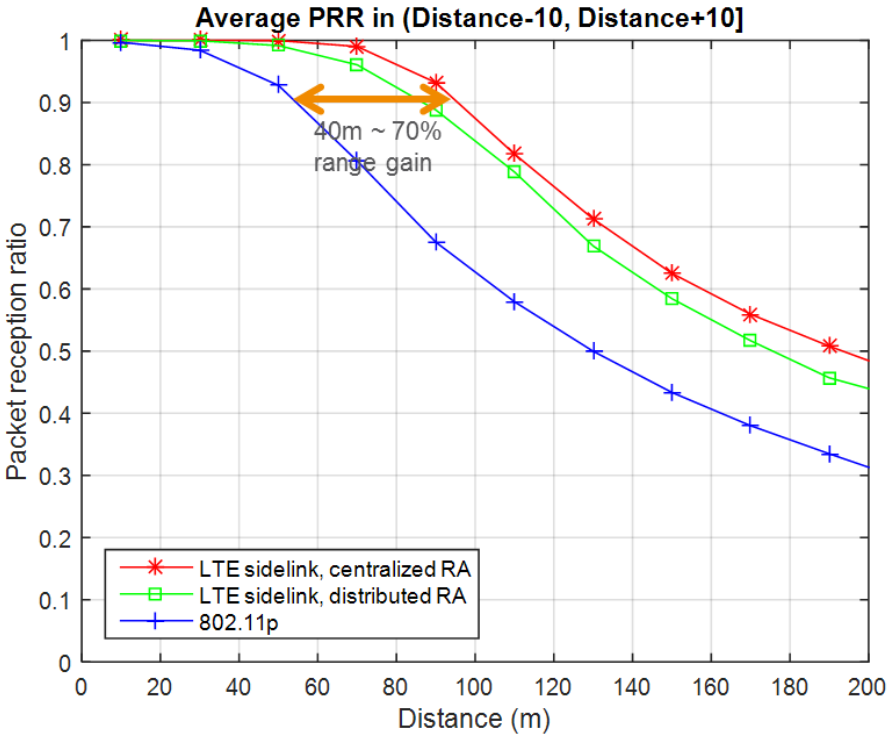

Figure 6 – Urban slow scenario, PRR vs. distance of two enhanced LTE sidelink schemes (based on centralized and distributed resource allocation) in comparison with that of a scheme using IEEE 802.11p.

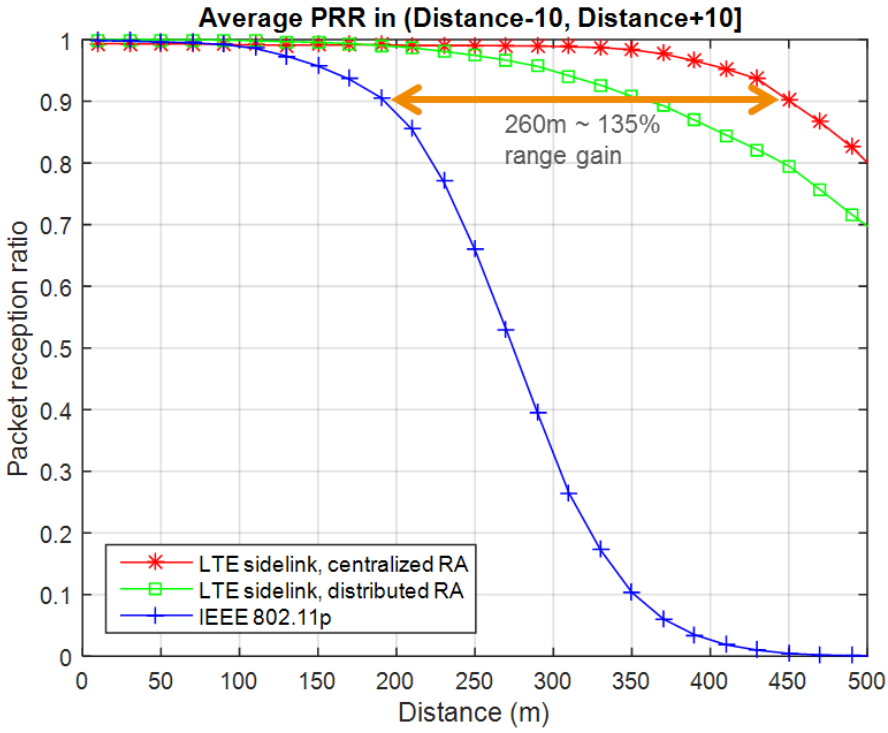

Figure 7 - Highway fast scenario, PRR vs. distance of two enhanced LTE sidelink schemes (based on

centralized and distributed resource allocation) in comparison with that of a scheme using IEEE 802.11p.

Figure 7 shows a similar comparison as shown in Figure 6, but for the *highway fast* scenario and each vehicle sends ten messages per second. Again, we can easily see that the schemes based on LTE achieve significant performance gains over the scheme based on IEEE 802.11p. In particular, the double arrow in the figure indicates that the LTE schemes can achieve the 90% average PRR at a distance that is more than two times larger than what the 802.11p scheme can achieve.

The LTE gains can be attributed to both the gain from a more robust PHY layer signaling scheme and the gain attained by the more efficient resource allocation mechanisms. Especially, the centralized resource allocation used in the simulation, although makes use of only information on geographical location of devices, can bring about significant improvements. A further advantage is the slotted resource allocation that enables better interference control in high-load scenarios.

Conclusions

In this work we discuss various enhancements being made to the 3GPP LTE in order to support ITS services. Initial numerical evaluations of the proposed enhancements show that the enhanced LTE-Advanced sidelink interface is capable of delivering reliable performance under evaluation scenarios defined by 3GPP. The results also show considerable gain of the enhanced LTE-sidelink in comparison with an instance of the IEEE 802.11p technology in such scenarios. Our study suggests that with enhancements the LTE-sidelink can satisfactorily fulfil the 5G requirements for ITS services.

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