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# Overview of LTE Based Cellular V2X Communication

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## ABSTRACT

Vehicle-to-Everything Communication (V2X) is a technology that allows a vehicle to communicate with different entities of the traffic system. These entities include other vehicles (V2V), pedestrians (V2P), infrastructure like traffic signals (V2I) and application servers (V2N). V2X applications can transform existing transportation systems into Intelligent Transport Systems (ITS) that will provide intelligent services such as autonomous driving, collision warning, traffic regulation and infotainment.

IEEE 802.11p Wireless Access in Vehicular Environments (WAVE) based radio access has laid the foundation for V2X communication. It defines enhancements to IEEE 802.11 to support ITS applications. IEEE 802.11p allows vehicles to communicate their state, such as position and speed, to surrounding entities. However, though IEEE 802.11p gives acceptable performance in sparse networks, its performance deteriorates drastically in dense and high load conditions. In dense networks, the probability of collision of data packets increases significantly thereby reducing throughput and increasing delays.

Cellular V2X is the use of cellular radio access technologies like LTE for V2X. It has been shown that LTE V2X provides better performance in different network conditions and provides better mobility support than IEEE 802.11p. It is also suitable for most of the use cases of V2X. In this study, we have done systematic literature review of LTE and IEEE 802.11p based V2X. We present a technical overview of LTE V2X and describe a few important use cases. We also present a comparison of LTE V2X with IEEE 802.11p and highlight the benefits of using LTE for V2X.

**Keywords:** V2X, LTE, IEEE 802.11p, ITS

## 1. INTRODUCTION

Vehicle-to-Everything (V2X) is a communication system that allows a vehicle to interact with all other entities of the traffic system around it. These entities can be other vehicles, pedestrians or road side units (RSU) like traffic lights, speed monitors, light poles etc.

The most important goal of V2X is to improve road safety. Studies show that road accidents are one of the leading causes of death across the world. V2X can be used to exchange timely warning messages between traffic entities thereby reducing chances of accidents. Each vehicle can also periodically broadcast certain parameters about it like location, speed, direction etc., which can help other vehicles take safe decisions.

Information exchange between RSUs and vehicles can also be used to monitor, regulate and manage traffic efficiently. An efficient traffic management system will ease congestion and reduce the average time spent by commuters on road. V2X will be a key enabler to redefine existing transport system into Intelligent Transport Systems (ITS) that will provide intelligent services such as autonomous driving and remote diagnostics. It will also open up a plethora of opportunities for service providers to develop and provide various new convenience and commercial applications that will benefit end users.

## 2. V2X LITERATURE REVIEW

V2X requirements are slightly different from the requirements of existing technologies like Wi-Fi and cellular technologies. Hence it is necessary to either come up with a new technology or enhance existing technologies so that they meet all the V2X requirements. Karagiannis et al. (2011) explain the characteristics of V2X in detail. They also discuss about the requirements and challenges of V2X. WAVE and LTE based Cellular V2X are two most promising technologies for V2X. Jiang & Delgrossi (2008) give details about WAVE which is an IEEE standard for V2X communication. 3GPP TS 36.300 gives an overview of LTE V2X. Service requirements of LTE V2X are described in 3GPP TS 22.185. 3GPP TS 23.285 and R1-15660 describe the enhancements done in LTE to support V2X applications.

## 3. OBJECTIVE OF THE PAPER

We have done systematic study of V2X and its technical requirements from existing literature. The purpose of this paper is to summarize the concept of V2X in simple terms. We also give technological insight into IEEE 802.11p based WAVE and LTE V2X and compare their performance under different conditions.

## 4. APPLICATIONS OF V2X

V2X applications can be classified into three main categories, namely, Road Safety, Traffic Management and Infotainment. Some applications in each category are mentioned below.

### 4.1 Road Safety

1. Collision Risk Warning: A vehicle that intends to take a sharp turn warns other vehicles and can prevent collision.
2. Overtaking Warning: A vehicle that is overtaking another vehicle sends signals to all other vehicles around it to make overtaking safe.
3. Vulnerable Road User Warning: Pedestrians or RSUs can warn approaching vehicles about the presence of a vulnerable user like a pedestrian or a cyclist.

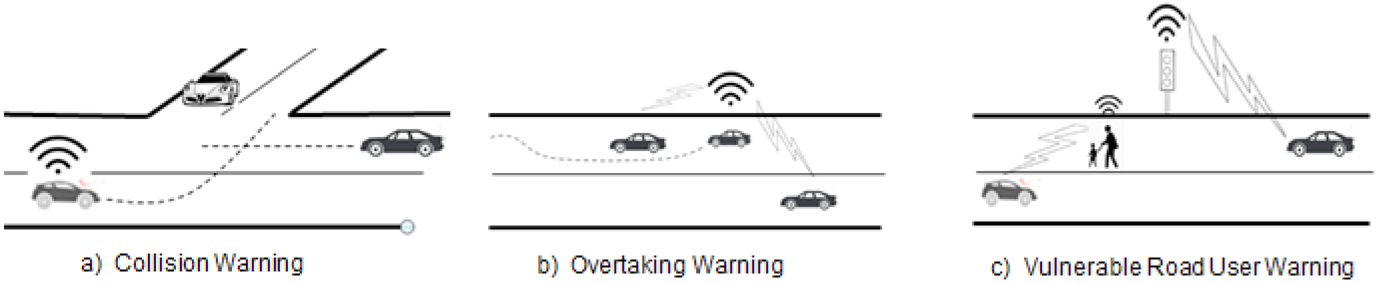


**Fig. 1: Road Safety Use Cases**

Source: ETSI TR 102 638

### 4.2 Traffic Management

1. Detour Warning: RSUs can broadcast messages to vehicles warning them about road work and ask them to take a detour.
2. Speed Limits: RSUs can periodically broadcast current local speed limits.
3. Intersection Management: Traffic signals at crossroads can interact with one another to improve traffic efficiency. For example, signal timings can be optimized based on the number of vehicles in each direction.

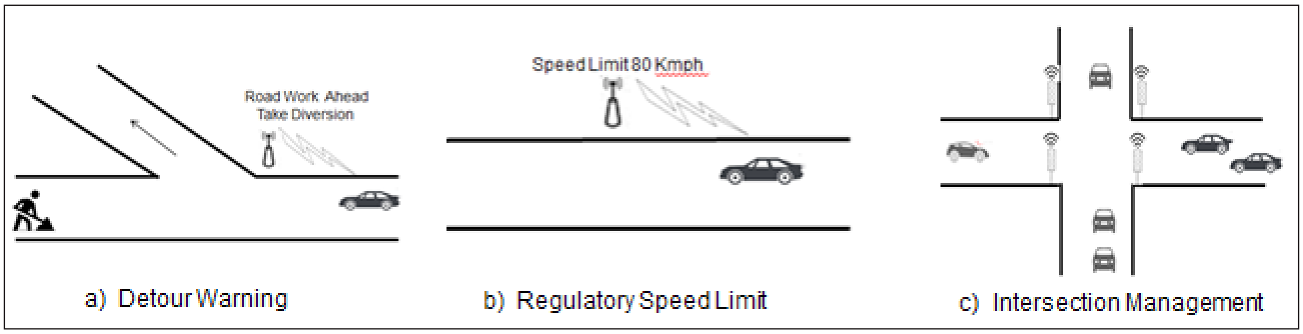


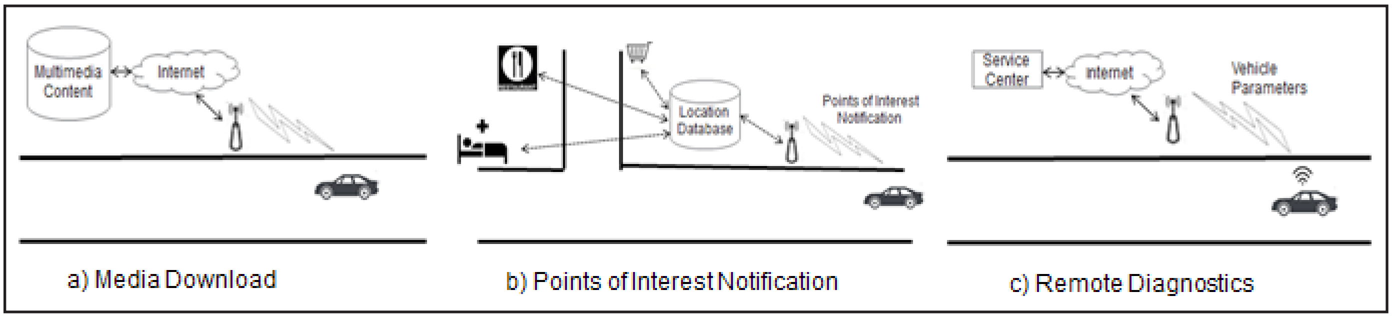
**Fig. 2: Traffic Management Use Cases**

Source: ETSI TR 102 638

### 4.3 Infotainment

1. Media Downloading: RSUs connected to internet can provide multimedia for passenger entertainment.
2. Point of Interest Notification: RSUs can inform vehicles about nearby points of interests like restaurants, malls etc.

3. Remote Diagnostics: Vehicles can report their current functional state to a nearby RSU which in turn can send the report to a service center. The service center can remotely provide help in case of any problem.



a) Media Download b) Points of Interest Notification c) Remote Diagnostics

**Fig. 3: Infotainment Use Cases**

Source: ETSI TR 102 638

## 5. V2X MODES OF OPERATION

To cater to the different use cases defined in the previous section, vehicular communication needs to operate in the following four modes (Fig. 4)

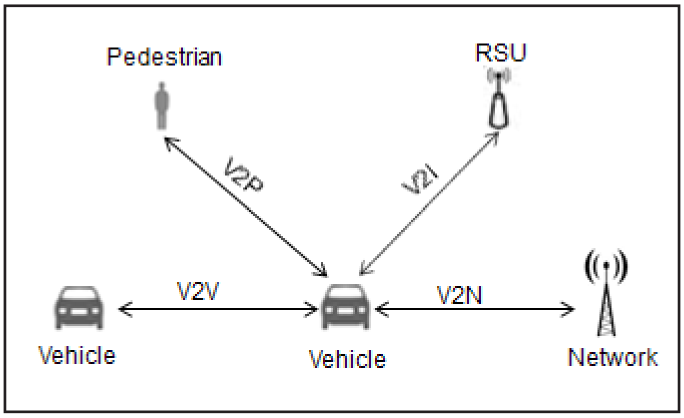


**Fig. 4: V2X Modes**

**Vehicle-to-Vehicle (V2V):** V2V is the communication between devices mounted on moving vehicles. Vehicles can exchange information about their current location, speed, direction and certain other parameters. The amount of data exchanged in this mode may not be very high but they do require very low latency. This mode of operation will be mainly used for road safety.

**Vehicle-to-Pedestrian (V2P):** V2P is the communication between vehicles and pedestrians or cyclists. This mode will also be mainly used for road safety. Throughput and latency requirements of V2P are similar to V2V. The main difference between V2P and V2V is due to the properties of the device. For example, the device used by pedestrians might have lower battery capacity, and therefore it may not be able to send messages with the same periodicity as devices mounted on vehicles. Mobility requirement is also low for these devices.

**Vehicle-to-Infrastructure (V2I):** V2I is the exchange of information between a vehicle and a RSU. This mode can be used for Traffic management and infotainment.

**Vehicle-to-Network (V2N):** V2N is the communication between a vehicle and application servers in the network. It can also be used for communication between vehicles that are not within communication range of each other. These applications may require high throughput but latency requirements are not as stringent as V2V or V2P.

## 6. REQUIREMENTS OF V2X COMMUNICATION

The underlying technology that is used for V2X communication should meet the following basic requirements.

**Interoperability**: It should be a standard solution that can guarantee interoperability between different devices.

**Range of Operation**: Road Safety Applications like Collision warning systems should work at a very short range of a few meters. However traffic management applications may need longer ranges of 500m – 1000m.

**Low Latency**: End-to-end latency for critical V2V and V2P applications should be less than 100ms.

**Multipath Environment**: The technology should work well even in extreme multipath environments without affecting receiver performance.

**High Speed**: It should work well in all four modes even at high speeds (280 km/hr.)

**Spectrum**: It should be able to operate in ITS bands allocated by regulatory bodies like FCC and ETSI. For example, FCC has allocated 75 MHz of spectrum in the 5.9 GHz band and ETSI has allocated 30 MHz of spectrum in the 5.9 GHz band for ITS.

To meet the above requirements, IEEE and 3GPP have come up with new standards for V2X communication called WAVE and LTE V2X respectively. In the next few sections we give an overview of both these technologies.

## 7. WAVE STANDARD FOR V2X COMMUNICATION

Wireless Access in Vehicular Environment (WAVE) uses IEEE 802.11p which is derived from the stable IEEE 802.11a Wi-Fi standard.

IEEE 802.11a is a proven standard and works well in indoor environments. However, V2X communication requirements are different from the regular indoor Wi-Fi requirements. Hence a few modifications are done to make it suitable for vehicular communication. Some important differences between IEEE 802.11a and IEEE 802.11p are tabulated in Table 1.

**Table 1: Differences between IEEE 802.11a and IEEE 802.11p**

| *Feature* | *IEEE 802.11a* | *IEEE 802.11p* |
|---|---|---|
| Band of operation | 2.4GHz and 5 GHz | 5.9 GHz ITS Band |
| Channel bandwidth | 20MHz | 10 MHz |
| OFDM Symbol Duration | 4 µsec | 8 µsec |
| Cyclic Prefix | 0.8µsec | 1.6µsec |
| Channel Access | CSMA/CA | EDCA and CSMA/CA |

In IEEE 802.11p, OFDM symbol and cyclic prefix durations have been doubled as compared to IEEE 802.11a. Longer OFDM symbol and cyclic prefix durations reduce ISI in multipath propagation environments. Bandwidth reduction from 20MHz to 10MHz also has the effect of reducing RMS delay spread in vehicular environments.

Channel access scheme has also been enhanced in IEEE 802.11p. Both IEEE 802.11a and 802.11p are based on CSMA/CA. In CSMA/CA, users sense the channel to see if it is idle. If the channel is idle, they transmit their packets. If the channel is busy or if they sense any collision, users back-off for a random amount of time and retry. IEEE 802.11p uses Enhanced Distributed Channel Access (EDCA) in addition to CSMA/CA. In EDCA, data packets are assigned different priorities based on their criticality. Higher priority data are assigned shorter back-off time, thereby reducing the latency for time critical applications.

### 7.1 Key Issues of WAVE

WAVE meets most of the V2X requirements and works well under low traffic loads. However with CSMA/CA, the probability of packet collisions and average latency increase significantly with traffic density. This has an adverse impact on critical time sensitive V2X applications which require extremely low latency.

Secondly, as a result of increasing the symbol duration and guard period to reduce ISI, the OFDM subcarrier spacing in IEEE 802.11p is halved to 0.15625MHz. This makes WAVE susceptible to Doppler Effect causing significant inter-subcarrier interference thereby reducing its reliability at high speeds.

## 8. LTE BASED CELLULAR V2X

3GPP has also introduced enhancements in LTE to meet V2X requirements. The main enhancements are addition of new nodes in the network architecture, use of sidelink communication for time critical applications, changes in scheduling methods and some changes in frame structure.

### 8.1 Architecture

LTE V2X network architecture is given in Fig. 7. A few additional nodes and interfaces are added to the LTE network to support V2X.

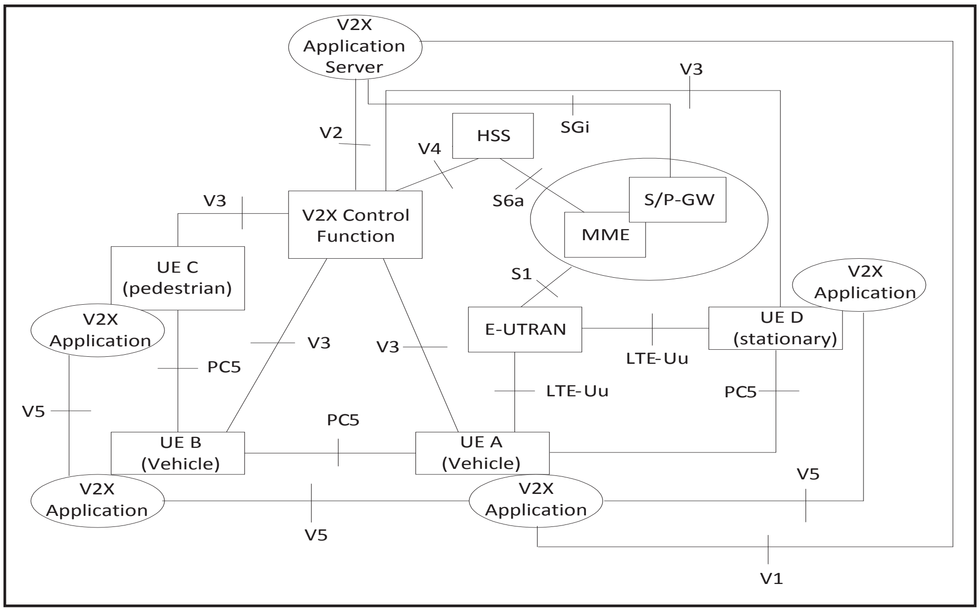


**Fig. 5: LTE V2X Network Architecture**

Source: 3GPP TS 23.285

The important functional entities with respect to V2X are mentioned below:

- V2X Control Function is a logical node that provisions UEs with necessary parameters for V2X communication. It provisions UEs with PLMN specific parameters that allow them to use V2X in those PLMNs. It also provisions UEs with parameters that are needed when UEs go out of network coverage.
- MME obtains subscription information related to V2X from HSS and provides indication to E-UTRAN about UE's authorization status for V2X.
- V2X Application Server receives unicast uplink data from UEs. They also deliver data to UEs in targeted areas either using unicast or multicast.
- V2X applications run on V2X capable UEs. These UEs can communicate directly using sidelink communication via the new PC5 interface. They can also communicate with E-UTRAN using Uu interface.

## 8.2 Sidelink Communication

Typically in LTE, devices communicate with each other via the network as shown in Fig. 5.

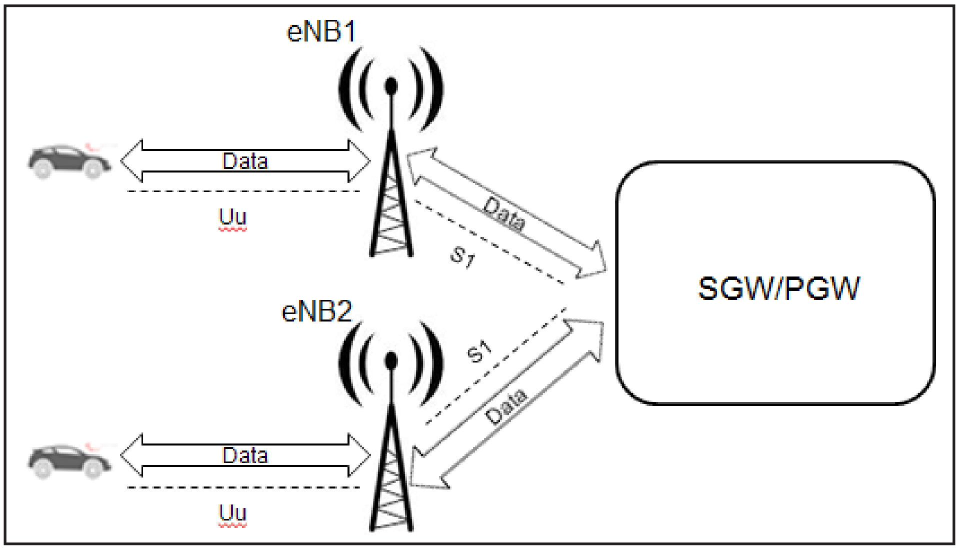


**Fig. 6: Data Path in Rel-8 LTE**

The cellular data path from UE to network and back to the UE introduces high end-to-end delay and does not meet the low latency requirements of V2X. Hence to reduce latency, Sidelink Communication feature is used for time sensitive V2X applications. In Sidelink communication, UEs communicate directly with one another via the new PC5 interface without the need for a network between them (Fig. 7).

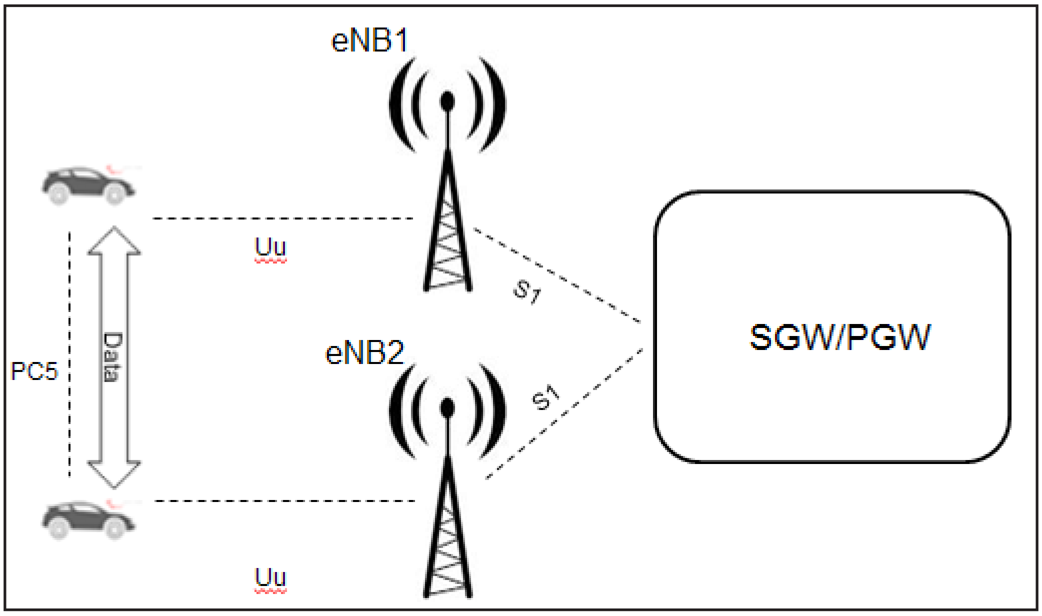


**Fig. 7: LTE Sidelink Data Path**

### 8.3 Scheduling

Scheduling refers to the allocation of radio resources to devices for communication. There are two modes of scheduling in V2X - Scheduled mode and autonomous mode.

Scheduled mode can be used only when UEs are under network coverage. In this mode, UE requests E-UTRAN to allocate resources for sidelink communication. E-UTRAN then allocates the exact time and frequency resources to be used by the UE for data and signaling. E-UTRAN can also allocate resources using semi-persistent scheduling. This further reduces latency.

Autonomous mode is used when UEs are not under network coverage. In autonomous mode, UEs select radio resources from a pre-configured resource pool. This resource pool can be provided either by the V2X control function when the device was in network coverage, or it can be pre-configured in the USIM.

### 8.4 Frame Structure

Typically, LTE UEs use SC-FDMA for uplink transmission and OFDMA for downlink reception. In V2X communication, UEs use the uplink SC-FDMA frame structure of LTE for both sidelink transmission and reception as SC-FDMA has lower PAPR than OFDMA leading to better power efficiencies at the UE side.

Secondly, additional Demodulation Reference Symbols (DMRS) are added in the frame structure to make it suitable for vehicular communication. DMRS helps receivers estimate the channel response properly. In legacy LTE, there are 2 DMRS in each subframe with an interval of 0.5ms. In V2V, the carrier frequency (fc) could be up to 6GHz and the maximum relative velocity (v) can be 280km/h. Doppler frequency shift (fd) is $\frac{(fc * v)}{c}$ = 1556Hz. And the coherence time $Tc = \sqrt{9 * \frac{fd}{4\text{Å}}}$ = 0.27ms.

Coherence time is the time duration over which the channel impulse response is considered to be not varying. The time interval of 0.5ms between DMRS in legacy LTE is larger than the coherence time of V2V and hence may not be enough to estimate the channel response properly. Hence V2X subframe for PC5 interface has 4 DMRS symbols at an interval is 0.21ms, which is less than coherence time. This makes LTE V2V work robustly at high speeds in ITS band.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2<br>DMRS | 4 | 5 | 6<br>DMRS | 7 | 8 | 9<br>DMRS | 10 | 11 | 12<br>DMRS | 13 |

**Fig. 8: DMRS symbols in V2X Subframe in PC5 Interface**

## 9. PERFORMANCE COMPARISON OF WAVE AND LTE V2X

**Effect of Load on Latency:** Simulation experiments to evaluate the performance of IEEE 802.11p were carried out by Khairnar & Kotecha (2013) and Bilstrup et al. (2008). The results show that performance of IEEE 802.11p in terms of channel access delays degrades severely at high loads.  If the load is very high, some nodes achieve successful channel access only 16% of the time. A comparison of WAVE and LTE V2X latency as a function of load was done by Hameed Mir & Filali (2014). These results also show that as the number of vehicles increases, the end-to-end delay increases drastically in WAVE. Results for LTE V2X also indicate that latency increases with number of vehicles. However, it still meets the latency requirements of most of the V2X applications.

**Table 2: Latency vs. Number of Vehicles (N) for an Average Vehicle Speed of 100Km/h**

| *Technology* | *N=25* | *N=50* | *N=100* |
|---|---|---|---|
| **WAVE** | ~100ms | ~500ms | ~1400ms |
| **LTE V2X** | ~10ms | ~10ms | ~42ms |

(Hameed Mir & Filali, 2014)

**Effect of Speed on Packet Delivery Ratio:** It is shown by Hameed Mir & Filali (2014) that vehicle speed has a significant impact on the Packet delivery ratio (PDR) of WAVE. PDR is computed as the ratio between the number of received packets and the transmitted packets during the simulation time.  In WAVE, as the vehicle speed increases, PDR drops to a great extent. However results show that in LTE V2X, speed has almost negligible effect on PDR.

**Table 3: PDR vs. Speed when Number of Vehicles N=50**

| *Technology* | *20Km/h* | *60Km/h* | *100Km/h* |
|---|---|---|---|
| WAVE | ~0.65 | ~0.45 | ~0.4 |
| LTE V2X | ~1 | ~1 | ~1 |

(Hameed Mir & Filali, 2014)

**Effect of Communication Range:** Packet reception ratio (PRR) of LTE V2X and IEEE 802.11p are evaluated as a function of communication range by Blasco et al. (2016). PRR is defined as the ratio between the number of vehicles that successfully received the transmitted packet and the total number of vehicles that are located in the given range. In both highway and urban simulation models, it is seen that LTE achieves significantly higher PRR than IEEE 802.11p. LTE achieves 90% PRR at a distance which is about twice the distance at which IEEE 802.11p can achieve the same PRR.

**Table 4: Range at which 90% PRR is Achieved**

| *Technology* | *Urban Scenario (Vehicle Density: 2540 /km$^2$ Vehicle Speed: 15 km/h)* | *Highway Scenario (Vehicle Density: 62 /km Vehicle Speed: 140 km/h)* |
|---|---|---|
| WAVE | ~55m | ~200m |
| LTE V2X | ~95m | ~450m |

(Blasco et al., 2016)

## 10. CONCLUSION

IEEE 802.11p based WAVE has been shown to perform well in sparse network conditions and it meets most of the requirements of V2X under low traffic loads and in short ranges. However as can be seen from Table 2 and Table 3, performance of WAVE deteriorates drastically with traffic density and vehicular speed. On the other hand LTE V2X performs better than WAVE even at high traffic densities and at high speeds.  Moreover, LTE V2X is more reliable at long ranges compared to WAVE (Table 4).  Hence, due to its better performance in terms of scaling, latency, range and reliability, LTE V2X appears to be a better solution for most of the V2X applications, especially for time critical safety applications.

## REFERENCES

Architectures, Challenges, Standards and Solutions. *IEEE Communications Surveys & Tutorials, 13*(4), 584-616.

Bilstrup, K., Uhlemann E., Strom, E. G., & Bilstrup U. (2008). Evaluation of the IEEE 802.11p MAC Method for Vehicle-to-Vehicle Communication. Vehicular

Technology Conference, 2008. VTC 2008-Fall. IEEE 68th, p.1-5.

Blasco, R., Do, H., Serveh, S., Stefano; S., & Zang, Y. (2016). 3GPP LTE Enhancements for V2V and Comparison to IEEE 802.11p, Paper number EU-SP0264, 11th ITS European Congress, Glasgow, Scotland, 6-9 June.

ETSI TR 102 638. (2016). Intelligent Transport Systems (ITS), Vehicular Communications, Basic Set of Applications, Definitions.

Hameed Mir, Z., & Filali, F. (2014). LTE and IEEE 802.11p for vehicular networking: A performance evaluation. *EURASIP Journal on Wireless Communications and Networking, 89*(2014).

Jiang, D., & Delgrossi, L. (2008). *Towards an international standard for wireless access in vehicular environments.* Proceedings of 67th IEEE Vehicular Technology Conference (VTC2008-Spring), Marina Bay, Singapore.

Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., & Weil, T. (2011). Vehicular Networking: A Survey and Tutorial on Requirements,

Khairnar, V. D., & Kotecha, K. (2013). Performance of vehicle-to-vehicle communication using IEEE 802.11p in vehicular ad-hoc network environment. *International Journal of Network Security & Its Applications, 5*(2).

R1-15660. (2015). Discussion on DMRS Enhancement for PC5-based V2V, ZTE.

3GPP TS 36.300. (2017). Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN), Overall description, Stage 2.

3GPP TS 22.185. (2016). Service requirements for V2X services, Stage 1.

3GPP TS 23.285. (2016). Architecture enhancements for V2X services.

## GLOSSARY

| *Term* | *Expansion* |
|---|---|
| CSMA/CA | Collision Sense Multiple Access/Collision Avoidance |
| DMRS | Demodulation Reference Symbol |
| EDCA | Enhanced Distributed Channel Access |
| ETSI | European Telecommunications Standards Institute |
| E-UTRAN | Evolved Universal Terrestrial Radio Access Network |
| FCC | Federal Communications Commission |
| ISI | Inter-Symbol Interference |
| ITS | Intelligent Transport Systems |
| LTE | Long Term Evolution |
| MME | Mobility Management Entity |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PAPR | Peak-to-Average Power Ratio |
| PDR | Packet Delivery Ratio |
| PLMN | public land mobile network |
| PGW | Packet Gateway |
| RMS | Root Mean Square |
| RSU | Roadside Unit |
| SC-FDMA | Single-carrier Frequency Division Multiple Access |
| SGW | Serving Gateway |
| UE | User Equipment |
| USIM | Universal Subscriber Identity Module |
| V2X | Vehicle to Everything |
| WAVE | Wireless Access in Vehicular Environment |