Ready to roll:
Why 802.11p beats LTE and 5G for V2x

A white paper by NXP Semiconductors, Cohda Wireless, and Siemens

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Abstract

V2x communication, which involves vehicles exchanging data with each other and the infrastructure, has proven to improve traffic safety and increase the efficiency of transportation systems. Direct Short Range Communication (DSRC), which is based on IEEE 802.11p, has been the subject of extensive standardization, product development and field trials by all stakeholders, proving its benefit for V2x. Unlike cellular technologies, DSRC is ready for V2x deployment today, and addresses the most challenging V2x use-cases.

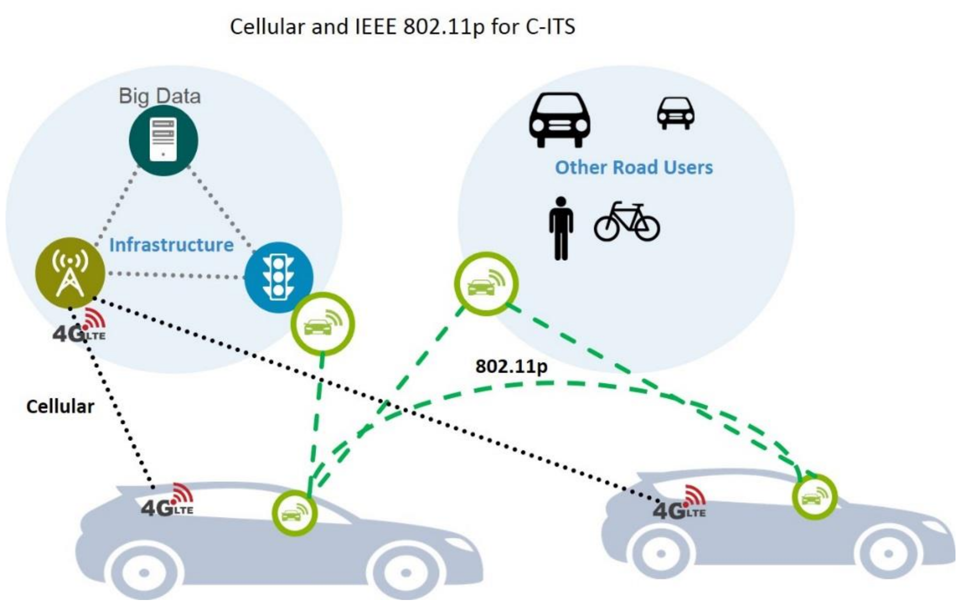

Figure 1 Comparison between IEEE 802.11p and cellular connectivity pipes to the car. The key difference is the direct communications among 802.11p equipped devices. Cellular based services rely on the presence of the network.

1. Introduction

The idea of vehicles sharing information and working together to make transportation safer, greener, and more enjoyable, is truly compelling. The technologies associated with this concept, collectively known as Cooperative Intelligent Transportation Systems (C-ITS), promise to reduce traffic congestion, lessen the environmental impact of transportation, and significantly reduce the number of lethal traffic accidents. The impact on safety alone makes C-ITS worth considering, since, according to the World Health Organization (WHO), roughly 1.25 million people died in 2015 due to traffic accidents, and with an associated governmental cost of about 3% of GDP [1].

A key enabling technology of C-ITS is wireless communication, covering vehicle-to-vehicle (V2V) communication, vehicle-to-infrastructure (V2I) communication, and infrastructure-to-vehicle (I2V) communication (Figure 2). Collectively, these wireless transactions are referred to as V2x communication.

V2x has to support the many safety-related and non-safety-related use-cases of ITS systems. Tables I

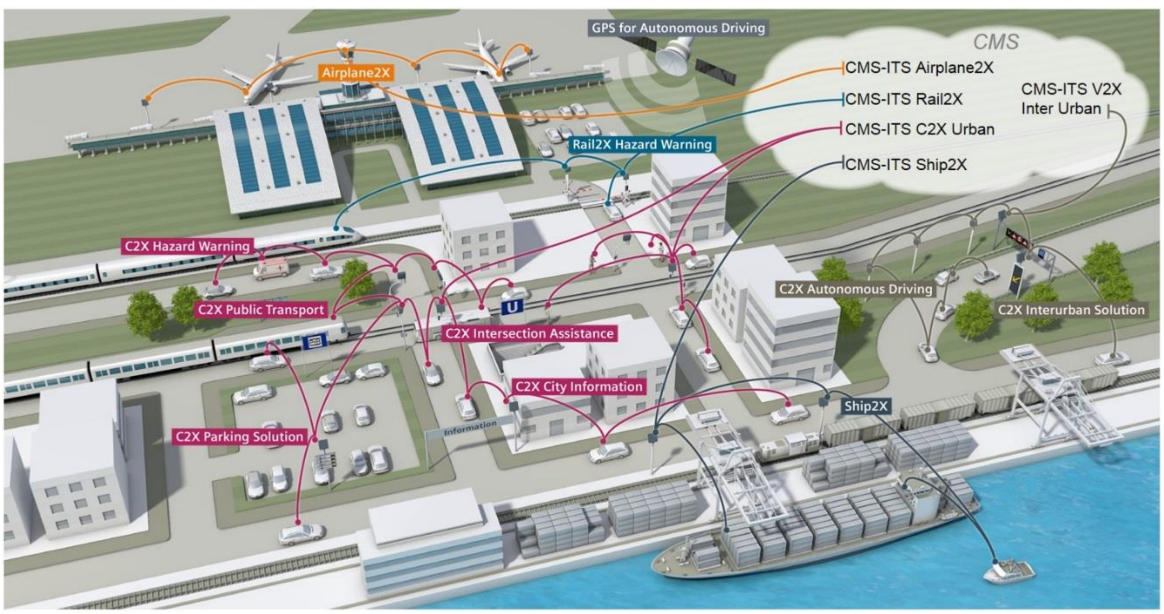

Figure 2 Artist's view of communicating vehicles and infrastructure. Vehicles can be cars, airplanes, trains and ships. The Central traffic Management System (CMS) manages the multiple aspects of the Cooperative Intelligent Transport System (C-ITS).

and II, in the Appendix, list the primary use-cases. Table I gives safety-related use-cases, such as the ability to transmit and receive the message “emergency electronic brake lights,” a message that is transmitted by a vehicle in broadcast mode every tenth of a second to signal the event of emergency breaking. Table II gives non-safety-related use-cases, such as the message “traffic light optimal speed advisory,” which is designed to improve traffic flow by using periodic broadcasts to recommend the best speed.

To support safety-related and non-safety-related messages, the wireless technologies used in V2x communication need to do several things. They need to operate in a very dynamic environment with high relative speeds between transmitters and receivers, and they need to support extremely low latency in the safety-related applications (50 ms for the “pre-crash sensing warning message”, see Table I). They also need to tolerate the high load generated by the periodic transmission of multiple messages by multiple actors, and the high vehicle density typical of congested traffic scenarios. Another consideration is that V2x messages are local in nature, meaning they are most important to nearby receivers. For example, a “pre-crash sensing warning message” is extremely relevant for the vehicles in the surrounding of the crash, but irrelevant to far-away vehicles.

2. 802.11p is here today

The de-facto standard for V2x is Direct Short Range Communication (DSRC) wireless technology, which is based on the IEEE 802.11p standard, the 1609 Wireless Access in Vehicular Environment (WAVE) protocol in the U.S., and the European Telecommunications Standards Institute (ETSI) TC-ITS European standards. This is confirmed by the publication of the report to congress written by the U.S. Department of Transportation (DoT) [2], which clearly explains the benefits of IEEE 802.11p for V2x.

IEEE 802.11p was designed, from the beginning, to meet every V2x application requirement with the most stringent performance specifications. In 1999, the U.S. Federal Communications Commission (FCC) set aside 75 MHz of bandwidth, in the 5.9 GHz region, for V2x, and the IEEE 802.11p standard operates within this range. The standard was approved in 2009, and since then, there have been a number of field trials. Several semiconductor companies, including Autotalks, NXP Semiconductors, and Renesas, have also designed and tested 802.11p-compliant products.

IEEE 802.11p is ready for deployment and is gaining momentum. There have been four ITS “Plug-test” events, organized by the ETSI, with the most recent taking place in Helmond, the Netherlands, in March 2015 [3] and the first in November 2011. There have been extensive field trials as well, in projects like Safety Pilot in the USA [4], Drive C2X in Europe [5], Score@F [6] in France, and simTD in Germany [7], the ITS corridor [6] in which the Dutch, German and Austrian infrastructure organizations assessed the maturity of 802.11p for V2I and the C-ITS central systems technologies. These field trials reflect the significant investments for the last 10 years to validate the 802.11p technology. Any other technology addressing the same application would require all of this to be re-done.

The United States have decided, based on collected evidence, that IEEE 802.11p technology can significantly reduce the number of collisions on the road, and is expected to mandate the use of 802.11p for safety-related use-cases in the second quarter of 2016 [2]. The DoT signaled its intention in 2015 with an Advanced Notice [8]. One American carmaker has already decided to include 802.11p in their production, in advance of the mandate [10].

The market for 802.11p is expected to pick up significantly in 2016, following the U.S. mandate. Adding to the momentum is the increasingly strong evidence for the safety benefits of V2x, and the gradual realization that alternative solutions, including cellular, are far from market-introduction – or even specification.

3. Cellular for V2V is still far out

C-ITS systems are typically defined by their application requirements and don't specify a particular technology. There are, at present, several technologies, in addition to 802.11p, that aim to support V2x use-case requirements. Among these are cellular-based technologies, including 3G, LTE, and LTE-A [11-13].

Used by billions of people around the world every day (Figure 3), cellular technology is, far and away, the most successful wireless standard of our time. The technical specifications for cellular are defined by the 3rd Generation Partnership Project (3GPP). What today is thought of as broadband cellular, and referred to as 4G or LTE, dates back to 2009, and Release 8 of the 3GPP standard. Because the cellular infrastructure is extensive, it takes time to upgrade. In all, it's taken roughly six years for Release 8 to obtain large-scale deployment.

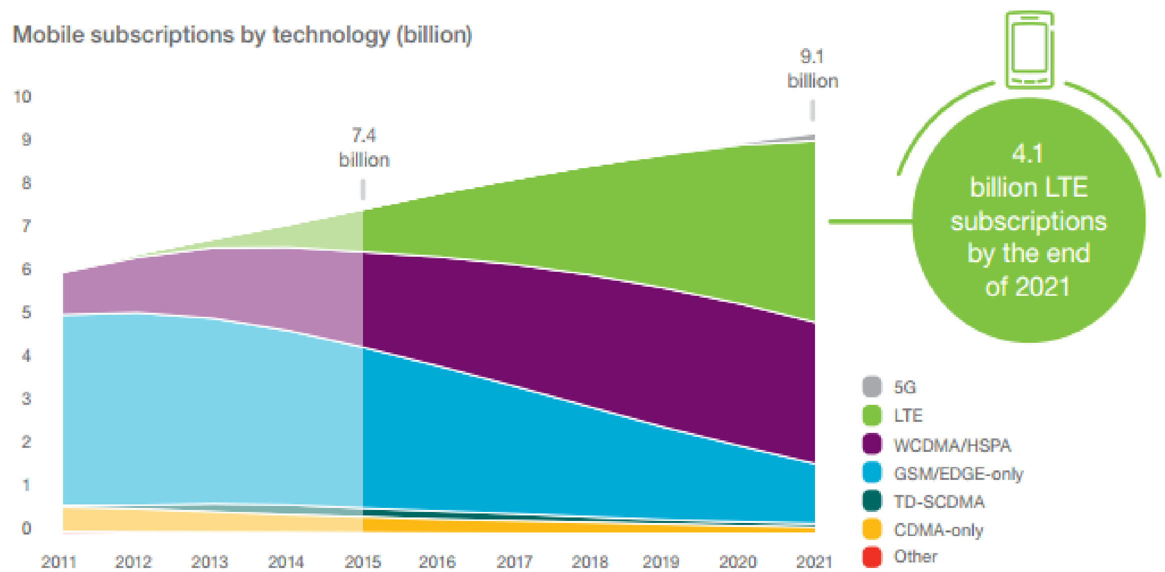

Figure 3 Mobile subscriptions worldwide.
Source: Ericsson Mobility Report, Nov 2015

Given the worldwide success, and global availability, of cellular, the possibility of exploiting the cellular infrastructure and cellular user equipment (UE) for V2x is extremely appealing. However, current versions of cellular can only address basic V2x use-cases, but lacks support for low latency and high mobility use cases. These are the items most closely associated with safety-related use cases.

Underscoring the need for further development of cellular to support V2x and the relevance of the benefits brought by C-ITS, the 3GPP has established a V2x study group to advance C-ITS technology. Once the 3GPP has assessed and agreed upon the new capabilities needed to support all V2x use cases, there will be a period of development, and significant investment, to implement these capabilities. Then, once new 3GPP standards are available for deployment, there will be a further delay as the infrastructure is upgraded to support the new capabilities. Realistically speaking, it will be many years before cellular technology is fully capable of meeting all the requirements of V2x communication (Figure 5).

3.1. Cellular for non-safety-related use-cases: V2I/I2V

Cellular technology, as it stands today, is well suited for non-safety-related uses-cases like those listed in Table II of the Appendix. On the whole, these are use-cases that involve the infrastructure, in V2I and I2V communication, where content originates or is processed in the cloud.

LTE Release 8 can cover most of these use cases with little or no modification, since it offers the required performance and bandwidth. It's unclear, though, how LTE networks will perform in very congested scenarios, and under certain operator roaming conditions. For example, messages for traffic management are particularly relevant to highly congested urban scenarios. As an option for managing high levels of congestion, one might consider a point-to-multipoint interface, such as the evolved Multimedia Broadcast/Multicase Service (eMBMS) as defined in the upcoming LTE-A Release 9. However, eMBMS is designed to support static scenarios, such as the crowd watching a football match in a stadium. That is, the interface can effectively manage communications for a crowd of people, as long as they remain fairly stationary, but won't provide the necessary efficiency when dealing with a high number of incoming and outgoing vehicles.

Similarly, it's unclear how handovers between mobile network operators (MNOs) and cooperation between application service providers will be managed, or how the presence of data traffic from other applications might affect I2V applications. There is also the question whether I2V applications present a compelling enough business-case to justify the investments needed to deploy eMBMS for such a purpose. There are very few multicast/broadcast solutions in place today, due to the high cost of infrastructure investment and UE upgrades.

Something else to consider is the use of cellular modems in domains that have different safety and security requirements. LTE modems will need to support the required safety certifications that govern being able to take active control of the vehicle. If, for example, the speed limit, transmitted from the infrastructure to a vehicle with an Advanced Driving Assistance System (ADAS), is used to set the cruise control of the car, the modem will have to meet the requirements of the relevant Automotive Safety Integrity Level (ASIL), and this will make the modem hardware more expensive.

Given that the current market for cell-phone subscriptions tops out at about 8 billion subscribers worldwide, while the automotive market represents only about 100 million cars worldwide per year, the modem industry may not see a need to support automotive-specific requirements. The automotive industry has a history of moving slowly, when it comes to cellular connectivity, in part because vehicles have, traditionally, been a lower priority for the cellular industry.

3.2. Cellular for safety-related use-cases: V2V

The technical challenges faced by cellular technology for non-safety-related use-cases, with I2V and V2I communication, are relatively minor when compared to the challenges faced regarding safety-related issues and V2V communication.

The cellular network could, if available, be used for V2V communication. A car generates a message, the network receives it, and then re-transmits it to all other cars. Assuming that there is complete cellular coverage along all roads (which is not the case), the service will need to provide very high data bandwidth with very low latency. The reality, though, is that today's cellular networks don't offer this level of performance.

Some V2V use-cases require continuous information exchange (0.1 to 20 Hz) among vehicles, and this generates too much data for unicast LTE networks to handle, see Table III in the appendix. According to the DoT's ITS Joint Program Office, a single car broadcasting V2V Cooperative Awareness Message (CAM), according to the E.U. standard, or the Basic Safety Message (BSM), according to the U.S. standard, generates about 0.5 Gbyte per month, at a peak rate of 2.5 Kbyte/second. That assumes a 256 bytes per message, at five messages per second, and four hours of driving per day. At the receiver side, assuming 30 cars (or a peak of 300) in the area of interest, the infrastructure has to handle roughly 16 GBytes per month (or a peak of 750 kBytes per second) [4].

Cellular networks are historically bandwidth hungry and increase their requirements for bandwidth with every 3GPP release. More data also means more business, as MNOs typically bill based on resources used ($/bit/s/Hz). V2V traffic is, in theory, required to be supported for free, and this means MNOs will have to develop alternative business models to justify any investments in additional V2x traffic. The use of eMBMS protocols, as already part of Release 8, could mitigate the issue, but, as discussed above, they are not widely deployed.

There are some V2V use-cases that don't require high bandwidth, including event-based broadcasting of Decentralized Environmental Notification messages (DENM). The cellular network could support these use-cases, but the fact that these messages require very low latency presents a problem. Cellular systems are capable of low latency, but not in all conditions, such as when operating across multiple MNOs, across borders, or even across cells, if resources are not pre-allocated to V2x services. This is particularly true for the most critical use-case, the pre-crash warning message, which requires a latency of only 50 ms.

Another way to support V2V use-cases with cellular is to develop a direct communication technology as part of the cellular system. This is, in fact, a focus of the 3GPP's V2x study group. The approach they envision builds on top of the Device-to-Device (D2D) communication protocol, which is identified as part of Release 12 but isn't suited for V2V use-cases. The D2D protocol relies on the cellular network having the required resources assigned to the user. For example, if two nearby users want to share a file, the network lets the terminals know which time-frequency resources that can use for direct communication (Figure 4). The network initializes the communication and manages the interference generated by the local D2D transmission. This approach won't work for V2V use-cases that have to be fulfilled even when

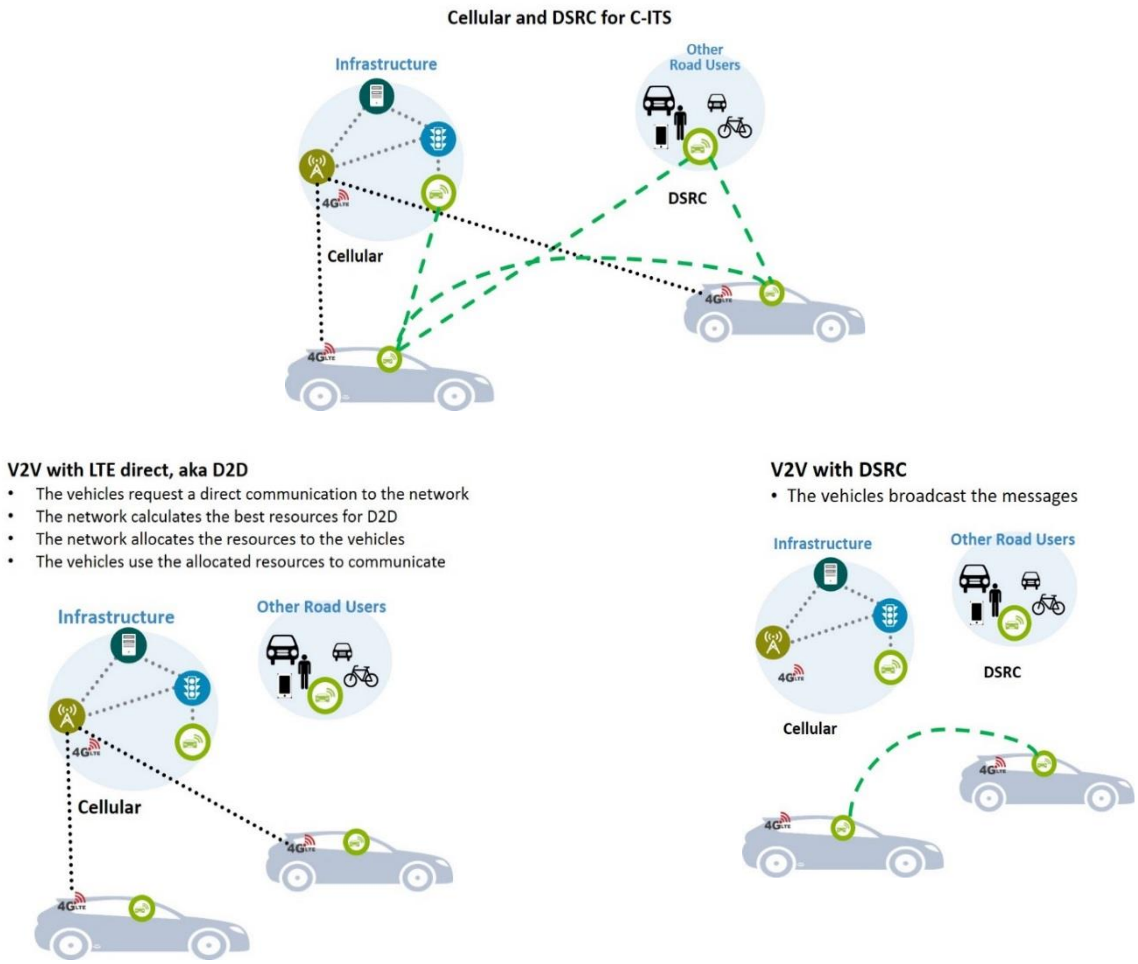

Figure 4 An impression on how the cellular device-to-device communication might work for V2V communications as compared to IEEE 802.11p. In the cellular case, the network remains in full control of the direct communication to ensure a proper management of the network interference. In IEEE 802.11p, the broadcasting of the message via the random access protocol ensures a fast execution of the transmission at the expense of a less efficient use of the wireless resources.

there's no network coverage. D2D can work in the absence of a network, but this is only allowed in emergency situations, and supported by a very slow protocol for device discovery. To make the D2D profile suitable for V2V communication, the 3GPP V2x study group has identified a number of fundamental challenges that will require changes to the signal structure (e.g. additional pilots to support a better channel estimation), and even a re-discussion of the best-suited modulation (e.g. SC-FDM or OFDM) [15,16]. Curiously enough, but maybe not too surprisingly, the technology choices being made by the 3GPP V2x study group are similar to those made by the 802.11p standard. These key changes will lead to new hardware solutions, and the associated time and costs for their development.

All cellular-based V2x services will require the active cooperation of application service providers (ASPs), so as to achieve the largest benefits from cooperative data-sharing. From a business standpoint, ASPs will have to define new models for cooperation, and these models will only develop very gradually. V2x services based on 802.11p don't require this kind of cooperation, since messages have already been standardized, and are sent out in the clear.

3.3. Timeline of cellular for V2x

We can be certain that the cellular community will find a technical solution for V2x, since the 3GPP has a very strong record with technology. The question is not really if, but when, since there is still a lot of

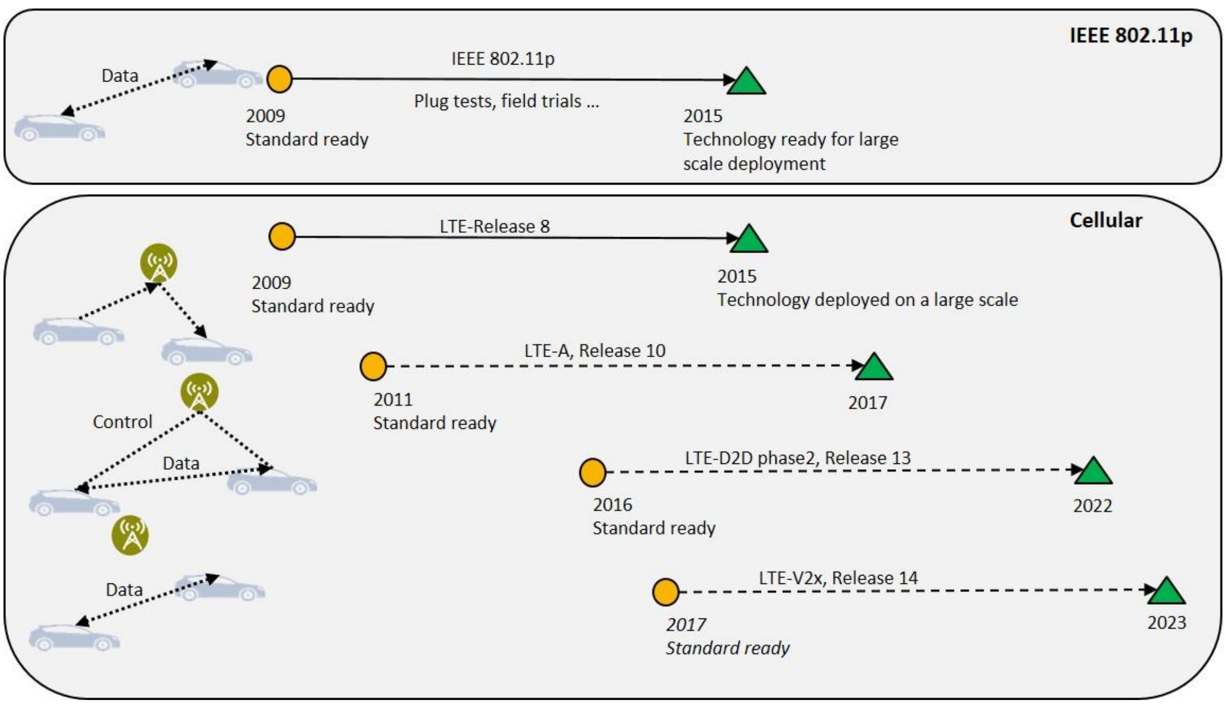

Figure 5 Timeline of IEEE 802.11p versus cellular technologies for supporting the V2V use case. Current and future LTE releases support V2V in a more and more efficient way. However, only LTE-V2x is designed to address the V2V use cases properly and it will be ready for large scale deployment only around 2023.

work to be done. It's reasonable to expect that support for V2x use-cases will become part of the 3GPP standard, at the earliest, with Releases 14 and 15, which are likely to be finalized by the end of 2017. It will then take more time – many years, perhaps – for the technology to be fully rolled out. In the past, large-scale infrastructure upgrades have, as mentioned above, taken as long as six years to complete. Using a similar timeline, V2x services for LTE-A won't be available until about 2023, and that's becoming optimistic (Figure 5).

The more realistic scenario is that V2x will be included in Release 16 onwards, in what is being referred to as 5G (Figure 6). At the moment, 5G remains a very broad concept. One of its most intriguing aspects, though, is that it will be heterogeneous in nature, with one umbrella technology that links together multiple, dissimilar communication pipes. V2x is likely to become part of the 5G ecosystem, with fundamentally redesigned hardware to support the architectural changes.

By the time the cellular community is able to address all V2x use-cases, other technologies, including

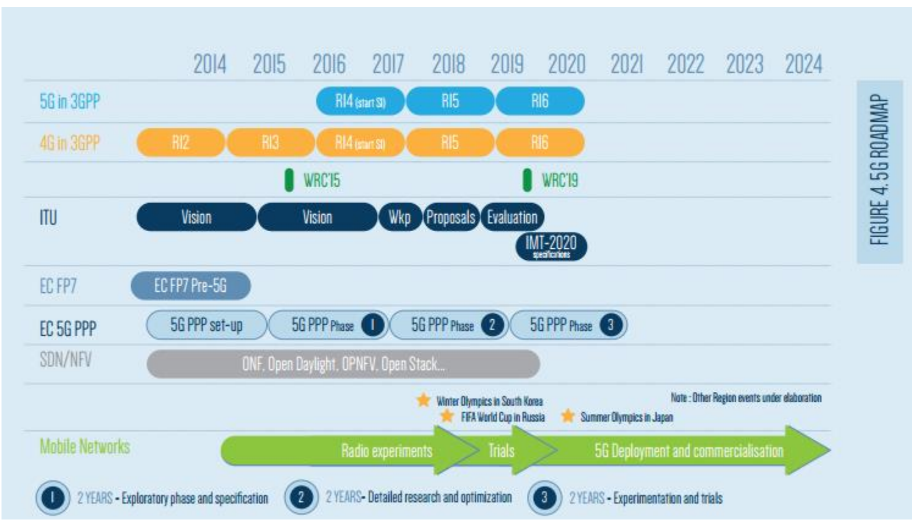

Figure 6 5G roadmap
Source: 5G Infrastructure Public Private Partnership (5G-PPP), 2015

802.11p, are likely to have already been put in place. This will make cellular a new competitor in a field that already has established players.

One might argue that waiting for cellular-based technologies would make sense because it means being able to re-use the car's existing communication pipe. However, as mentioned above, the hardware requirements for V2x are likely to be different enough that they will require separate solutions. Also, V2x use cases may become part of the 3GPP system, but probably won't become part of the mass-market silicon designed for mobile phones.

3.4. Safety and privacy considerations for cellular

Security is another aspect that needs to be considered. Current cellular systems use the Subscriber Identity Module (SIM) card in the phone for network authentication. The network recognizes the SIM card and, based on this recognition, provides a secure connection. SIMs may work for network-assisted V2x communication, but in the absence of a network, there needs to be some other kind of security mechanism in place. 802.11p defines this kind of security mechanism, and the 3GPP may well adopt a similar approach, but has not yet formally addressed the issue.

In the United States, the National Highway Traffic Safety Administration (NHSTA) has raised the issue of privacy [17]. In a network-based solution, user data will pass through the network on its way to the cloud. Operators will need to provide the appropriate mechanisms to protect user data in the cloud and, perhaps more important, users will have to accept and trust those mechanisms. Privacy is a growing concern for everyone, so one can expect significant opposition of cloud-based systems. With an IEEE 802.11p based solution, messages don't have to go to the cloud, and this can make it easier to address privacy-related concerns.

3.5. Implications for the cellular infrastructure

The fact that cellular networks are already in place around the world is often cited as a reason to use cellular for V2x solutions. The main argument is that, since the cellular infrastructure is already there, there's no need to invest in and deploy a new infrastructure for 802.11p. But, as mentioned above, using the existing cellular infrastructure for V2x is not as simple as it sounds, because today's infrastructure isn't equipped to support the many V2x use cases that require short latency in situations of high mobility or congestion.

It's important to note that 802.11p-based technology, in the form of road-side units (RSUs), can be deployed in much of the existing roadway infrastructure, including traffic lights and traffic signs. Unlike the cellular infrastructure, which requires new base-station towers for expansion, the 802.11p infrastructure can make use of structures that are there today, and this represents a significant cost savings in terms of near- and long-term deployment. RSUs in intersections also makes sense from a system requirements point of view. Signal Phase and Timing controllers are collocated with the RSU enabling many safety, mobility and traffic efficiency applications. Intersections are where the "action" takes place.

Another aspect to keep in mind with 802.11p is that the spectrum for 802.11p-based V2x services has already been allocated worldwide. As described earlier, the 5.9 GHz region includes 75 MHz of bandwidth set aside for use with 802.11p-based V2x services. This is one of 802.11p's greatest assets. Countries, states, carmakers, and infrastructure providers need to prove their compliance with the standards and then they will be able to simply operate in the 5.9 GHz region. No need of subscriptions, roaming agreements or similar. Today's providers of cellular services already face challenges with bandwidth, in light of growing consumer activity and expansion of the IoT, and may have difficulty meeting the technical and business requirements of V2x.

4. Conclusions

LTE Release 8 may already be part of vehicles, but it will take a long time – perhaps eight years or more – before the required cellular standards, namely LTE-A and 5G, fully support all safety-related and non-safety-related V2x use-cases. By contrast, field proven, compliance tested solutions based on 802.11p are ready right now, and can be deployed on a large scale, worldwide, at any time. Moving ahead with 802.11p means enjoying the benefits of V2x use-cases that much sooner.

At NXP, Cohda Wireless and Siemens, we believe 802.11p is the better choice for deploying V2x applications today, because it's ready to roll. But we also see the need for broader compatibility. We are working on co-existence, which will make 802.11p and LTE-A/5G more compatible, and are even considering the option to merge the two, to create a heterogeneous vehicular networking system that leverages the best of both – the ability of 802.11p to support safety-related use-cases, and the ability of LTE-A/5G to support non-safety-related use-cases.

Endnotes

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See Also

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5G Infrastructure Public Private Partnership: 5G Vision Brochure (https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf)

Appendix

Safety Service	Use-case	Type	Communication mode	Minimum Frequency	Maximum latency
Vehicle status warning	Emergency electronic brake lights	DEN / V2x	Time limited, event-based periodic broadcast	10 Hz	100 ms
	Abnormal condition warning	DEN / V2x	Time limited, event-based periodic broadcast	1 Hz	100 ms
Vehicle type warning	Emergency vehicle warning	CAM / V2x	Periodic broadcast, vehicle-mode dependent	10 Hz	100 ms
	Slow vehicle warning	CAM / V2x	Periodic broadcast, vehicle-mode dependent	2 Hz	100 ms
	Motorcycle warning	CAM / V2x	Periodic broadcast	2 Hz	100 ms
	Vulnerable road user warning	CAM / VRU2x	Periodic broadcast	1 Hz	100 ms
Traffic hazard warning	Wrong way driving warning	DEN / V2x	Time limited, event-based periodic broadcast	10 Hz	100 ms
	Stationary vehicle warning	DEN / x2x	Time limited, event-based periodic broadcast	10 Hz	100 ms
	Traffic condition warning	DEN / x2x	Time limited, event-based periodic broadcast	1 Hz	100 ms
	Signal violation warning	DEN / I2x	Time limited, event-based periodic broadcast	10 Hz	100 ms
	Roadwork warning	DEN / I2x	Time limited, event-based periodic broadcast	2 Hz	100 ms
Dynamic vehicle warning	Overtaking vehicle warning	DEN / V2x	Time limited, event-based periodic broadcast	10 Hz	100 ms
	Lane change assistance	DEN / V2x	Time limited, event-base periodic broadcast	10 Hz	100 ms
	Pre-crash sensing warning	DEN / V2x	Time limited, event-based periodic broadcast	10 Hz	50 ms
	Co-operative glare reduction	DEN / V2x	Time limited, event-based periodic broadcast	2 Hz	100 ms

Table I. Safety-related use-cases. DEN stands for Decentralized Environmental Notification, CAM for Cooperative Awareness Message.

Non-safety services	Use-case	Type	Communication mode	Minimum Frequency	Maximum latency
Traffic management	Speed limits	I2V	Periodic broadcast	1 Hz	
	Traffic light optimal speed advisory	I2V	Periodic broadcast	2 Hz	100 ms
	Intersection management	I2V	Periodic broadcast	1 Hz	100 ms
	Co-operative flexible lane change	I2V	Periodic broadcast	1 Hz	500 ms
	Electronic toll collection	I2V	Periodic broadcast	1 Hz	500 ms
Infotainment	Point of interest notification	I2V	Periodic broadcast	1 Hz	500 ms
	Local Electronic commerce	I2V, V2I	Duplex, Internet access	1 Hz	500 ms
	Media download	I2V	Duplex, Internet access	1 Hz	500 ms
	Map download and update	I2V	Duplex, Internet access	1 Hz	500 ms

Table II. Non-safety-related use-cases.

Acronyms

3GPP	Third Generation Partnership Project
4G	forth Generation
5G	fifth generation

ADAS	Advanced Driving Assistance System
ASIL	Automotive Safety Integrity Level
ASP	Application Service Providers
BSM	Basic Safety Message
CAM	Cooperative Awareness Messages
C-ITS	Cooperative Intelligent Traffic Systems
DEN	Decentralized Environmental Notifications
DoT	Department of Transportation
DSRC	Direct Short Range Communications
eMBMS	enhanced Multimedia Broadcast Multicast Services
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GDP	Gross Domestic Product
LTE	Long Term Evolution
LTE-A	Long Term Evolution- Advanced
MNO	Mobile Network Operator
NHTSA	National Highway Traffic Safety Agency
OFDM	Orthogonal Frequency Division Multiplexing
RSU	Road Side Unit
SC-FDM	Single Carrier Frequency Division Multiplexing
SIM	Subscriber Identification Module
UE	User Equipment
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2x	Vehicle to infrastructure and Vehicle to vehicle
WAVE	Wireless Access in Vehicular Environments
WHO	World Health Organization