Towards 5G based Ultra-Reliable Vehicular Communication

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ABSTRACT
Cooperative Intelligent Transportation Systems (C-ITS) are enablers for development of innovative vehicular applications, offering safer and more efficient traffic and transport systems. Reliable wireless communication between vehicles and road infrastructure is crucial for high-performance C-ITS applications. Most of the existing C-ITS applications are based on broadcast communication, using the IEEE 802.11p protocol which does not have any explicit acknowledgement mechanism and therefore, no reliability guarantees. In this paper, we look at the potential of the next generation cellular networks, 5G, to contribute to vehicular communications with a higher level of reliability. The ultra-reliable Machine-Type Communication (uMTC) service of 5G, is proposed as a means of providing very high reliability and low latency for critical applications. Hence, we investigate what are the potential enhancements to the current generation mobile networking system, 4G, as a step forward, towards the next generation, capable of supporting C-ITS applications, with strict reliability requirements.

Keywords
Vehicular networks, IEEE 802.11p, reliable broadcast, mobile networking systems, 5G, uMTC.

1. INTRODUCTION
Vehicular networks and ITS systems have been of significant importance and development over the last decade and new advanced systems have already shown noteworthy improvements in traffic efficiency and safety. Many applications in the domain of vehicular networks aim to notify large number of vehicles with rather short latency. Accordingly, reliable data dissemination is fundamental for such applications. Reliability implies that messages must be correctly delivered to all intended receivers in a network, with reasonable latency, which is challenging to accomplish, mainly due to unstable characteristics of vehicular networks.

Broadcasting is one of the main types of information dissemination in vehicular networks and is based on the IEEE 802.11p protocol family [6]. The drawback of this protocol lays in its reliability, since it does not have any explicit acknowledgment scheme for broadcast [6, 15]. While reliability is always targeted for all communication, it could be of significant importance for safety critical applications, such as safety applications in the domain of vehicular systems.

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Many approaches, introducing reliability to vehicular broadcast communication, are proposed in the literature [6, 7]. Although they improve reliability to some extent, it is still an open research issue to provide ultra-reliable vehicular communication, particularly in challenging situations such as high density and velocity of vehicles [15].

The current generation of the mobile networking system is considered as a promising alternative for dependable vehicular communication in a number of works [3, 8]. During the design process of the mobile networking systems, vehicular communication was not a specified use case, therefore, the design of these systems are not optimized for vehicular communications. As a result, in its current form, this communication system also does not meet all requirements regarding reliability, delay and scalability to enable high-performance C-ITS applications [8].

The proposed next generation mobile networking system, 5G, is considered as a potential enabler for ultra-reliable communication, as we will discuss later in this paper. It is not just an enhancement of the 4G mobile networking system, but rather an end-to-end system, which alongside mobile broadband services in its core, will also focus on other types of services from the very beginning of its design.

In this work, we discuss the limitations and potentials for enhancing the current mobile networking system for vehicular communications, considering the integration of mobile networking and vehicular systems. Furthermore, we propose solutions for integrating these two communication domains, with their technical challenges and expected gains. To achieve this, we investigate what are the design principles and which potential components in the current architecture of 4G mobile networking system are demanded, to facilitate enabling such reliable communication. This can be seen as a step towards the next generation cellular system, 5G, and realization of the uMTC service.

The paper is organized as follows. Section 2 discusses the related work. Section 3 provides the objective of this research, the research questions that this work tries to answer and the research methods used to answer these questions. Section 4 is about the demanding requirements of ITS application and the potential benefits and limitations of utilizing the existing mobile networking system for vehicular communication. Section 5 is devoted to the integration principles of these two domains. Section 6 discusses possible enhancements to the architecture of the current mobile networking system to support vehicular communication, in an efficient manner. Then, section 7 concludes the work and discusses future research subjects.

2. RELATED WORK

Information exchange between vehicles is an important enabler for C-ITS applications. Reliable communication is a crucial requirement for these applications. Therefore, many works propose possible enhancements of IEEE 802.11p, the communication standard for C-ITS applications, or discuss alternatives technologies that can improve the reliability in vehicular communication.

Many enhancements of the IEEE 802.11p protocol family are proposed in the literature. For example, in [6] M. Gholibeigi et al. introduce a single-hop receiver-based reliable broadcasting variation that is modeled and analyzed to show how messages can be distributed reliably in a network of nodes using IEEE 802.11p. The work in [7] by M. Gholibeigi et al. show results of evaluating the progress of multi-hop broadcasting in vehicular networks. Additionally, in [13] G. Remy et al. discuss a possible enhancement of IEEE 802.11p using a Multi-Hop forwarding communication system in aggregation with cellular technology. Finally, in [17] the author discusses the use of a Decentralized Congestion Control (DCC) algorithm that targets to deal with the increased network load of using a multi-hop enhancement of IEEE 802.11p.

Although improvements for IEEE 802.11p have been achieved to some extent, the necessary requirements for vehicular communication to enable high-performance C-ITS applications are not met. Therefore, alternative technologies have been proposed as a replacement of IEEE 802.11p for vehicular communication.

Furthermore, the next generation mobile networking systems, 5G, introduces, next to improved mobile broadband, support for Machine Type Communication (MTC). As introduced in [10], a part of this MTC service is ultra-reliable MTC (uMTC), which is targeting very reliable communication with an extremely low latency. The works [9, 10] are deliverables from the METIS2020 project, a project aiming at laying a foundation for 5G. These works discuss, alongside many other things, the requirements and test cases targeted for 5G. Furthermore, in [15] E.G. Ström et al. discuss regarding applying uMTC for vehicular broadcast and reason about its benefits compared to IEEE 802.11p and how the interaction between the applications and the service could be orchestrated. Also some integration approaches between IEEE 802.11p and uMTC are introduced.

Additionally, the concept of Device-to-Device communication (D2D), as introduced in [5, 16], is also mentioned as a concept for vehicular communication. The idea behind D2D is that devices that are located close to each other communicate directly instead of using the uplink and downlink from the base station, which is common for cellular communication. In [5] G. Fodor et al. show how D2D communication can be used to reduce energy usage at base stations, while at the same time reducing the probability that the available Signal-to-Noise Ration (SINR) is insufficient for a stable connection. In [16] W. Sun et al. show how this can be used in vehicular communication. The main focus in this research is to ensure the message reliability for the vehicles, while maximizing the data rates for cellular users.

In [3] the applicability of LTE, which is the last generation of the mobile networking system, for vehicular communication is investigated by discussing what requirements, required for enabling C-ITS applications, could be met by LTE. The authors concluded that there are several challenges ahead before LTE can be used for vehicular communication. Especially vehicle-to-vehicle (V2V) communication is extremely challenging for a centralized architecture, which is an architecture where communication is regulated from a center point, called a base station, because it is not optimized for the rapidly changing positions of vehicles.

In [8] there is a comprehensive comparison between LTE and IEEE 802.11p discussing their ability to meet vehicular communication requirements. Comparisons are made using simulations in terms of delay, reliability, scalability and mobility support using different speeds, traffic densities and transmission frequencies. The authors concluded that LTE, although not realizing all requirements for high-performance C-ITS applications, performs significantly better than IEEE 802.11p for these performance indicators.

As also referred in this work, there are many approaches in the literature to improve broadcast reliability in vehicular networks. However, ensuring ultra-reliable broadcast communication, using existing technologies [7] is beside the point and not yet achieved. Therefore, Motivated by the concepts of Internet of Things (IoT) and heterogeneous networking, as the main design criteria for the next generation of the mobile networking system, this research considers the integration of the current mobile networking systems in vehicular communication and it provides an architecture using todays design principles as a first step towards 5G.

3. RESEARCH OBJECTIVE

The objective of this research is to conceptualize a system, composed of the integration of the current mobile networking and vehicular communication systems. This is proposed as a means of realizing the reliability requirements of high-performance vehicular C-ITS applications. This system will be in line with the current advancements, initiated for the introduction of the uMTC service in the 5G mobile networking system.

3.1 Research questions

In order to achieve our research goal, we formulate the following research questions:

RQ1 What are the main requirements of critical vehicular applications and the limitations of existing technologies to fulfill them.

RQ2 What is the potential gain of the mobile networking system to realize these requirements.

RQ3 What are the design principles to enhance the current mobile networking system accordingly, to support such requirements.

3.2 Research methods

The following research methods will be used to answer the research questions:

The first research question is answered by doing literature research regarding the requirements of critical vehicular applications and limitations of existing technologies for such applications.

The second research question is answered by doing literature study regarding the current research activities, by the industrial and academic initiatives, with the focus on the next generation of the mobile networking system.

Given the knowledge, obtained by the first two questions, we come up with the main design principles of a unified system and propose a corresponding architecture.

4. THE CURRENT STATE OF VEHICULAR COMMUNICATION

As discussed in section 1 and 2, the IEEE 802.11p protocol family, which is the standard communication technology for vehicular communication, has some limitations, such as the lack of reliability guarantees. Furthermore, alternative methods for vehicular communication have been introduced, such as cellular technologies. In this section we first discuss the requirements for vehicular communication. Additionally, we discuss the limitations and potentials of the existing technologies that have been proposed for vehicular communication over the years.

4.1 Requirements of C-ITS applications

Vehicular communication required to enable high-performance C-ITS applications has strict requirements. There are no exact requirements established, however, many works agree that high reliability and low latency are of the utmost importance [3, 9, 15]. An example of how important the reliability and latency requirements are, can be seen in [9], where the METIS2020 projects provides a test case for vehicular communication targeting a reliability of 99.999% with a maximum end-to-end (E2E) latency of 5ms. Furthermore, there are some other requirements important for vehicular communication, in particular, the ability of networking systems to be operational at very high relative speeds. For example, two cars driving in opposite directions, while communicating, can have a relative speed of up to 300 km/h, this should be well supported by the networking system. Additionally, to be able to actually use the previously mentioned requirements, it is important that the network has very good coverage. It should be possible to establish a connection with nearby vehicles even in the most remote places.

4.2 Limitations and potentials of existing technologies

IEEE 802.11p, as discussed in the introduction, is a protocol specifically designed for communication in vehicular systems [8]. Ad-hoc connectivity and broadcasting are some of the desirable features that make it suitable solution for vehicular communication [17]. The main difference of IEEE 802.11p, compared to IEEE 802.11, which is the basis for wireless networking systems, is that it does not establish a basic service set for data exchange. However, it does have limitations that hinders it from being used in high-performance C-ITS applications. First of all, IEEE 802.11p does not have an explicit acknowledgement scheme for broadcast type of communication, which prevents it from having Quality of Service (QoS) guarantees regarding packet delivery. Furthermore, its delay and throughput performance significantly degrades as the network becomes more dense. Consequently, a maximum latency cannot be guaranteed. There are solutions that cope with issues caused by an increased network load, for example, the Decentralized Congestion Control (DCC) algorithm [17]; however, these bring new limitations, which in the case of the DCC algorithm are a significant decrease in the amount of broadcasts possible by a vehicle in a second. Finally, another limitation of IEEE 802.11p is the limited transmission range, which is typically several hundred meters. This can be extended using a multi-hop configuration, however, multi-hop communication introduces other challenges, such as inefficient resource allocation, rapidly changing topologies and a significant increase in the amount of messages communicated over the network, due to vehicles relaying messages to extend the transmission range [4, 7].

In contrast, the centralized architecture of mobile networking systems also has a number of advantages. First of all, it allows for a number of additional applications that are not possible in a local IEEE 802.11p network. For example, it allows for traffic information and traffic efficiency applications [3]. Servers can receive and process the destination and route data from every vehicle on the road. This allows them to analyse the routes of the different vehicles and predict when a certain road will be busy. This information can then be used to alternate the route of some of the vehicles to prevent delays through traffic jams [13] Another application could be scheduling the periority of vehicles to cross at an intersection. These applications are not possible with IEEE 802.11p, because of the decentralized and local properties of the network and the concerns with none line of sight interference in combination with the lack of QoS guarantees for communication around intersections[3]. Furthermore, the Internet connection can be used to enable infotainment functionalities such as streaming music and video or making Voice over IP (VoIP) calls. It also allows vehicles to send messages to a single vehicle and it enables communication with an nearly unlimited transmission range.

However, as discussed in [17] the mobile networking system also have significant limitations. First of all, the latency rises when the number of users in a cell increases. For example, event triggered messages distributed to all devices can reach up to 150 devices. Furthermore, the centralized architecture of mobile networking systems requires data packets to traverse the infrastructure involving a transmission over the uplink and the downlink. This is not only suboptimal, compared to a single transmission from source to destination, but it also introduces additional delay, because of the double amount of transmission and this may also result in the bottleneck of becoming a single point of failure. Additionally, the current generation of the mobile networking system is designed for mobile broadband and may, therefore, not be optimized for the large amount of small data packets to be sent to support vehicular communication. Besides all these facts, the random access procedure of the current generation mobile networking system requires at least one preamble transmission and one downlink feedback. This will introduce additional delay before the data packets are actually transmitted. Finally, none of the releases of the current generation of mobile networking system have perfect coverage and vehicular applications communicating using these networking systems will, therefore, not be able to communicate everywhere due to a lack of coverage, for instance in rural areas.

As an alternative to IEEE 802.11p direct communication could also be accomplished using D2D communication. LTE, as the latest mobile networking system introduced by the 3GPP initiative also has a D2D service called Proximity Service (ProSe) [3]. This service will allow users, when they are inside communication range, regardless of the coverage from infrastructure, to directly communicate with each other. This service, however, also has a number of limitations. The current release of the ProSe specification has been designed for the use in public safety applications, more specifically, with low mobility support, no QoS guarantees and exclusively one-to-many communication, in contrast to the all-to-all broadcast used for vehicular communication [17]. Another limitation of the current specification is the rather slow connection setup procedures, which increases the delay before messages can be sent. Additionally, optimization of the specification is required for the handover of allocated resources. This is especially important since fast-travelling cars will cross cell boundaries often [17].

As discussed in this section, all existing technologies suggested for vehicular communication have their limitations. The main remaining issue is the lack of reliability in vehicular communication. Therefore, this work discusses possible solutions for both the near future and thereafter.

5. 5G-BASED VEHICULAR COMMUNICATION

As discussed earlier in the introduction, the next generation of the mobile networking system, 5G, alongside enhanced mobile broadband as its core, aims to provide an end-to-end communication system for many diverse use cases. In [10] METIS project describes 5G as a combination of three generic services for different use cases, as illustrated in Figure 1.

Figure 1. 5G Services.

The first one is xMBB, which stands for extreme mobile broadband, and represents the next generation of mobile broadband. Mobile broadband has always been the key service offered by the mobile networking system. 5G is targeting to, similar to the old systems, increase the data rate significantly from its predecessor. Therefore, xMBB targets support of 10 to 100 times more devices at the same time, enabling a good user-experience even in a very dense area.

The second service is massive Machine-Type Communication (mMTC). This service is aimed at smart infrastructures and other Internet of Things (IoT) related applications. Nodes inside these networks usually only send small event-triggered messages that do not have very strict delivery time requirements. Therefore, this service also aims at supporting a high number of devices, however, in contrast to xMBB, while trying to minimize the battery usage by the devices. Examples of use cases for mMTC are smart cities, smart grids and sensor networks.

The third one is ultra-reliable Machine-Type Communication (uMTC) service. The aim for this service is to realize communication at a low latency with a high reliability. Example use cases are eHealth applications, mission critical communication and safety vehicular applications.

5.1 uMTC

uMTC is the service proposed as part of the next generation mobile networking systems targeting reliable communication with little latency. The requirements stated for the test cases target a reliability of 99.999% and a maximum E2E latency of 5 ms [10]. These requirements make it a good alternative for vehicular communication. Alongside these properties, uMTC has some other properties which are important for vehicular communication. uMTC will be operational at a relative speed of 500 kmph and it will support various levels of infrastructure assistance, allowing applications to adapt to the quality of the network connection. For example, if the current state of the network is fairly composed, then vehicles are notified about this and they can fully utilise the network for communication. However, if for some reason, for example heavy workload on the network, the network is very occupied, then the vehicles will be notified and applications can adjust their communication and services accordingly. An important enabler for these communication requirements is D2D communication, which will be discussed in the next section.

5.2 Device-to-Device Communication

There are two main motivations for introducing D2D communication for Machine-Type Communication. The initial reason is the possibility to offload the mobile networking system [12], the network is less occupied with this communication, since only one transmission is necessary and that transmission goes directly from source to destination. Additionally, it also introduces the opportunity of having reliable peer-to-peer links for direct communication [12]. Next to these two reason, D2D has other properties beneficial for vehicular communication. Availability of the network is also a requirement for uMTC and cellular coverage in remote areas is not always possible, D2D communication is operational even with limited or no network connectivity. Furthermore, the use of D2D immediately enables the use of broadcast communication, which also was established as one of the requirements. This means that after proper synchronization with either the assistance of the eNodeB, which is the name of the base station in LTE and 5G or exclusively between the communicating cars, when the cars are outside of network coverage, all cars will be able to broadcast messages to all other cars in its range.

5G may sound like the perfect technology to enable reliable vehicular communication, however, it is merely in the design and research phase. The requirements mentioned are only a proposal of what the next generation of mobile networking systems are supposed to accomplish. History tells us that these technologies will not be released before the next decennium. Since every generation is an enhancement of the previous one, we focus on the current generation mobile networking system, 4G, as the building grounds for the next generation. The same goes for 5G, which will be an enhancements of the current generation mobile networking system and the current generation will be used as input for the development of 5G. Therefore, the enhancements for the current generation mobile networking system proposed in this paper can be seen as a first step towards 5G.

6. ENHANCEMENTS TO THE MOBILE NETWORKING SYSTEM

When integrating the mobile networking system with vehicular networking, the first focus is to answer which communication technology to use. The two main communication categories in the 4G mobile networking system (LTE) are 3GPP-based (using eNodeB base stations) and non-3GPP-based (using WiFi and WiMax antennas) communications. The main difference between these two categories is that WiFi and WiMax are IEEE efforts, which means that it is an open standard debated by a large community of engineers and researchers. 3GPP standards on the other hand are developed by a group comprised of carriers and equipment vendors and is not an open standard. In this paper we discuss the design principles of using alternative communication technologies for integration purpose.

LTE is the implementation of the current 4G generation of the mobile networking system, used by most of the telecom operators. LTE is backwards compatible with previous generations cellular networks, such as 3G, and it still allows for the use of these previous generations of mobile networking systems if LTE is not available. Furthermore, it can handle a connection even at high speeds up to 450 km/h [3]. Additionally, LTE can provide a round trip time of theoretically under 10 ms and a transfer latency in the radio access up to 100 ms [3]. It also prioritizes serving flows based on the QoS requirement of a package, for example, depending on the delay requirement or on the packet loss rate

Another communication technology is WiMax, which is a standard based on IEEE 802.16 [2, 11]. It has a theoretical range of 50 km. However, it is optimized for shorter range communication and data rates fall off significantly when the distance to the base station increases over 10 km. Furthermore, the set-up of WiMax as a communication technology is more cost-efficient than LTE, therefore, the cost for end users are possibly also lower. WiMax has a strict master-slave technique, where base stations have full control transmission scheduling, allowing for higher levels of QoS guarantees at the cost of additional scheduling at a base station, which causes additional overhead and delay. Additionally, WiMax has lower bit rates and less throughput than LTE, making it a not very well suited solution when the density on the road increases.

The main strengths of LTE, motivating its use for vehicular communication, are the lower round trip time, the support for high velocities and the backwards compatibility with the previous generations of mobile networking systems. A downside of using LTE is that the On Board Units (OBU) inside vehicles have to be changed to support cellular communication. (e.g., to use a SIM card to enable a connection to the network, which means that there will be costs for the use of the network. WiMax has as positive properties the more cost-efficient mobile networking system setup, which might reduce the costs for users. Additionally LTE and WiMax have varying QoS mechanisms. WiMax has a QoS mode optimized for fixed-interval fixed-size communication, therefore, optimized for Co-operative Awareness Messages (CAM), which are safety messages send on a time interval to update the cars in the area with the current situation of the car. However, LTE has a very low latency mode, which would be of good use for Decentralized Environmental Notification Messages (DENM) [1], which are safety messages triggered by events, such as an accident or a slippery road. Additionally, WiMax has as disadvantage, compared to LTE, an increased latency, reduced throughput and inferior mobility support.

To improve the efficiency of mobile networking systems for vehicular communication, a number of changes and improvements are suggested to be applied to the components in the mobile networking system. First of all, using Multimedia Broadcast Multicast Service (MBMS) on the downlink [3]. MBMS is a feature of LTE that supports broadcasting on the downlink. It allows eNodeBs to send a message to all relevant vehicles at the same time. The main advantage of using MBMS, compared to unicast, is the fact that it is more resource efficient [3], saving resources for other users of mobile networking services. However, it may imply an increase of latency due to the MBMS session setup [3]. However, especially in situations with dense traffic, MBMS has less latency and is more resource efficient than unicast. Additionally, the current state of MBMS is not efficient for vehicular broadcasting, since it has predetermined and fixed broadcast areas, which are not adjusted to the road infrastructure. Therefore, broadcasts in the current situation are less efficient due to the possible necessity of a message being spread over multiple MBMS areas, while the targeted vehicles are close by each other, requiring additional resources. Next to that, an additional server is necessary to keep track of the geographical positions of vehicles to determine to which vehicles a message should be broadcast to. Furthermore, it does not support the fast differing topology and characteristics of vehicular communication, making it necessary to setup the MBMS session for every transmission [14].

Additionally, the use of D2D communication between vehicles as a substitute of IEEE 802.11p could be an enabler for more reliable communication. D2D is a direct communication between two or more devices on the spectrum of the mobile networking system. It is currently only supported by LTE under the name Proximity Services (ProSe). The direct connection surpasses the base station and any other core network, allowing transmissions at lower latencies and with multicast functionality, the broadcasting of a message to a previously established group of recipients at once. ProSe is, however, as discussed in section 4, not well suited for vehicular communications, as it is designed to meet the requirements for public safety applications and commercial consumer applications.

Besides the use of mobile networking services as a replacement of IEEE 802.11p, an aggregation between IEEE 802.11p and mobile networking systems could be a good approach. For instance, using IEEE 802.11p for local communication, such as CAM

data packets, significantly decreases the traffic load, while the dissemination of DENM messages using LTE can increase the range and accordingly the reliability of these messages significantly, compared to IEEE 802.11p. A reasonable set-up of such aggregation will be a major challenge, since vehicles have to decide which messages are critical to send over mobile networking systems or can be send locally using IEEE 802.11p.

To further enhance the possibilities of this aggregation and to overcome the challenge mentioned, a possible improvement would be the integration of clusters for the uplink. Clusters could be created with vehicles in a close proximity on a certain road. The eNodeB determines a cluster head of an established cluster. The cluster head is the vehicle that collects the Floating Car Data (FCD), which is the data regarding the state of a car used for traffic efficiency applications, and the CAM messages of all vehicles inside that cluster. After collecting all this data, the cluster head summarizes all the data from every vehicle in the cluster and sends it to the server processing the data for traffic efficiency applications. The main advantage of such approach is that only one uplink data packet has to be sent for every cluster, instead of all vehicles sending them. This prevents congestion on the uplink. However, an additional component is necessary for eNodeBs to support the creation, adaption and handover of these clusters. This system can both support CAM messages for safety applications and FCD messages for traffic efficiency applications [13].

Given these enhancement possibilities, we propose an architecture that uses an aggregation of IEEE 802.11p and cellular services, in particular LTE. In this aggregation IEEE 802.11p will be used for CAM messages. Besides the fact that it has a lower latency, it will also reduce the amount of messages send over the LTE network significantly. Furthermore, reliability is important for CAM messages, however not crucial when one message is not received by a number of vehicles then there is not immediately an accident. Additionally, certain informative DENM messages are also send using IEEE 802.11p. An example of an unimportant DENM message could be a message that the road is slippery. This message will be send by many vehicles in the area, therefore, the reliability of a single message is not that important. The only possible exceptions to this are very important DENM messages, for example, in the case of a big accident. In that case the transmission range of IEEE 802.11p may not be sufficient and due to the large coverage range of eNodeB, which is up to 100 km [2], LTE can be used to distribute the DENM message outside the IEEE 802.11p transmission range. For this, the knowledge regarding vehicles geographic positions is necessary for LTE. This enables eNodeBs to determine the vehicles that are relevant recipients of the DENM message. Furthermore, MBMS will be used on the downlink to enable efficient use of resources when distributing these messages.

For traffic efficiency applications, this aggregation could be used to implement the cluster infrastructure. As discussed earlier, clusters are a group of vehicles inside IEEE 802.11p broadcasting range where one cluster head collects the FCD messages from all vehicles and collectively sends them to a server. This server is part of our new architecture and will have to be placed in the core network. Furthermore, this server can be used to solve the previously stated issue of determining relevant recipients of important DENM messages. This entire concept is illustrated in Figure 2.

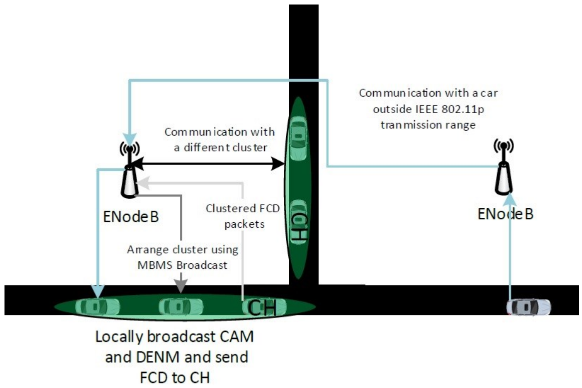

Figure 2. Proposed architecture.

Finally, ProSe could in the future be a possible substitute for IEEE 802.11p. In its current state it has many limitations to be integrated in our architecture, however, targets set for the next release of LTE, determined by the 3GPP initiative, are enhancements of ProSe to improve the support of Vehicle-To-Vehicle communication.

7. CONCLUSION AND FUTURE WORK

Many challenges towards reliable vehicular communication have already been solved over the years, however, without a solution that guarantees the required reliability. We discussed what the requirement for reliable vehicular communication are and we discussed what the limitations are of existing technologies. Furthermore, it was concluded that, although the current mobile networking systems and next generation of mobile networking systems are getting closer to allowing the levels of reliability necessary for high-performance C-ITS applications, this subject is an important open research issue. Additionally, we introduced an architecture based on an aggregation between IEEE 802.11p and LTE that could be used as a next step towards reliable vehicular communication, using existing technologies.

In future research, continuing with this work, the proposed architecture can be analysed by either mathematical models or simulations to give a more accurate perspective of its potentials and limitations. Furthermore, with the introduction of new communication technologies, this architecture could be improved to support

Additionally, the most significant remaining challenge in the field of vehicular communication is reliable communication between vehicles. Existing technologies, such as the current generation cellular networks and IEEE 802.11p cannot guarantee the necessary QoS regarding reliability and latency, for applications to rely on. The proposals introduced for 5G and, before that, release 14 of LTE show potential towards a solution for the reliability problem.

Solutions for the reliability problem, that are introduced by improved mobile networking systems brings us closer to the actual integration of C-ITS applications in vehicles. However, this brings us a next challenge, the implementation and integration of these services in both the mobile networking system's architecture as in vehicles. This could be an important subject of future research. Traffic efficiency applications require additional calculations somewhere centralized in the mobile networking system's architecture, while safety applications require a lot of judgement from vehicles themselves about what are possibly dangerous situations. Both these problems are also interesting subjects for future research.

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APPENDIX

A. Table mobile networking system improvements

Method	Necessary architecture	Pros	Cons	Applications
IEEE 802.11p	Communication units RSU	Ad hoc connectivity Low latency Operational at high vehicle speeds	Lack of QoS guarantees Costly set-up with RSU's Poor scalability	Safety applications CAM and DENM messages Local traffic efficiency applications only
D2D	Mobile networking system supporting D2D Communication unit supporting mobile networking systems	Decentralized communication, similar to IEEE 802.11p More QoS guarantees for latency and reliability than IEEE 802.11p	Current ProSe too limited Share spectrum with mobile broadcasting users	Safety applications, enables direct V2V communication over the LTE network.
LTE	Connectivity arranging for LTE and communication units Infrastructure for high performance traffic efficiency applications	Centralized architecture enabling other types of applications. Operational at high vehicle speeds High data rates. Support of past mobile networking systems.	Throughput issues in dense traffic situations. Other QoS concerns than only vehicular communication. Resource inefficient because of unicast for safety applications	Traffic efficiency application Limited support of safety applications
WiMax	WiMax router integration Needs additional infrastructure to enable traffic efficiency applications.	Centralized architecture, enabling other types of applications. Long range, allowing cheap network setup.	Throughput issues in dense situations more severe than with LTE. Other QoS concerns than only vehicular communication. Limited support of high speeds. Safety applications are resource inefficient because of unicast	Traffic efficiency application, great support for both local intersection scheduling and traffic scheduling on a larger scale. Can support safety applications with cons discussed.
Unicast for downlink	Needs LTE integration in vehicles and infrastructure to determine relevant receivers of a message	Higher reliability than MBMS, requires additional no set-up. A server could summarize messages from a number of CAM messages to reduce number of messages to be send.	May overflow downlink when many messages are send	Safety applications, more specifically, when LTE is used for V2V, unicast can send messages on the downlink to every vehicle separately.
MBMS	Needs LTE integration in vehicular communication. Needs Improved infrastructure to support MBMS used in vehicular communication	More resource efficient use of the downlink when LTE is used to broadcast messages. A server could summarize messages from a number of CAM messages to reduce number of messages to be send.	More latency do to session set-up possibly for every broadcast	Safety applications, more specifically, when LTE is used for V2V, MBMS can broadcast messages on the downlink.

Unicast for uplink	Needs LTE integration in vehicles.	Less prearranging necessary than with clusters.	More traffic on the uplink. Resource inefficient.	Safety applications, more specifically, when LTE is used for V2V, messages can be send as unicast on the uplink to the eNodeB from every vehicle separately. Traffic efficiency applications, FCD can be send using unicast on the uplink.
Clusters	Needs LTE integration in vehicles. Needs an additional component at eNodeB for support of clusters and the allocation of a cluster head.	Less traffic on the upstream	Additional software to setup clusters. Vehicles could appear in and outside a cluster repeatedly, may cause a vehicles to not send data to the server at all during multiple intervals.	Safety applications, more specifically, when LTE is used for V2V, clustered messages can be send on the uplink in unicast all at once. Traffic efficiency applications, FCD can be clustered and then send using unicast on the uplink all at once.