5G Connected Vehicles Supported by Optical Fiber Access

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ABSTRACT
Future autonomous vehicle will require a high level of computation, communication, sensing and fast response actuation. Communication among vehicles, and vehicles to infrastructure, accessing to remote systems and services will help to reduce other requirements in computation and sensing. This paper revise current state of the art of wireless technologies as: LTE, LTE-A Pro, IEEE802.11p and 5G, as well as optical fiber access technologies as: TDM, WDM, D-WDM and uD-WDM, for the different communications requirements in diverse scenarios as: Vehicle-to-Infrastructure (V2I), Vehicle-to- Vehicle (V2V), Vehicle-to-Pedestrian (V2P) and Vehicle-to-Network (V2N).
Keywords: 5G networks, connected vehicle, optical fiber access.

1. INTRODUCTION

In the last years, software and electronics have become the core of the new generation vehicles, changing the trend established over the 20th-century (where the automotive industry was based on mechanics). However, as the importance of electronics components and embedded software has grown, so has also grown the complexity [1].

All this electronic deployment in the vehicle is justified with the development of new business like autonomous vehicles [2]. The autonomous vehicle concept evolves in parallel with sensing technologies like automotive radar [3], automotive 2D - 3D Lidar [4], and cameras, but currently is strongly limited by the cost of these technologies [5]. In most of these systems, complex electronics are required for signal processing and intelligent environmental mapping and actuation [6]. All these functions, which are oriented to safety improvements, are included in the global framework of the Advanced Driving Assistance Systems (ADAS) [6], and are key for autonomous vehicle.

ADAS are an important part of autonomous vehicles, however the cost of some of them makes impossible to develop self-contained solutions. In order to improve the economic viability, for end users, of these vehicles it is mandatory to limit sensor and electronic expenses. For this reason, it is important to create alternative solutions for environmental perception and detection. Recently, as a solution for this issue, has appeared the connected vehicle concept [7]. Connected vehicle, which is understood as one massively connected to everything or V2X [7], is based on densification of the radio access [8].

On the other hand, safety requirements for communication and electronic systems make mandatory to apply strong considerations for real time operation and robustness for the system and services. For these reason, latency, coverage, reliability, security, and others [9] are a fundamental part of the connected vehicle. In the last years, 5G has appeared as a revolutionary system (where the densification concept is applied), which is able to achieve all the requirements defined for connected vehicle solutions [10]. However, on itself it is not a full solution for connected vehicle, other systems for access and interconnection must evolve. Especially, fiber access and front-hauling [11] must achieve higher efficiencies and data rates in order to ensure the quality and the safety that the automotive sector requires.

In this paper it is presented a full solution for connected vehicles. This solution is based on 5G radio access, which is evaluated with typical impairments. On the other hand, a fiber access network has been evaluated considering DWDM and UDWDM for high performances transmission.

2. STATE OF ART OF CONNECTING TECHNOLOGIES

This section briefly overviews main technologies currently under research, tested or implemented in order to provide a short background about the evolution of the technologies potentially implementing solutions for V2X.

2.1 Wireless Technologies

Long term Evolution (LTE), a standard for cellular networks, is currently considered as 3.9G. Started as a project in 2004 by the Third Generation Partnership Project (3GPP), the Release 8, the first of this project, was published at 2008, and it is an evolution from the Universal Mobile Telecommunication System (UMTS) [12], defining a new radio access method for mobiles. At the physical layer, downlink implements Orthogonal Frequency-Division Multiple Access (OFDMA). For the uplink, Single-carrier Frequency Division Multiple

Access (SC-FDMA) techniques is used. The data is encoded in multiple narrowband subcarriers, minimizing the negative effects of multipath fading and distributing the effect of interference between different users [13]. In order to reach all 4G requirements, LTE-Advanced was completely defined in the Release 10 of 3GPP, started in 2010. Further improvements were achieved in release 11 and 12. Release 10 introduced some functionalities as carrier aggregation (CA), the dual connection (DC) and an improvement in the use of Multiple-Input Multiple-Output (MIMO) techniques, thus providing better network efficiency due to the increase of the bandwidth [14].

LTE-A Pro, 4.5G, it's the last standard presented by 3GPP in the Release 13 as part of a path toward 5G. A significant feature added to this technology is the increase of the number of carriers from 5 until 32 thereby improving the data rates. Other functionalities of this standard are an unlicensed spectrum usage and the introduction of a network densification technique, called self-organizing networks (SONs) for Adaptive Antenna System AAS [3].

Table 1. Principal features of Long Term Technologies [12], [14].

Technology	LTE	LTE-A	LTE-A Pro
Bit Rate	Up to 300 Mbps	Up to 1Gbps	Up to 3Gbps
Carrier Bandwidth	20 MHz	100MHz	640 MHz
Latency	20 ms	10 ms	2 ms

Five Generation (5G) is the next generation of mobile networks, the first Release should be published in 2020. It is expected to work in licensed and unlicensed spectrum. The technologies that will be included in this standard are not clearly defined, but most of researches include mmWaves, massive Multiple Input Multiple Output (MIMO), and small cells. These technologies allow different use cases where 5G could reach 1ms latencies, and data rates of 1Gbps or bigger [13], [14], [15], [16].

In contrast with all the standards explained above, 802.11ac is a WiFi standard. It works in unlicensed spectrum, approved and published in 2014 [17], [18]. This standard operates in 5 GHz frequency band avoiding the interference caused by the big number of devices working at 2.4 GHz, the bandwidth occupied by other WiFi standards, and it supports a peak throughput of 1.3Gbps [18].

2.2 Fiber Access Networks

Time Division Multiplexing (TDM) based Passive Optical Networks (PON) were developed as an alternative to expensive point to point solutions. They include Broadband PON (BPON), Gigabit PON (GPON), and Ethernet PON (EPON), etc., all based on similar passive tree topologies. In this technology data is sent in time slots, which limits the average bandwidth per user to hundreds of megabits per second [19], and a maximum reach of 20 km [20].

Wavelength division multiplexing based on PON is an optimal solution to extend the capacity of optical networks without drastically changing the fiber infrastructure. In general terms this technology allows multiple carriers (4, 8 or 16) may be transmitted at the same time in the same fiber. WDM PON is also capable of reaching 60 km [21].

Dense – WDM-PON (DWDM-PON) is an evolution of WDM- PON were the channel spacing is considerable reduced from tenths of nm [22] to 0.8nm or 1.6nm [23], offering thereby better spectral efficiency. Also it has a longer reach, between 70 and 135 km [24]. Finally, Coherent ultra-dense Wavelength Division Multiplexing Passive Optical Networks (UDWDM-PON) allows a more efficient use of the optic spectrum, introducing a new concept: WTTU wavelength-to-the-user, through decreasing the channel spacing as low as 2–3 GHz [25].

2.3 Connected Vehicle from IEEE 802.11p Towards 5G

At present, the two communication standards more specifically developed for vehicular networks are IEEE (Institute of Electrical and Electronics Engineers) 802.11p and LTE –V2X. The IEEE 802.11p is an adapted version of IEEE 802.11 standard (Wi-Fi), approved in 2009, and designed to fulfil the requirements of V2X. It works in 5.9 GHz frequency, in ad-hoc mode without the need of belong to a Basic Service Set (BSS) [26], an infrastructure conformed by some equipments connected to an Access Point (AP) [32]. In high-traffic conditions it's not a highly reliable option due to its simple random access scheme [27]. On the other hand, LTE-V2X o C-V2X (Cellular-V2X) is more recent than IEEE 802.11p, (first discussions started in 2015) and it is an extension of the Device to Device (D2D) functionality of the 3GPP Release 12 [26]. It can work in two modes: centralized or decentralize [28]. IEEE 802.11p is ready, it has been tested [26], but it does not show prospective for improvements in critical parameters as latencies and data rates. The physical layer is well designed to supports V2V communication, particularly important in the absence of other network infrastructures. On the other hand, despite the limitations of LTE – V2X, its main attraction is that it is considered the best way towards 5G, as it also offers higher degree of security than Wi-Fi. A high bandwidth, as expected to be provided by 5G, will be essential to communicate the massive amounts of data generated by sensors like cameras, radars and lidars required by autonomous vehicles in near future. As it is detailed latter on, some use cases as for example the broadcasting of emergency messages, require the strictest latencies only achievable by 5G [29].

2.4 Use Cases and Expected Requirements

The main use cases and their requirements are listed below:

- Platooning (Fig 1.d): a number of vehicles travelling together and sharing common mobility patterns. The vehicles are electronically coupled. In this way, vehicles can reduce the security distance between them and improve the traffic flows, in cases of high traffic density. It requires latencies better than 10 ms and a 99% reliability [30].
- The self-driving vehicle: without needing any human driving the car, or for example to go to the parking, pick someone, or automatic overtaking. This is one of the most critical use cases requiring: ultra-reliable communication links (> 99%), and a much lower maximum end-to-end latency (1 – 10 ms) [27].
- Infotainment applications requires much less demanding latencies of 500 ms and non-critical reliability [31].
- Cooperative awareness and maneuvers which involves latency values as stringent as 3 ms and ultra-reliable communication too [27].

3. NETWORK ARCHITECTURE FOR CONNECTED VEHICLE WITH REMOTE PROCESSING

In Figure 1, an example of a potential scenario for 5G deployment is presented. The link a) represents the connection between the car and the Remote Radio Units through 5G radio access, supporting latencies, data rates, coverages and reliability required by all the use cases previously mentioned. In order to reduce the deployment cost, several antennas are clustered and aggregated to a dedicated edge computing domain, located in the RRU aggregator, b), which is a dedicated equipment which performs tunneling protocols, supports micro services and process execution over a virtualized environment, its placed between hundreds of meters or few kilometers (if optic fiber is used) from the RRU cluster. Link b) shows the link between the Radio Unit combiner and the Mobile Edge Computing (MEC). This connection can be stablished using radio or optical fiber interfaces. The key function for this MEC architecture is to allow the computing of any critical function (in real time) which is processed outside of the vehicle. MEC structure is performing a virtualized processor, where extreme-to-extreme latencies are eliminated by reducing the distance between antenna and virtual data center. A MEC Orchestrator is another important element in the architecture. It is in charge of managing the handovers of the virtualized processes between MEC domains. MEC orchestrator must coordinate the process execution between MEC's, managing vehicle context transfer between MEC domains without any penalty in delay, latency or quality of service for the vehicle. Finally, c) represents a link between multiplexer and demultiplexer through optical fiber using, e.g., coherent UDWDM until the central office where resources are allocated. In that case, UDWDM is improving the number of users allowed in the network reducing the deployment cost.

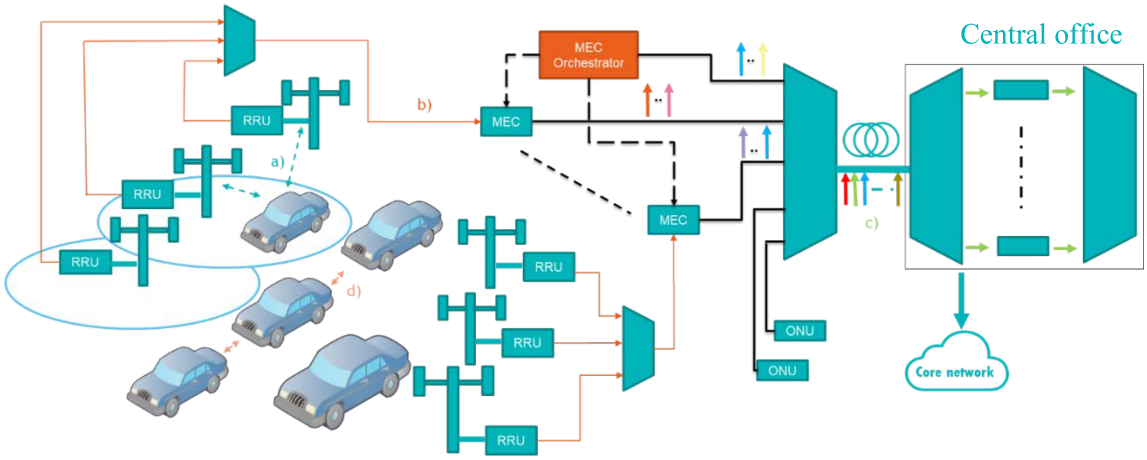

Figure 1. Concept network system: a) wireless connection between vehicle and RRU, b) link between a group of RRU's and MEC, c) coherent ultra-dense wavelength division multiplexing, d) vehicle platooning.

4. CONCLUSIONS

In this paper, a new V2X architecture, with remote ADAS functions and real time process execution at network Edge, is presented. It is important to notice that in this network architecture, extreme-to-extreme communications have been avoided through the use of virtual process execution in MEC domains. For in progress advanced driver assistance systems, real time and safely execution are strongly required. Most of ADAS functions are computed using multi-core Graphic Processor Units (GPU). For this reason, virtualized GPU execution over MEC domains is mandatory. Even though GPU virtualization is achieved, context and execution handover between MEC domains must be executed without delay and ensuring the total safety of the process. Nowadays, MEC orchestration for real time MEC handover is a not fully resolved challenge.

Access network between radio units, MEC equipments, and orchestration can make possible to reduce communication latencies. On the other hand, solutions based on PON architecture and UDWDM techniques can reduce the total cost for the network deployment allowing more users with less infrastructure than current solutions.

Radio access based on 5G is the most feasible solution for these scenarios. Although, 802.11p and LTE-A Pro have already demonstrated enough data rates and reduced latencies for automotive applications; for real time, high throughput applications (for video streaming for example) 802.11p is not a useful solution since it cannot provide enough data rate. Instead, LTE-A Pro access ensures data rates for moderated applications, however, it could be limited in throughput for massive sensors embedded at vehicles with higher data transfer requirements.

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