Connected Vehicles using Short-range (Wi-Fi & IEEE 802.11p) and Long-range Cellular Networks (LTE & 5G)

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***Abstract*—In recent years, the vehicular ad hoc networking (VANET) concept has supported the development of emerging safety related applications for vehicles based on cooperative awareness between vehicles. This cooperative awareness can be achieved by exploiting wireless sensors and technologies to transmit periodic messages to neighboring vehicles. These messages normally contain information regarding vehicles, such as position, speed, distance between vehicles, etc. For the transfer of safety messages, Wi-Fi and the suit of IEEE 802.11p/WAVE protocols were commonly used initially but now cellular-based LTE and 5G are the emerging technologies for VANETs. In this paper, a comparison is performed considering the European ITS-G5 standard, Wi-Fi, LTE and 5G by exchanging safety messages in VANETs. We have exchanged real-time road weather and traffic observation data to evaluate the performance of the aforementioned wireless technologies in terms of successful message delivery probability. Our results reveal that due to weak communication links and the lack of line of sight (LOS) communication for Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) scenarios, Wi-Fi and 802.11p are outperformed by LTE and 5G networks.**

Keywords*—*V2V, V2I, ITS-G5, LTE, 5G, Wi-Fi, VANET

I. INTRODUCTION

Intelligent transport systems exploit both short-range networks (IEEE 802.11p, Wi-Fi and Visible Light Communications) and long-range cellular technologies. These technologies are useful to provide safety related information such as slow vehicle and lane changing warnings, crash avoidance, etc. These safety applications related to cooperative awareness increase the driver awareness regarding the surrounding environment. In cooperative awareness, the wireless technologies can interconnect vehicles in V2V and V2I scenarios. VANET communications emerged with the introduction of the IEEE 802.11p standard. The IEEE 802.11p is complimented by a feature wireless access in vehicular environments (WAVE) [1]. It defines the improvements to 802.11 (Wi-Fi) needed to specifically meet the VANETs requirements for short-range communications. One of the drawbacks of the IEEE 802.11p protocol is that it is incapable to offer essential time-probabilistic features in dense environments, i.e., vehicle density increases in a same area [2]. Additionally, the VANETs are built mainly on direct V2V interaction and, thus, focused on the effect of network, creating a challenge for appropriate installation design and strategy.

These issues in the IEEE 802.11p gives the opportunity to consider the existing infrastructure of wideband cellular communication. The 3rd generation partnership project (3GPP), with 3G, LTE and 5G, provides a powerful communication platform for VANETs. For VANETs, the 3GPP specifically defines the LTE to offer cooperative awareness for road safety. A study comparing the performance of 3G and UMTS system in vehicular scenarios is performed in [3]. There is a clear need to validate the LTE suitability for safety critical vehicle applications. Recently, the pros and cons of 3GPP technologies with LTE have been investigated. Authors in [4] and [5] discussed the delays and latency for vehicular communication by performing simulation in LTE networks. However, these results are somehow contradictory. For instance, [4] illustrates that in the downlink channel, the capacity of the LTE network is limited during the transmission of safety critical messages. However, in [5], authors claim that the bottlenecks arise in the LTE uplink channel for ITS use case scenarios. The conflicting results by [4] and [5] are most probably because authors used different network characteristics in their studies. In this paper, we create a realistic logical framework that allows a fair comparison between Wi-Fi, IEEE 802.11p, LTE and 5G technologies using realistic road weather and observation data. This paper is organized as follows. Section II discusses the pilot scenarios and test locations, and Section III presents the results and followed by the section IV of conclusion.

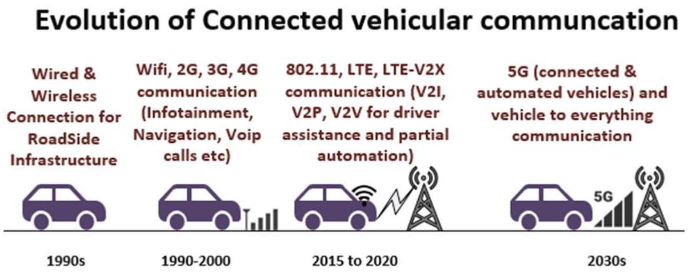

Fig. 1. Evolving wireless technologies for vehicular communication

II. PILOT SCENARIOS AND TEST LOCATIONS

This section discusses the pilot use-case scenarios considering V2V and V2I scenarios using road weather and road friction data. The pilot measurements have been conducted on a 1700-meter test track in Sodankylä, at the Finnish Meteorological Institute (FMI). Fig. 2 depicts the test track and installed equipment on the track. The weather information is collected by using different Internet of Things (IoT) sensors installed on Road Weather stations (RWS). Similarly, the vehicles were primarily providing the service-related information such as road friction data, road state, accident alerts, and the vehicle telematics data by CAN-bus. The vehicles exchanged the safety messages with other vehicles and with RWS in twenty-one test drives using Wi-Fi, IEEE 802.11p, LTE and 5G test networks. These filed measurements have been performed by using the following devices and software: Python program, LabVIEW,

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Cohda MK5 and MK6 wireless radios, iperf3, network routers, Samsung S7 with 5G capability and network simulator. A Sunit vehicle PC is used for user interfacing in vehicle. The road weather and friction information exchange were performed by using indirect (multi-hop) or direct (single-hop) ad hoc networks by exploiting wireless links, i.e., Wi-Fi, IEEE 802.11p, LTE or 5G test networks. Primarily, Wi-Fi and IEEE 802.11p protocols operate as the underlying technology for V2V communication [6]. Long-range cellular based LTE and 5GTN have been used to make a connection stable and robust. The V2I connectivity between RWS and vehicles was attained by exploiting multi-hop or single-hop wireless networks. For these pilot measurements, the vehicles were facilitated by multi-mode OBU (IEEE 802.11p, Wi-Fi, LTE and 5GTN interfaces) working through the multi-layer network of 5G test network micro-cell and RWSs. To start a communication, the scanning process of the available networks is initiated through the OBU in vehicles and the whole communication process is mutually performed by the vehicle (mobile node) and network by exchanging few of the connectivity events.

Fig. 2. Test track equipped with different IoT sensors, RWs and 5GTN

III. RESULTS AND DISCUSSION

This section discusses the results of the pilot measurements considering Wi-Fi, IEEE 802.11p, LTE and 5G test networks. This performance was analyzed by exchanging real-time road weather and road friction data in V2V and V2I scenarios.

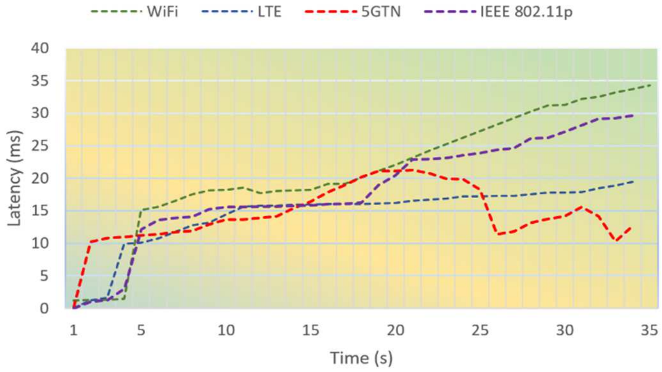

Fig. 3. Latency Comparison Between Wi-Fi, 802.11p, LTE and 5GTN

Fig. 3 illustrates that the short-range networks Wi-Fi and IEEE 802.11p performed proficiently initially after connection establishment between vehicles and RWSs. As the distance increases, the latency increases in IEEE 802.11p and Wi-Fi in contrast of long-range LTE and 5G test networks.

Table I and Fig. 3 show that the long-range network works well on the test track to exchange safety critical messages in V2V and V2I scenarios. Similarly, the latency impacts the average throughput in Wi-Fi and IEEE 802.11p, in contrast of LTE and 5G test networks, as presented in Fig. 4. Thus, long-range LTE and 5G test networks outperform IEEE 802.11p and Wi-Fi networks in key performance figures.

TABLE I. WIRELESS VEHICLE TECHNOLOGIES COMPARISON

Technology	Packet Loss	Latency (ms)	Average Throughput
Wi-Fi	21	31	1.49
IEEE 802.11p	18	26	1.94
LTE	14	22	2.78
5GTN	17	14	3.12

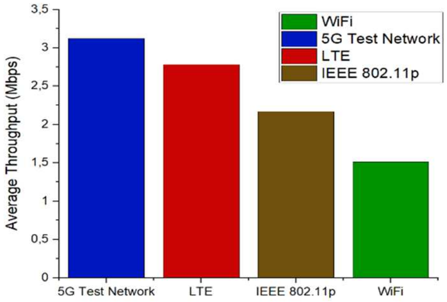

Fig. 4. Throughput Comparison Between Wi-Fi, 802.11p, LTE and 5GTN

IV. CONCLUSION

For road traffic safety, there is a need to support seamless connectivity in VANETs that can be performed by using different wireless technologies i.e., Wi-Fi, IEEE 802.11p, LTE and 5G test networks. This paper has provided a comparative insight of short-range Wi-Fi, IEEE 802.11p and long-range cellular based LTE and 5G test networks considering V2V and V2I communication scenarios. This study compared realistically the Wi-Fi and IEEE 802.11p to the similar measurements with 4G and 5G pilot networks. This comparison shows that the short-range networks work efficiently with restricted mobility complemented by the long-range cellular-based LTE and 5G test network to provide a seamless connectivity in V2V and V2I scenarios. The long-range LTE and 5G test network outperform short-range IEEE 802.11p and Wi-Fi. But the short-range Wi-Fi and 802.11p performs well in dense environments, in contrast of long-range cellular networks.

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