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Deployment and Analysis of Cooperative Intelligent Transport System Pilot Service Alerts in Real Environment

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ABSTRACT The industry is providing vehicles with advanced features and technologies that allows vehicles to connect and communicate with their nearby environment. These technologies' umbrella term, Cooperative Intelligent Transportation Systems (C-ITS) are aimed to enhance road traffic efficiency, safety and assist the drivers in multiple ways. The C-ITS communication system should be able to offer the functional benefits to different sets of use-cases, each having a particular sub-set of requirements. In this paper some of the relevant use-case scenarios utilizing road weather and traffic information are studied in terms of communication technology. The key requirements for C-ITS use-case scenarios are analyzed and an evaluation of the ITS-G5 protocol stack is performed. The performance of ITS-G5 in use-case scenarios is considered testing messages (alerts) on road weather and traffic information in realistic environments. The results indicate that the performance of ITS-G5 in tested use-case scenarios offers 90-98% success rate in the delivery of safety messages at a transmission frequency of 10Hz. Also, ITS-G5 delivers safety alerts with a minimum delay so that it satisfies the C-ITS use-case requirements in real environments. The C-ITS pilot platform also performs efficiently in terms of transmitting packets from a safe distance with minimum network latency and packet loss between vehicles and infrastructure. C-ITS pilot use-cases were tested on the platform developed and tailored by the Finnish Meteorological Institute (FMI).

INDEX TERMS Cooperative intelligent transport system, ITS-G5, vehicular network, road weather station, roadside unit, Finnish Meteorological Institute.

I. INTRODUCTION

THE DEVELOPMENT and deployment of C-ITS (Cooperative Intelligent Transport Systems) is aimed to enhance road safety, traffic efficiency and assist drivers. A C-ITS platform is supported by ICT (Information and Communication Technologies), i.e., telecommunication, information control, data processing and sensor technologies. In a C-ITS system various technology can be integrated by using techniques to build a cooperative system (C-V2X) and in vehicle systems. In integrating C-ITS provides a platform for vehicles and roadside infrastructure (traffic light controllers, Road Weather Stations etc.) by using different wireless technologies. The C-ITS system is also recognized as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) networking platform and provides a communication platform between road users and other roadside infrastructure [1].

C-ITS helps to increase the road safety, by assisting the driver during a trip to take a right route and adapting to the road traffic environment and avoiding possible accident. For example, the communication between vehicles and

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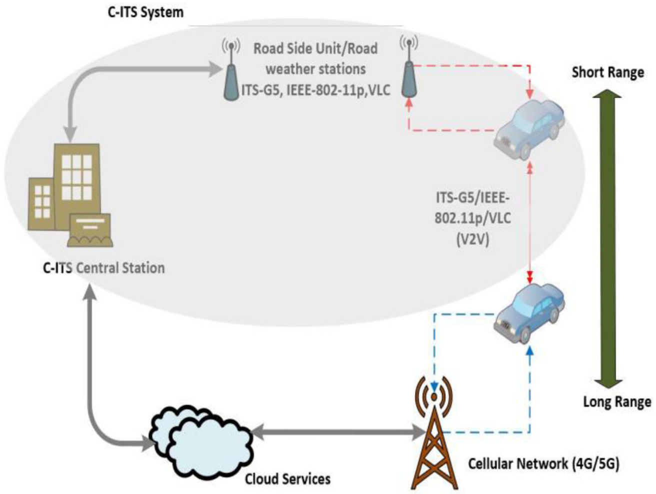

FIGURE 1. C-ITS System architecture.

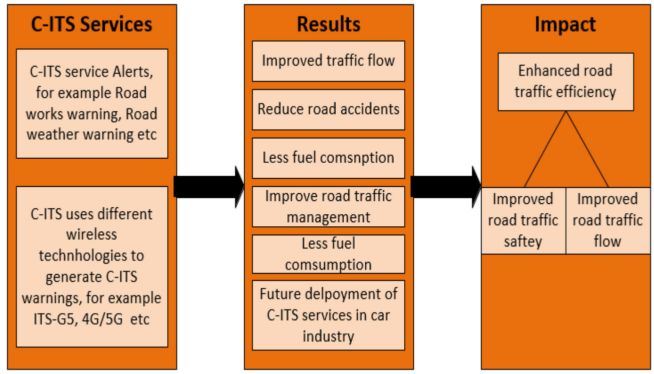

FIGURE 2. Logical framework of C-ITS services.

road-side-infrastructure by conveying real-time information, e.g., speed and position of the vehicle, would help to increase awareness of the driver concerning potential hazards and increases the accident avoidance. This factor helps to reduce the road accidents and severe injuries. With the use of C-V2X technologies, it is possible to decrease the road congestion by generating alerts for potential traffic jams and proposing substitute itineraries and making the vehicle driving less resilient. Lastly, C-ITS technologies also helps to enhance the driving of environment friendly vehicles equipped with the in-vehicle technologies, sensors, and management of smart transport at the network level.

In a C-ITS framework the vehicles and the road-side-infrastructure should be equipped with intelligent devices and a reliable communication link between them. Hence, it is worthwhile to analyze the communication technologies used for different C-ITS services. For both the safety-critical and not-safety-critical C-ITS services an appropriate communication technology needs to be adopted, such as ITS-G5. The IEEE-802.11 protocol is defined as ITS-G5 standardized protocol in Europe that normally uses channel bandwidth of 10 MHz in the 5.9 GHz band. ITS-G5 standard is defined by the European Telecommunications Standards Institute (ETSI) group for Intelligent Transport Systems (ITS). It supports the Geo-Networking protocol for V2V and V2I networking [2]–[4]. It is also important to note that the communication between vehicles and infrastructure are essential for the safe use of future Automated-Vehicles (AVs).

The Finnish Meteorological Institute (FMI) has developed and tailored C-ITS pilot use-case scenarios using road traffic and weather and information collected from Road weather stations (RWS) and vehicle sensors. In the conducted field test, the use of ITS-G5 was piloted. The testing of use cases was done on Sodankylä 1.7 km test track in northern Finland.

II. AIMS, SCOPE, EXPECTED OUTCOME, AND STRUCTURE

It is important that any C-ITS pilot system functionalities are verified in real-world conditions. In this study, the verification was done by considering numerous points of view, e.g., task specific testing, impact assessment, user-acceptance and specially the technical evaluation. This paper also discusses the functionalities in the presence of different constraints, i.e., speed, latency, throughput, location etc. The aim of this article is to report field testing of some crucial C-ITS services, namely road weather warnings, emergency vehicle warnings, road works warning, and general hazard warnings. These are tested in V2V and V2I scenarios.

Fig. 2 illustrates the logical framework of C-ITS service alerts. It is expected that the quality of information collected during pilot measurements using different sensors and exchanged data between vehicles, is enough to make decisions. These decisions would assist the drivers to choose the optimal route, and also assist in traffic management functions, performed, e.g., by traffic management centers. This logical framework would help to validate that whether the C-ITS pilot platform performs as expected and is capable to provide the safety-critical data effectively. In sum, the tested pilot C-ITS platform and use-case scenarios help to enhance road traffic safety, road network service performance and ultimately pave the way for automated transport. Last but not least, the results help the automobile industry's product development of C-ITS solutions.

The paper is structured as follows, from hereon: Section III introduces the C-ITS protocol based mainly on ETSI ITS-G5 standard. This protocol was followed and applied throughout the testing. Section IV provides the European C-ITS perspective identifying the most prominent services as well as challenges constraining the deployment and penetration of C-ITS. Section V describes the testing and piloting, giving details of the test site, procedure, and measurements. Also, the testing architecture is elaborated. Section VI concludes this paper with some remaining open questions, evaluation of the consequences of results, and suggestions for further research needs.

III. C-ITS PROTOCOL

The performance assessment of the medium-access techniques in Vehicular Networks (VNs) has been a hot topic discussion for years. In 2007 the author in [3] found out the issues with an initial version of Wireless Access in Vehicular Environments (WAVE) and established that the probability of collision is slightly high for access data group with high priority [3].

The author in [4] also identified that the periodic switching between channels in dense scenarios can lead to high delays due to long message queues. Nevertheless, the node movement in real-time and topologies for roads were not considered and there was no more study on packet error-rates relying on the distance between two nodes. The other researchers in [4], [5] validated these outcomes, providing further insights on the reception possibilities considering the physical distance between nodes [6]. However, the physical layer configuration was simplified (i.e., transmission power, fading, sensitivity) but do not depend on real-time measurements or hardware. They highlighted the key problems that originated with the IEEE-1609.4 standard. The author in [7] indicated the dependency on the beacon frequency and updated the latency (the latency between two decodable messages from the same source) that can increase the values where the operational functionality of safety applications is not available. Although their study was established on ITS-G5 Medium Access Control (MAC) layers. It also discussed the broadcast of Cooperative-Awareness-Messages (CAMs) timely, but it could not contain the Decentralized Congestion Control (DCC) state machine at this point. The delay between transmission and receiving of messages depends on the load on channel, size of message, data-rate, traffic density and other aspects. More details can be found in the study [8] in which the acceptable latency for road traffic safety applications was established to 100ms that follows the measurement frequency of 10Hz. We use a resulting metric of their latency update in order to enumerate the scope to which operational safety functionality that is affected by the loss of packet.

The CAM messages are crucial for the safety of VNs with less packet loss. For example, the systems such as intersection points or traffic accidents or long queues can be notified by using CAM messages in vehicular networking. The author in [8], [9] made a comparison between ITS-G5 and WAVE and provide valued contribution for the improvement of channel access in VNs. The carrier frequency for of ITS-G5 and WAVE standard is 5.9GHz with few channels operate at slightly high or low frequencies. The channel bandwidth is 10MHz. The Fig. 3 presents the different bands of the ETSI based ITS-G5 standard, which are dedicated to different tasks. ITS-G5 uses the transmission power of 25dB, and the receiver's sensitivity of 95dB. ITS-G5 permits the exchange of messages between vehicles and infrastructure on different channels (e.g., Service Channel (SCH) and Control Channel (CCH)). ITS-G5 do not requires a dualistic transceiver structure by using an access technique with alternating channels having a guard band of 4ms as shown in Fig. 3.

FIGURE 3. Alternate channel access of ETSI ITS-G5 standardization.

We have confirmed few of literature conclusions based on our results but not completely. This is because of our physical channel parameter settings that is close to real-time hardware, when it comes to communication ranges, carrier sense thresh-holds and fading. Similarly, the configuration of the DCC state machine looks to differ from the current values suggested by the standard. In summary, although various performance evaluations of IEEE 802.11p based systems exist and we are unaware of a study of same depth as this work, meanwhile it concentrates on the comparison of the distributed standardized protocols and commissioning realistic mobility techniques and parameter settings of wireless channel.

IV. C-ITS EUROPEAN FRAMEWORK

The C-ITS communication is supported by the European Commission (EC) in Europe, and they are working significantly to design and develop a reference framework to assist Cooperative-Connected and Automated Mobility (CCAM) program [1]. It is quite difficult issue since it can also show many side-effects that needs to be considered as well. The Fig. 4 summaries the framework defined by EU that supports the development of C-ITS service platform. Particularly, the EC C-ITS proposed framework aimed to develop a mutual platform in European Union (EU). It helps to make a collective effort platform with different stakeholders.

In 2014, the EC proposed a C-ITS platform, considered as a framework for cooperative and automated vehicles to be deployed in EU. In 2016, the EU member states designed and developed a platform "C-Roads" to connect and communicate C-ITS events in the whole EU. Table 1 is showing the C-ITS functionality constraints to deal with the challenges for use-case scenarios. This Table 1 would help to identify the challenges and effectiveness of the C- ITS pilot scenarios.

Nonetheless, this paper concentrates on the technical and functional characteristics of the matter that are crucial for C-ITS services utilizing road weather and traffic information and implemented communication technologies. Hence, it is

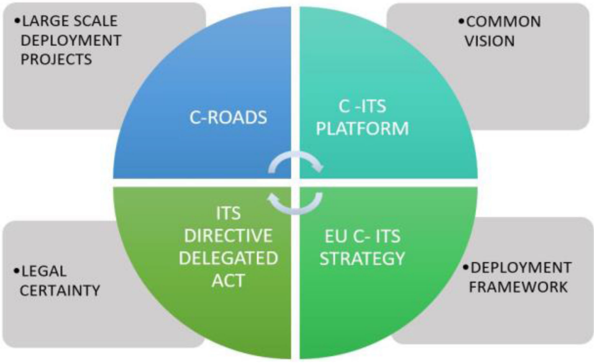

FIGURE 4. C-ITS European Framework [13].

TABLE 1. C-ITS functionality constraints.

C-ITS Challenges	C-ITS use-case fuctionality
Latency Constraints	In Emergency situation, the run-time data analysis and decision making to avoid latencies.
Communication Constraints	Short range (C-ITS/VLC/Wifi) and long range (Cellular) communication can fulfills all C-ITS requirements.
Bandwidth Constraints	C-ITS data transmission transpires between vehicles and road-side-infrastructure placed at the edge of the network. Remaining bandwidth would also be available for some other C-ITS applications. Bottle neck can also be avoided.
Cost Constraints	C-ITS user speicfic application has to only pay for the particular services they use from the cloud.
Security Constraints	C-ITS use-case scenarios can take benefit by using local data to identify potential threats timely. At cloud level, C-ITS platform can take advantage of offering security authorizations and algorithms to defend the data from intruders.
Storage Constraints	The road weather and traffic data to be managed for long run are transmitted to the cloud data storage.

important to describe EU group defining the C-ITS services. Here are the C-ITS services:

A more detailed description of the features and applications of the above-mentioned C-ITS services can be found in [10]–[17].

V. C-ITS EVALUATION FRAMEWORK

In this section the evaluation framework of C-ITS pilot platform is discussed that is, how the technical performance, possible impact, advantages, and user-acceptance can be achieved. The evaluation of C-ITS service alerts was done by following the guidelines mentioned in [18]. This assessment methodology is illustrated in Fig. 5 and the key points of the assessment are the following:

1) C-ITS services technical performance
2) C-ITS services impact
3) C-ITS services user-acceptance
4) C-ITS-services demographic performance.
5) C-ITS services financial performance

This assessment process would successively demonstrate the problem investigation and requirement evaluation, designing of assessment procedure, development of an evaluation strategy, data collection procedures, implementation of field tests and information gathering, analysis and description of C-ITS service contents.

This evaluation strategy would integrate the quantitative and qualitative data collection techniques. The qualitative

TABLE 2. EU defined C-ITS services.

No	C-ITS services	Service Description
1	Emergency-Electronic Brake Light (EEBL)	Provide alerts and warning to the drivers ahead instead of vehicle hard braking in abnormal situations to avoid collisions
2	Emergency-Vehicle Approaching (EVA):	Provide early alerts regarding approaching vehicle in emergency situation, before any siren or light-bar being noticeable
3	Stationary/Broken or Slow Vehicles (SSVs)	Provide warning alerts to approaching drivers about stationary/broken/slow vehicle ahead
4	Probe Vehicle Data (PVD)	Designed to collect vehicle data for a many reason regarding traffic safety, management, efficiency as well as environmental problems
5	Traffic Jam ahead Warning (TJW)	TJW is particularly useful beyond visual alert about traffic jam tail i.e., hilltop or curve roads.
6	Road Weather Conditions (RWC)	Provide information to vehicles about dangerous weather situations about i.e. black ice (slippery condition or wind/ice storm).
7	Shockwave Damping (SWD)	Reduce the incident of traffic shockwaves (e.g., switching between different traffic zones moving through a traffic environment)
8	Hazardous Location Notification (HLN)	Providing an advance warning of forthcoming locations on the road that might be hazardous (i.e., steep or sharp bended road, slippery or obstacle road service).
9	In-Vehicle speed limit (VSPD)	Provide notifications and updates to the vehicle driver about speed limitations, constantly or on a specific occurrence including the regions near to the urban araes.
10	IN-Vehicle SGNnage (VSGN)	Provide early information regarding related traffic signs in the surroundings of the vehicle, therefore enhancing driver perception
11	Road Works Warning (RWW)	RWW is projected for notifying vehicle drivers about the ongoing road work and related limitations
12	Time-To-Green (TTG) / Green Light Optimal Speed Advisory (GLOSA)	Provide assistance related to the vehicle speed about the upcoming traffic lights on the way and helps to reduce the number of braking events or rapid accelerations
13	Road intersection safety/Signal violation (SigV)	SigV is designed to reduce the severity and number of collisions at intersections that are at traffic signals.
14	Traffic Signal Priority (TSP) (Designated vehicles request)	TSP is designed to give authorization to vehicle drivers of priority vehicles including emergency vehicles and public transport to be given importance at traffic signal intersections.
15	Infotainment Services	This C-ITS service is expected to provide multiple data notifications to the drivers eg Information on charging stations for alternative fuel vehicles (iFUEL) and fueling.
16	Loading Zone Management (LZM)	LZM is specifically designed to support, organize and manage parking zones in urban areas
17	Zone Access Control (ZAC)	ZAC is meant to design for urban areas to notify and update the information about access limitations.
18	Vulnerable Road User (VRU)	VRU is aimed to provide safety to susceptible road users, e.g., pedestrians and cyclists.
19	Cooperative and Connected Navigation (CCN)	Provides advance C-ITS services, where tasks like route suggestion, information updates about parking and synchronized traffic lights
20	Wrong Way Driving (WWD)	WWD is aimed to deliver alerts of wrong-way drive, hence informing the particular vehicle about the wrong lane

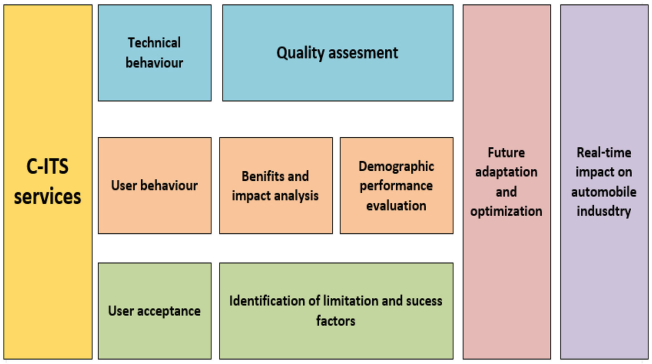

FIGURE 5. C-ITS structural evaluation framework.

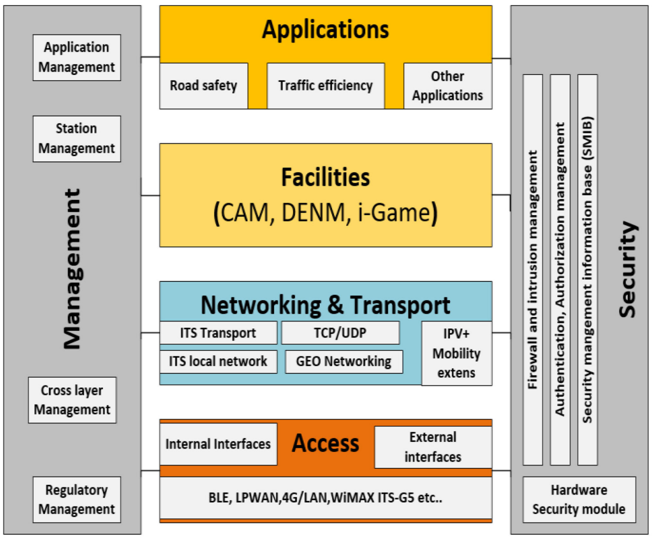

FIGURE 6. C-ITS reference architecture for pilot use-case scenarios.

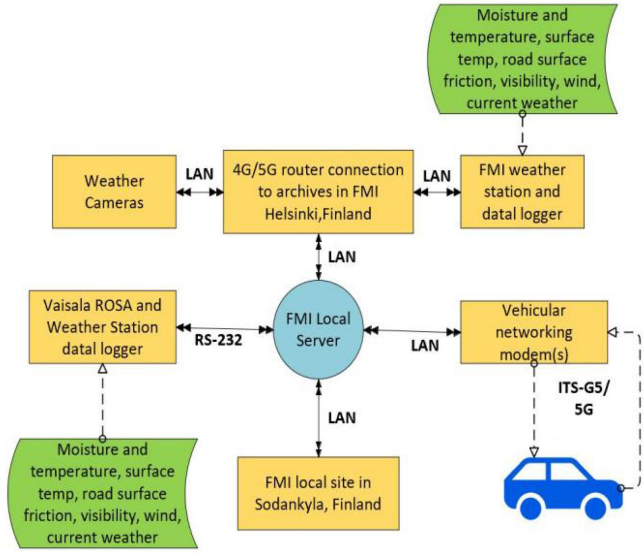

FIGURE 7. RWS-RSU communication process for C-ITS alerts.

FIGURE 8. Test track and test infrastructure for C-ITS service alerts.

technique will be useful to identify the adaptations and effects owing the C-ITS service alerts. The quantitative strategy will provide a proof of concept on the significance and trust assessments of the impacts in pilot system performance.

VI. C-ITS PILOT SYSTEM ARCHITECTURE AND TEST LOCATIONS

In this section we are discussing the pilot system architecture and test location for C-ITS scenarios utilizing road weather and traffic data to provide warning messages to vehicles.

The C-ITS pilot system is built by using the ETSI, ISO, IEEE jointly proposed reference architecture. The reference architecture presented in Fig. 6 is the starting point of our filed measurements. This reference architecture helps to enhance the vehicular communications, the integration of different components in the three-plane model shown in Figure 1 have been proposed.

By using aforementioned C-ITS reference architecture we have built a state-of-the-art joint RWS–RSU platform for C-ITS services in Sodankylä Finland. The Fig. 7 presents the communication system and operational process of RWS-RSU with vehicles using ITS-G5. The similar software entities save the information distribution between vehicles and RWS and FMI local test site, while collecting and updating the local C-ITS service data of RWS–RSU.

The advance C-ITS services are designed, developed, and tailored on FMI test track (1.7 km) in Sodankylä Finland and distributed back to the RWS–RSU for further transfer of the warning messages to vehicles. The development of C-ITS pilot system architecture is to design, develop and assess performance of C-ITS-assisted road weather and traffic service alerts and the service alerts exchange between vehicles and RWS [18]. The collected data from vehicles and RWS are managed or saved directly in RWS-RSU before the further transmission.

The designed and developed C-ITS services are tested on Sod5g test-track constructed by FMI to evaluate and validate the performance of C-ITS service alerts in Vehicular Networks (VNs). Table 3 presented the technical specifications for our ITS-G5 measurements. The test location is featured with different sensors and RWSs, cameras etc. as presented in Fig. 8.

The Fig. 8 and Fig. 9 illustrates the test track with the deployed equipment and facilities and their connection set-up

TABLE 3. ITS-G5 parameter settings for pilot scenarios.

Parameters	ITS-G5 Settings
Power Transmission	-10 to +23 dBm
Operating Frequency	5.9 GHz
Modulation	BPSK, QPSK, 16QAM, 64QAM
Transmission Rate (Max)	27-54 Mbps
Data Traffic	Bi-directional
Duration of Symbol	16, 8, 4 us
Bandwidth	5, 10, 20 MHz
Supply Voltage	12V
Temperature	-40 ºC to +85 ºC
Range (Max)	1000 m

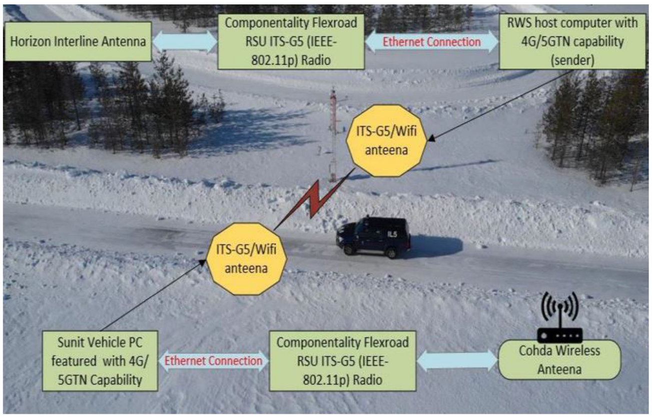

FIGURE 9. Connecting devices using wireless networking technologies.

TABLE 4. C-ITS pilot field measurement results.

Ave Speed (km/h)	Packet loss (%)	Throughput (Mbps)	Latency (ms)	Distance (m)	Warning (Alarm)
30.33	3.31	0.190	14.23	524.33	Roadworks warning (V2V)
29.40	6.1	0.741	18.66	247.50	Emergency Vehicle Approaching (V2V)
25.92	3.94	0.80	17.59	282,10	Road Weather Warning (V2I)
27.49	6.14	0.53	20	207.48	Road Works Warning (I2V/V2I)
32.98	5.61	0.61	10.72	251.75	Hazard Warning (I2V/V2I)

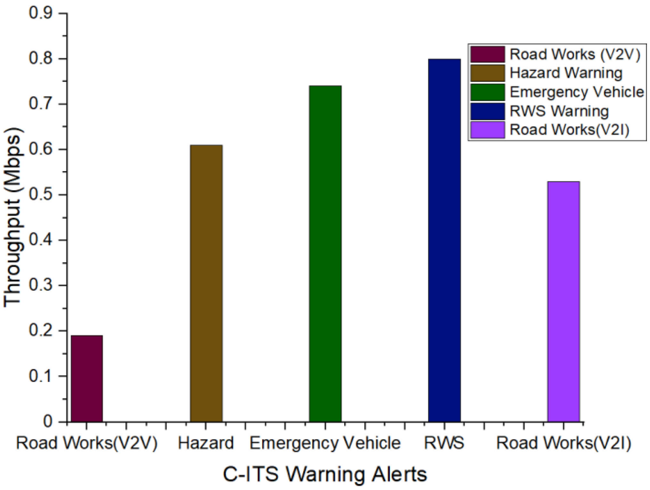

FIGURE 10. Comparison of throughput during C-ITS warning alerts generation.

in C-ITS scenarios. The Fig. 9 also presents the operational procedure for the communication in C-ITS scenarios. We have used the python program in Sunit vehicle PC, and all programs are started simultaneously in vehicle and RWS. The Devices are connected according to Fig. 9. Vehicle radios are constantly searching for nearby ITS-G5/Wi-Fi networks to make a connection for real-time C-ITS service alerts.

The C-ITS services are conducted on a test track by using different devices to deliver message alerts. We have used Cohda MK5 radio transceiver, laptop, or Android tablet. For User-Interface (UI) we used SUNIT F-series vehicle PC as an On-board Units (OBU). OBU provides the relevant message alerts to the driver. The data collection and transmission of message alerts is performed by the transfer layer that ensures the communication between the FMI local server, OBUs and RWSs-RSUs. OBU is to collect data using cellular network but, in this article, we are only considering ITS-G5. The combination of networks also ensures the seamless connection between RWS-RSU and OBU in situations without ITS-G5 coverage.

C-ITS Pilot service Results and discussion: In this section we will discuss the C-ITS pilot measurement results. These pilot measurements have been conducted to fulfil the requirement of C-ITS warning alerts by using the vehicles and RWSs collected data. This data has been exploited by the vehicles for the road safety applications. In the pilot measurements, the collected data is used to generate the emergency vehicle warning, road works warning, road weather warning and hazard warning. Table 4 presents the collected data for the generation of warnings during pilot measurements. As shown in Table 4, these different C-ITS warnings were analyzed by considering the vehicle average speed, lost packet (%), throughput, latency, and communication range. The C-ITS warnings have been delivered in a systematic way with the help of different sensors in vehicle and RWSs. The warnings are simply initiated by our python program in our vehicle Sunit PC by sensing the dangerous situations while driving on the test track.

The data in Table 4 shows that we have received the warnings timely without any extra delay that makes the driving safer in dangerous situations.

The data packet transmission is one of the important elements that affects the throughput of the network in vehicular networking. Fig. 10 illustrates the maximum throughput in our pilot measurements on the test track, the estimation of data throughput measurements piloted between combined RSU/RWS and passing nearby vehicle are presented in Fig. 10.

The throughput comparison shows that the hazard warning presents the highest throughput, and the road works warning has the least throughput during pilot measurements. The difference between hazard warning and road works warning

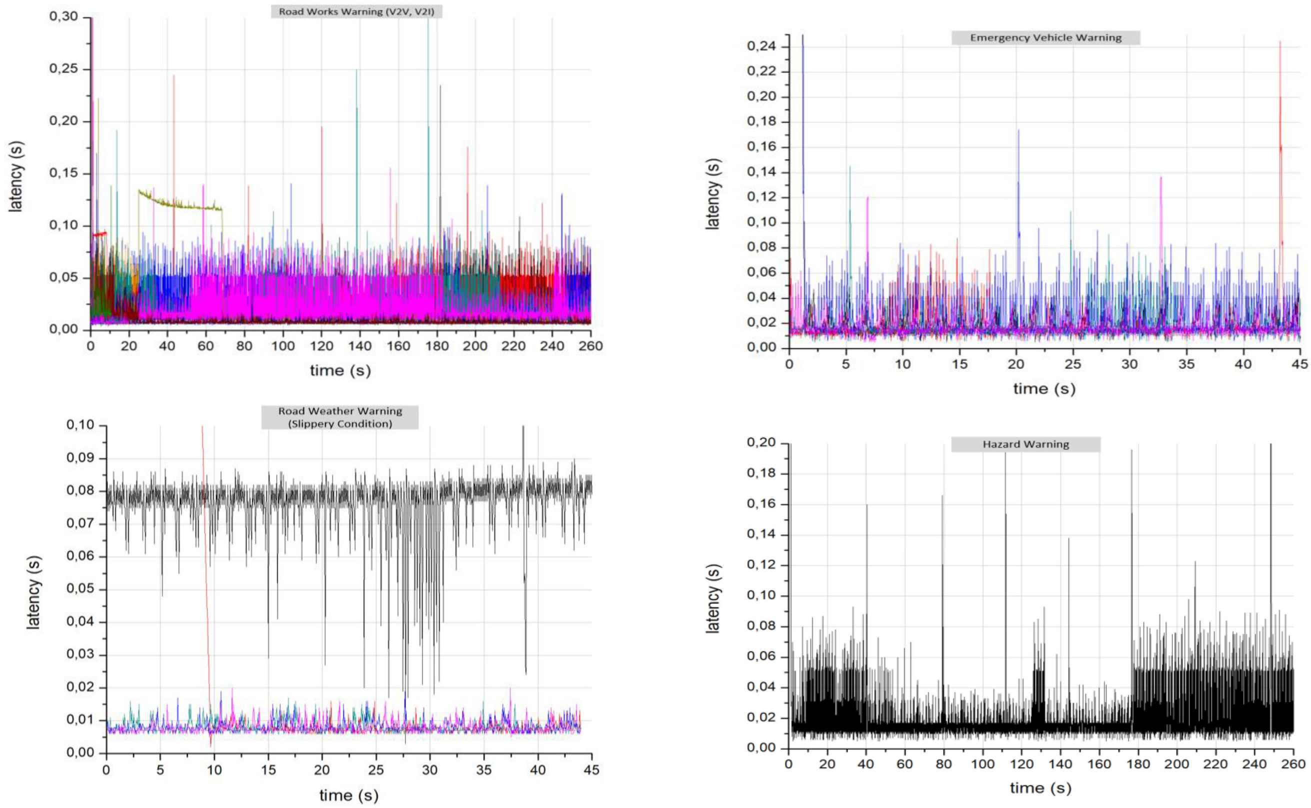

FIGURE 11. End-to-End latency of C-ITS pilot use-case scenarios.

throughput is because of haphazard nature of our test track with thick forest. The second reason is the location of warning alert generation, because the warnings are generated at different places of test track with different distances between vehicle and hazard/road work warning. If the message transmission would have been increased, then the throughput would have also been increased dynamically according to the available safety-critical data.

Normally, the network throughput of a particular network decreases considerably due to the interference of another network, i.e., Wi-Fi on test track etc. But in our pilot scenarios the main goal was to exchange the emergency messages more reliably with low latency. We have used small size packets to transfer only the warning information to the driver. That is the one of the reasons for low throughput in all filed measurements. In our previous measurements we have achieved almost 2-3 Mbps situation specific average throughput using ITS-G5.

The latency is another key element to warn and assist the vehicle drivers with minimum delay. So, in our pilot measurements, we have also analyzed the latency during C-ITS scenarios. In Fig. 11 we can see the end-to-end latency in C-ITS scenarios. The End-to-End latency is slightly long in some C-ITS scenarios specially during the connection establishment. We can also notice that after the connection has been established the latency is stable except some places where the latency goes high. For connection establishment the sending device and the receiver need some time to handshake and make a connection. The end-to-end latency in C-ITS scenarios is stable and fulfils the minimum requirement (< 100ms) to generate real-time C-ITS service alerts. It can also be seen in the collected results in aforementioned Table 4 and Fig. 12 that we have achieved minimum required latency successfully for C-ITS scenarios. The latency d(a,b) is calculated as:

$$d_{(a,b)} = \Delta T + L/g_{(a,b)} \tag{1}$$

where L is the data length in bytes and $g_{(a,b)}$ is the transmission rate

$$\Delta T = \Delta x/y \tag{2}$$

where Δx is the distance between vehicle a and the RWS-RSU b at a vehicle speed y.

In our C-ITS pilot service alerts, we have also calculated the packet loss and we realized that the lost packets percentage is odd in V2V scenarios. The potential reason can be that when the connection has been established between vehicles, the connection has not been dropped since the vehicles have gone out of range. In Table 4 and Fig. 12 we can illustrate the packet loss in different C-ITS scenarios. The highest packet loss in Fig. 12 is road works warning V2I and the lowest packet loss is in the road works warning I2V/V2I scenario. The packet loss in C-ITS scenarios is due to the correlation between closely located transmitters and

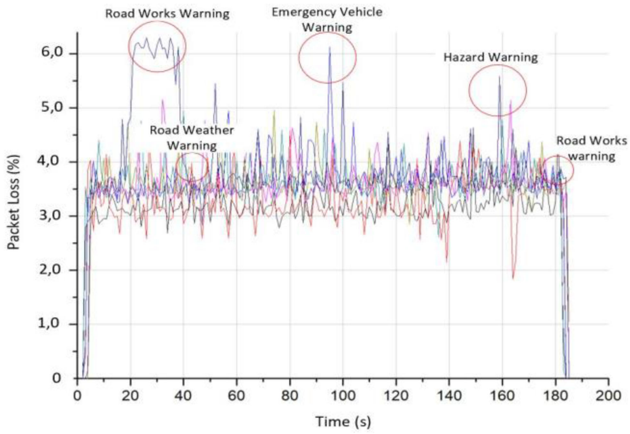

FIGURE 12. Packet loss percentage in C-ITS pilot scenarios.

receivers and the correlation is low in a closely connected vehicles/RWSs that indicates the significant part of packet loss is because of the localized errors in C-ITS scenarios.

VII. CONCLUSION

The opportunity and challenge for C-ITS services is to offer working methods in different scenarios for the real-time dissemination of road weather and traffic data. Such methods, once operational, will not only justify the costs and efforts required by C-ITS, but also show to a wider stakeholder community that C-ITS can be made operational and is worth investing in. In this paper we have presented some C-ITS use-case scenarios in the provision of safety alerts, contributing to the common objective of interoperable and synchronized deployment of C-ITS. We have also considered to ensure that the generated data in the road traffic system is beneficial for all stakeholders and road users. We selected the C-ITS communication technologies depending on different parameters, i.e., performance, costs etc. This is the reason why we deployed ITS-G5 for pilot C-ITS scenarios - it is appropriate for applications with safety-critical nature sharing the spectrum of 5.9GHz assigned for C-ITS.

The main goal of this paper is to contribute to the deployment of overall C-ITS location-based services. The aim of the testing was to enhance the levels of technology maturity, so that the critical performance indicators fulfil functional requirements. We tested and demonstrated C-ITS use-cases in real environment. The tested use cases were emergency vehicles approaching, emergency vehicle approaching, road works, road weather and hazard warning. We showed that the cooperation between vehicles and RWSs fulfills the maximum of the system requirements to generate the C-ITS service alerts. The service alerts were demonstrated on a test track. The next steps would entail expanding the testing and analysis public road networks.

REFERENCES

[1] G. Toulminet, J. Boussuge, and C. Laurgeau, "Comparative synthesis of the 3 main European projects dealing with cooperative systems (CVIS, SAFESPOT and COOPERS) and description of COOPERS demonstration site 4," in *Proc. 11th Int. IEEE Conf. Intell. Transp. Syst.*, 2008, pp. 809–814.

[2] M. N. Tahir, K. Mäenpää, and T. Sukuvaara "Evolving wireless vehicular communication system level comparison and analysis of 802, 11 p, 4G 5G," in *Proc. 2nd Int. Conf. Commun. Comput. Digit. Syst. (C-CODE)*, 2019, pp. 48–52.

[3] A. B. Nkoro and Y. A. Vershinin, "Current and future trends in applications of Intelligent Transport Systems on cars and infrastructure," in *Proc. 17th Int. IEEE Conf. Intell. Transp. Syst. (ITSC)*, 2014, pp. 514–519.

[4] M. Kilicarslan, J. Y. Zheng, and K. Raptis, "Pedestrain detection from motion," in *Proc. 23rd Int. Conf. Pattern Recognit. (ICPR)*, 2016, pp. 1857–1863.

[5] A. Vesco, R. Scopigno, C. Casetti, and C. Chiasserini, "Investigating the effectiveness of decentralized congestion control in vehicular networks," in *Proc. IEEE Globecom Workshops (GC Wkshps)*, Atlanta, GA, USA, 2013, pp. 1314–1319, doi: 10.1109/GLOCOMW.2013.6825176.

[6] D. Eckhoff, C. Sommer, and F. Dressler, "On the necessity of accurate IEEE 802.11p models for IVC protocol simulation," in *Proc. 75th IEEE Veh. Technol. Conf. (VTC-Spring)*, Yokohama, Japan, May 2012, pp. 1–5.

[7] F. Goudarzi and H. Al-Raweshidy, "Distributed transmit power control for beacons in VANET," in *Proc. 3rd Int. Conf. Veh. Technol. Intell. Transp. Syst.*, vol. 1, 2017, pp. 181–187, doi: 10.5220/0006289401810187.

[8] M. N. Tahir and M. Katz, "Heterogeneous (ITS-G5 and 5G) vehicular pilot road weather service platform in a realistic operational environment," *Sensors*, vol. 21, no. 5, p. 1676, 2021.

[9] L. Wang, R. F. Iida, and A. M. Wyglinski, "Performance analysis of multichannel EDCA-based V2V communications via discrete event system," in *Proc. IEEE 90th Veh. Technol. Conf. (VTC-Fall)*, 2019, pp. 1–5.

[10] M. N. Tahir and U. Rashid, "Intelligent transport system (ITS) assisted road weather & traffic services," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, 2020, pp. 1–2.

[11] B. Kloiber, T. Strang, M. Röckl, and F. de Ponte Müller, "Performance of CAM based safety applications using ITS-G5A MAC in high dense scenarios," in *Proc. IEEE Intell. Veh. Symp. (IV)*, 2011, pp. 654–660.

[12] M. Van Eenennaam, W. K. Wolterink, G. Karagiannis, and G. Heijenk, "Exploring the solution space of beaconing in VANETs," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, 2009, pp. 1–8.

[13] B. Kloiber, T. Strang, F. de Ponte-Müller, C. R. Garcia, and M. Röckl, "An approach for performance analysis of ETSI ITS-G5A MAC for safety applications," in *Proc. 10th Int. Conf. Intell. Transp. Syst. Telecommun.*, 2010.

[14] J. M. León-Coca, D. G. Reina, S. L. Toral, F. Barrero, and N. Bessis, "Intelligent transportation systems and wireless access in vehicular environment technology for developing smart cities," in *Big Data and Internet of Things: A Roadmap for Smart Environments*. Cham, Switzerland: Springer, 2014, pp. 285–313.

[15] "Intelligent transport systems (ITS); Vehicular communications; Basic set of applications; Definitions," Eur. Telecommun. Stand. Inst., Sophia Antipolis, France, Rep. TR 102 638, Jun. 2009.

[16] M. Botte, L. Pariota, L. D'Acierno, and G. N. Bifulco, "An overview of cooperative driving in the European union: Policies and practices," *Electronics*, vol. 8, no. 6, p. 616, 2019.

[17] B. Marilisa, P. Luigi, D. Luca, and B. G. Nicola, "C-ITS communication: An insight on the current research activities in the European union," *Int. J. Transp. Syst.*, vol. 3, pp. 52–63, 2018.

[18] L.-E. Lervåg, T. Levin, A. D. Storsæter, Using C-ITS on road status information in winter maintenance operations, 2016.

[19] H.-J. Fischer, "Cooperative ITS: The SDO perspective for early deployment," in *Intelligent Transportation Systems*. Boca Raton, FL, USA: CRC Press, 2016.

[20] P. Rahimian, E. E. O'Neal, S. Zhou, J. M. Plumert, and J. K. Kearney, "Harnessing vehicle-to-pedestrian (V2P) communication technology: Sending traffic warnings to texting pedestrians," *Human Factors J. Human Factors Ergonom. Soc.*, vol. 60, no. 6, pp. 833–843, 2018.

[21] M.-A. Meyer, C. Granrath, G. Feyerl, J. Richenhagen, J. Kaths, and J. Andert, "Closed-loop platoon simulation with cooperative intelligent transportation systems based on vehicle-to-X communication," *Simulat. Model. Pract. Theory*, vol. 106, Jan. 2021, Art. no. 102173.

[22] L. P. Robert, "The future of pedestrian-automated vehicle interactions," *XRDS Crossroads ACM Mag. Students*, vol. 25, no. 3, pp. 30–33, 2019.

[23] M. N. Tahir, T. Sukuvaara, and M. Katz, "Vehicular networking: ITS-G5 vs 5G performance evaluation using road weather information," in *Proc. Int. Conf. Softw. Telecommun. Comput. Netw. (SoftCOM)*, 2020, pp. 1–6, doi: 10.23919/SoftCOM50211.2020.9238267.
[24] M. N. Tahir, M. Katz, and U. Rashid, "Analysis of VANET wireless networking technologies in realistic environments," in *Proc. IEEE Radio Wireless Symp. (RWS)*, 2021, pp. 123–125.
[25] H. Fouchal, E. Bourdy, G. Wilhelm, and M. Ayaida, "A validation tool for cooperative intelligent transport systems," *J. Comput. Sci.*, vol. 22, pp. 283–288, Sep. 2017.
[26] F. J. Martinez, C.-K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Emergency services in future intelligent transportation systems based on vehicular communication networks," *IEEE Intell. Transp. Syst. Mag.*, vol. 2, no. 2, pp. 6–20, 2010.
[27] M. S. Quessada *et al.*, "ITSMEI: An intelligent transport system for monitoring traffic and event information," *Int. J. Distrib. Sens. Netw.*, vol. 6, no. 10, 2020, Art. no. 1550147720963751.

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