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Extending VLC Safety Applications using Mixed Technologies and Microservices

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Abstract: The World Health Organization and the European Commission in 2018 announced the initiative to support the implementation of actions to reduce the number of accidents by 50% by year 2030. This initiative is an indicator of the recognition of the major impact of road accidents in the society. This desire in relation to the ever-increasing number of vehicles is a major challenge for the society. Of the 22 actions envisaged, only one is aimed at implementing new technologies, but this is at the request of car manufacturers to intelligently adapt the speed and help drivers to meet speed limits. Since these measures may be insufficient, according to the annual reports to reach the proposed target, we come up with new research that changes the driving style, from one prone to the immediate ability to respond to anything intervening on the road, to one informed with multiple communication systems, optical using visible light and radio using mobile communications to increase road safety. Using all vehicle entries in traffic every second in a database we are able to send alerts to all road users may concern that alert, giving them more time to make a decision, especially with the purpose of reducing their speed ahead.

Keywords: traffic safety; information services; micro services; visible light communication; mobile communication

1. Introduction

According to the World Health Organization (who) and the European commission in 2018 announced the initiative to support the implementation of actions to reduce the number of accidents by 50% by 2030. This initiative is an indicator of the recognition of the major impact of road accidents in the society. Also, this desire in relation to the ever-increasing number of vehicles represents a major challenge for the society. This action is a reminder of actions previously implemented in 2010 for the period 2011-2020. According to an official document, a package of technical actions for road safety was designated, presenting six key components to increase road safety and improve the life-saving capacity(World Health Organization, 2017). These components aim to manage traffic speed, design and improve infrastructure, promote leadership on road safety, verify the application of road safety standards, enforce road legislation, and improve chances of survival after an accident. A total of 22 shares related to these components have been associated. Of all these actions, only one is aimed at implementing new technologies, but this is at the request of car manufacturers to intelligently adapt speed and help drivers to meet speed limits.

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Road transport is an indispensable part of our daily life. Although road safety should be of important concern to users of pedestrian road infrastructure and drivers of vehicles, unfortunately at European level, Romania ranks first with about 86 deaths reported per million inhabitants. Data reported in 2022 as shown in Figure 1(JAHNZ, Adalbert, n.d.). As the title of the figure suggests, the actual numbers of compared to the report displayed in the graph are higher. This means that the progress towards the 50% made so far is low.

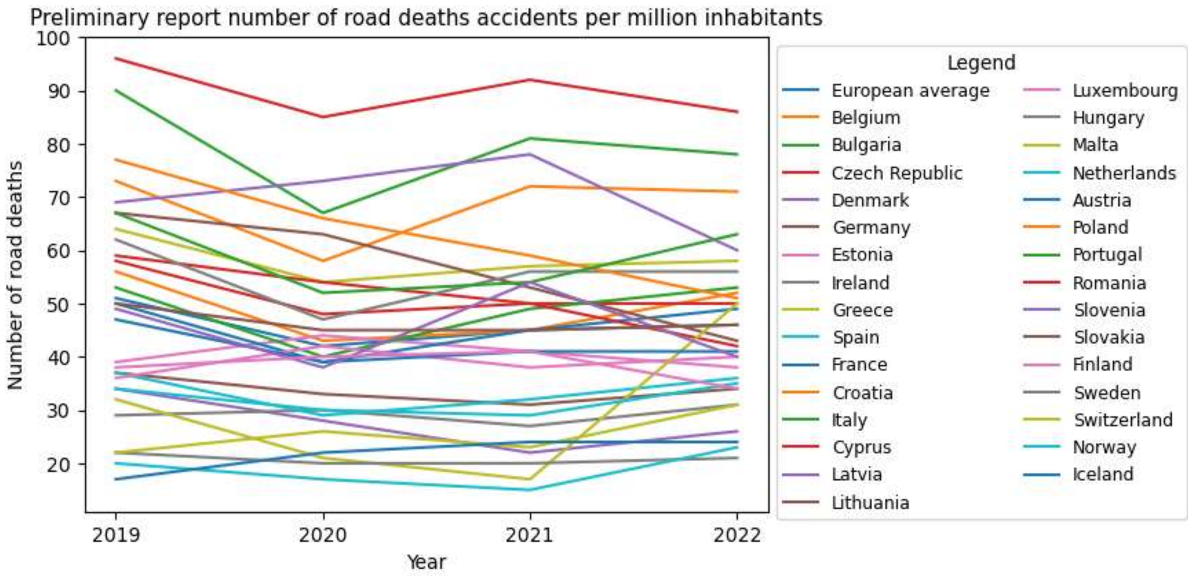

Figure 1. Preliminary Number of Road Deaths Reported per Million Inhabitants per Country

Moreover, worldwide road reports show that more than 1 million people die each year, and more than 50 million people are victims of traffic accidents (World Health Organization (WHO), n.d.-a). The statistical analysis on life losses show that the age groups most affected are children between the ages of 5 and 14, as well as young people between the ages of 15 and 29 (Commission, 2019). There are a number of studied effects, given by the loss of human lives leading to the loss of human, economic and other resources (World Health Organization (WHO), n.d.-b).

2. Related Work

Currently there are technologies dedicated to road contexts, such as vehicular ad hoc network (VANET) that facilitates vehicle-to-vehicle communications (V2V). This form of wireless communication is achieved through the wireless network. Applications include brake light signal, column circulation, traffic information systems, emergency services for road transport and road services respectively. These applications can take place within a radio frequency (RF) band, around the frequency of 5.9 GHz, as part of the IEEE 802.11p standard. These systems are made on short-range radio communication technologies or DSRC.

Intelligent transport systems (ITS) have regulated in the European space a frequency band of 5875-5905 MHz according to the European commission decision 2008/671/EC, while in the USA the same system is allocated for a frequency band between 5850-5925 MHz. Another variation of this technology is the mobile ad hoc network (MANET). Infrastructure-type systems can also participate in these systems, so communication can take place between vehicles and all systems, V2X. According to a practical study of such an implementation for road safety applications concurrently with ITS can address about 81 percent of accidents (Wassim G. Najm, Jonathan Koopmann, John D. Smith, 2010)(National Technical University of Athens (NTUA) & (ERF), n.d.).

Although researches of these types of networks dates back to 2000, their implementation is limited, in areas where pilot testing programs have been carried out and has not yet been internationally regulated as the standard of implementation on all vehicles. This indicates that the technology has not reached maturity or a critical decision-making mass of their implementation has not been reached. Some car manufacturers have joined the initiative to adopt DSRC-type V2V vehicle communication systems in the future, including Toyota, BMW, Daimler, Honda, Audi, and Volvo on some car classes. However, in 2019 Toyota announced that it would withdraw plans to implement DSRC systems from 2021(Shepardson, n.d.). This decision was taken as a result of the failure to join these systems and the lack of support to adopt them (US Transportation, n.d.). After this stalemate this year, National Highway Traffic Safety Administration (NHTSA) announced the steps to advance and evaluate the performance of DSRC C-V2X cellular technology (Heidi R. King, n.d.). Introducing this new technology has made some changes on the previously regulated operating frequencies for DSRC. However, the reduction of the DSRC operating band from 75 MHz to 30 MHz at the end of 2020 reduces the applicability of previous results. The Federal Communications Commission (FCC) has decided to offer the 45 MHz difference to internet usage. DSRC systems, called C-V2X that incorporate 4G mobile communications, have been introduced to conduct new pilot tests. However, it is incompatible with previous DSRC devices, so a DSRC system cannot communicate with a C-V2X system and vice versa(Commsignia, 2020). Unlike the DSRC with a typical 300-meter range, the new C-V2X systems have a 20-30% better range and better performance in the event of obstructions. New C-V2X systems with 5G connectivity were later introduced in 2021, and some vehicles may have them on some models(Group, 2021).

Another technology that has the potential to be implemented in ITS is VLC. This optical communication technology, within the standard 802.15.7, has the ability of ensuring low latency communication for vehicular safety applications(Nawaz et al., 2019), which can reach highly reliable VLC links up to 188 meters in daylight outdoor conditions(Căilean et al., 2021). Its advantages can supplement connectivity channels established thorough RF without interference and also can use existing lighting systems of the vehicle.

3. Problem Statement

While Advanced driver assistance systems (ADAS) are available today on some particular cars, and other systems like adaptive cruise control (ACC), which can help the driver in keeping the lane and a proper distance from the vehicle in front in an instructive mode or in automatic mode, increased number of vehicles as in a highway can increase the probability of a car crash due to higher level of attention cost and maneuvers due to road users that overcame or are speeding. Also, in some cases high density of cars at high speed in a highway together with combined with unpredictable phenomenon's like drastic drop of visibility (Jessica D'Onofrio, 2023)(Marinescu, 2023) or dust storms due to strong winds within the proximity of agricultural terrains can lead also to significantly reduce visibility in a very short amount of time(Das et al., 2018). In these cases, it is almost impossible to predict drivers' behavior. Some of them will reduce the speed, some will even stop, however other won't take any decision, thus maintaining speed while others will not, will definitely lead to a car crash or even a pile-up.

Traffic safety is uneven due to many reasons. First, the car that we drive might be light or heavy like a truck. Inertia of the vehicles makes the outcome differ in the same conditions of some event. This relativity between cars, in the case where are being close together increases the probability of an accident and also increases as the speed is higher. Heavier trucks have a greater stop distance in comparison with lighter cars, thus car crash prevention must be taken in order to be able to dodge a crash event. Pile-up accidents are daisy chain events. Simply put, there is not enough time to make a significant change in order to reduce the impact. Moreover, the drivers that did not reduce speed will also increase the number of cars involved in the chained event. It is enough for just one car to drastically reduce speed in order to inflict this kind of unfortunate event. Traffic legislation specifies there is a space that must be maintained between the vehicles and also increased with speed. However, most of the drivers do not know their car stop distance. Also, significant differences in stop distance values occur when the road is dry and when the road is wet. Not knowing the car stop distance leads to ignoring recommendations and also leads in taking risks, engaging in speeding and overcoming.

As the car density increases, risk assessment is difficult to estimate or predict. Furthermore, driver's attention must be increased and also driving fatigue is likely to take less time to step in. This means that as drivers, we must take much more driving breaks to regain sharp reflexes. Even professional drivers are prone to driving fatigue due to high traffic and due to a large number of maneuvers. In some cases of light loss of visibility, maintaining speed may be a way of keeping the distance between vehicles constant. However, likelihood for a car crash is higher than normal.

The problem that still exists in the world even with the presented systems, is not the connectivity or the latency. It is the lack of signaling or information during driving. As a consequence, new solutions and advanced technologies must be involved to better understand risk assessment, to predict and signal alerts from and back to the drivers. While a universal system to alleviate these safety issues does not exist yet, we live in a technological advancement that can give significant answers for road safety, in order to reduce mortality incidence in road accidents.

4. Solution Approach

Recent events have shown that a single system cannot respond to all use cases of high risk. In response to the identified problem of the society, a mixed technology solution is proposed to achieve a higher-level of safety in road transportation. The mix is composed of an of optical technology that uses VLC to send and receive safety relevant data and a mobile radio technology ensuring 4G or 5G connectivity from small device that helps keeping track of the car position at regular intervals. First, the optical technology is subjected to line-of-sight (LoS) communication, where sufficient conditions of communication between the VLC emitter and receiver are met.

Incoming VLC messages can be delivered to the driver and consequently can be passed to the VLC emitter located in the back, so the message is encoded into the light modulation of the car stoplights. Therefore, the car behind the driver's car, can also receive the same message with a reduced delay. Consecutively, the mobile technology can bring messages from a non-line-of-sight (NLoS) sources, either from an ITS or another road user, and also can send an alert or relevant message to other road users outside the bounds of VLC range. The use of this technologies is complementary; hence their use does not interfere and also support the scope of increasing road safety. For example, a road user exists a forest and is followed by other road vehicles. If an important message/alert is received through the mobile technology while the other cars did not, the data can be sent to the other cars through VLC as shown in Figure 2. A second example can be considered where VLC receiver is blocked, then VLC link cannot be established with that particular car. The radio technology, solves the issue of communication until VLC receiver is cleaned.

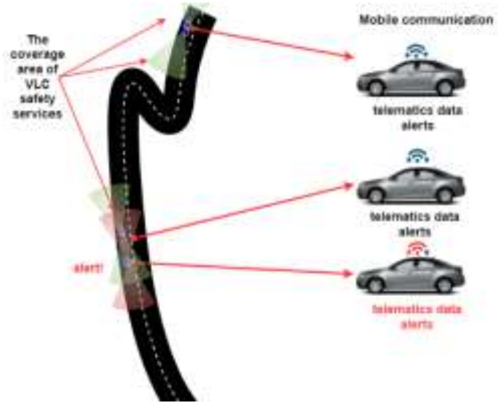

Figure 2. Road Safety Networks, VLC and Mobile Communications

By adding interaction between the cars, the driver as road participant can pass relevant information to others with minimum distraction from the road. This behavior can lead to the informed participation of the road users to the traffic. This also protect driver's life and their passengers, and increases the level of safety on the road. The adoption of this new way of driving can help increase awareness and can shift the view on driving, from getting there fast to getting there safe. This can be a small step in developing a better solution on the long term, in the commitment of reducing road accidents by 50% by 2030. In order to be able to respond to the whole ensemble that forms road traffic, the development of a road safety technology of this kind it is necessary to respect the following guidelines:

- Installation must not affect the car operations

- The costs of such system must be attractive enough in order to massive adoption in an after-sales market installation to ensure the safety of the drivers and its passengers

- Its operation must respond to vehicles of all types

The above proposal comes from the background of our research on VLC technology and from our goal to add to the society, in need to protect its people in the long run. Road traffic takes an intricate place in our life and it is bound to our way of living, wherever we are living in rural or an urban place. The mobile communication between the vehicles links the user interaction with the mixed safety system, which is supported by cloud computing resources, microservices and databases as represented in Figure 3.

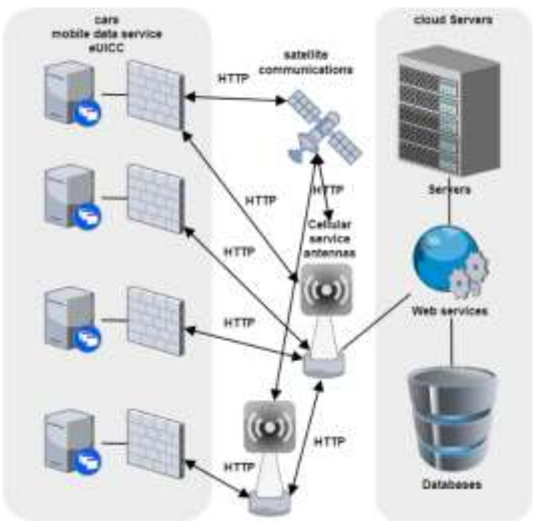

Figure 3. Road Safety Networks, Mobile Communication and Cloud Microservices

In our case, in the mixed technology proposal, each technology must independently be implemented and operating together. Thus, there will be two channels of communication from one car to another. The second one, the mobile communications between vehicles will be supported by microservices. This is an important piece in the system that will provide the safety services. Without a proven efficient operation of the microservices, the coverage of VLC system will be significantly reduced to the line of sight and also to the unidirectional, established from the car in front to the one in the back.

Having the hardware does not make it right to say we have a complete solution. Therefore, the central component of the road safety application is represented by the availability of the cloud based microservices that process the requests of all road users and delivers meaningful and relevant information back to them. As technology advances, it is the software solution component that makes the technology work the way it does.

Our approach can overcome some of the limitations that MANET networks have(Fazeldehkordi et al., 2016), because mobile communication today offers better security and low latency connectivity. There are also some disadvantages. The information provided due to user interactivity in the network is volatile and can also be falsely or wrongful reported. However, the advantage that the road user has is enough time to acknowledge its validity in the following minute or tens of seconds. Obtaining more time for the road user in the decision making, is the key component to the envisioned mixed safety application.

5. Analysis of Results

We want to ensure quality of service (QoS) of the safety system and also to increase coverage of the VLC safety service, giving drivers the time to act in an informed manner, different from the one we are accustomed. The central piece is composed of multiple pieces that work together. A Spring Boot Java application ensures fast, reliable communication of the Internet of Things (IoT) device through the HTTP protocol, with the purpose of informing the drivers and propagating the messages to the road network with scope to transmit telematics data (road, position, direction) and traffic alerts. This network is supplementary from the one present in ITS. Spring boot implementation increases throughput of a typical database and extends the capability of response in a short amount of time. At the vehicle level, information between VLC and mobile communication is shared even though it operates separately.

Our software application differs from a monolithic one due to its client's distribution. Each road user can receive alerts; however, each road user participates to the network once a second with new information, location only or with an additional information like an alert. Any alert that comes from the user is recorded in a table *alerts* inside the application database. A special table called *alert receivers* facilitates which users will be the recipient of those alerts. This query runs every second and searches for recipients with two conditions: a computation of the distance and a limitation to the users driving in the same sense. The driving of the user will be assisted with the alert that corresponds to the conditions previously established for 1.5 kilometers, leaving up to 108-41 seconds for a driving speed between 50 and 130 km/h, enough to take a decision. In order to achieve complete coverage each car has to have the mix of technologies installed, also a load balancer must be implemented in the cloud service in order to successfully process response in real-time to thousands of cars on each road. Also, road users with speeds above the specified range have less time, but still, some in order to take action.

A virtual case study was taken into consideration to demonstrate the capability of the software solution to inform drivers with relevant information. The case is represented by a road with a single direction of travel, with vehicles that drive in both ways.

Figure 4. Case Study for Solution Development

Eight cars travel on the national express road E85, four in each direction are represented in Figure 4. The four yellow-marked circulate from north to south, while vehicles 1,2, 3 and 4 travel from south to north, in the opposite direction. At some point the second vehicle issues an alert on the direction of travel. Under these conditions, an alert shall be issued within a radius of 1.5 km in the direction of travel of the vehicle in that place, where all vehicles enter the perimeter of this circle for 30 minutes will receive an alert. In this case the green-marked vehicle 1 will immediately receive that alert.

The scope of this scenario was successfully concluded using an H2 in memory database and using the following spring boot dependencies: spring-boot-starter-data-jpa, spring-boot-starter-web, where the vehicle to be informed receives the alert according to the discussed criteria of road, distance and direction of travel.

6. Conclusions

VLC road safety applications can achieve increased coverage by merging VLC technology with mobile communication. The benefits of the co-implementation are the significant greater coverage of road safety services, to facilitate the exchange of safety information between vehicles at distances much longer than the VLC communications range and to the redundancy of road safety services if one of them is temporarily inactive.

Once these vehicle communication and safety services are active and available in the road space, the shortcomings due to the lack of time required to make a decision would be diminished, and participation in traffic at any time of the day could become informed. Moreover, if the weather conditions: heavy rain, fog, blizzard affect or blocking the ability to receive information transmitted through VLC, here the mobile communication vehicle safety service can respond successfully while maintaining a high level of road safety.

This envisioned complex application, with both software and hardware components, assisted by cloud services, will make possible to facilitate and maintain road safety services for all vehicles on a road sector. Also, in this application all vehicles participating in traffic can issue and receive traffic alerts based on onboard sensors or through human-machine interaction. All inputs and outputs in a machine or server communication system following any interactions, comply with a protocol for prioritizing information both in VLC communications, as well as in mobile communications.

7. Future Work

In the future we want to further develop this solution together with the hardware implementations of the two technologies, VLC and mobile communication and further investigate new ways to increase road safety and reduce road accidents incidence.

8. Acknowledgement

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