A Systematic Mapping of IoT Sensor Networks for VANETs supported by Edge Computing for Road Blind Spots

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***Abstract*—As part of a technological evolution, the Internet of Things - (IoT) has been showing changes both in terms of hardware and software. In particular, IoT protocols have brought some differentiated changes by acting particularly on devices with low processing power, low energy consumption and little RAM, these restrictions must be carefully evaluated to guarantee aspects of performance and functionality within the characteristics of this environment. In this way, the present work presents a systematic mapping of literature about the use of sensors to support an anti-collision system in VANET (Vehicular Ad-hoc Networks), V2V (vehicle to Vehicle) and V2I (Vehicle to Infrastructure) networks. Through this mapping we also evaluate the use of Edge computing architecture, in order to produce lower latency and consequently a more adequate response time to the needs of the scenario.**

***Keywords*—Internet of Things (IoT); IoT Protocols; QoS (Quality of Service).**

I. INTRODUCTION

Deaths caused in traffic accidents, whether on highways or even in urban areas, often occur due to improperly performed overtaking, where the driver performs an action without proper security or in an irresponsible manner. Although there is legislation in Brazil that aims to prevent these accidents which is widely publicized and policed, yet achieving a greater reduction in the number of victims still seems little feasible. Based on this scenario, one of the solutions to be employed would be Information and Communication Technologies (ICTs) that, through sensors and a support system on roads, highways or intersections of “Urban perimeter”, could result in one of the viable solutions to the issue of traffic accidents.

The spatial analysis of traffic accidents are essential to understand and recognize critical points or stretches and, therefore, essential to establish strategies to reduce these occurrences[1]. Traffic accidents result in public health issues, which has high monetary costs for the government and takes a big toll on society in general. Those costs are studied in order to be measured and reversed through preventive investments.

According to the information from the Pan American Health Organization (PAHO) in 2019, approximately 1.35 million people die every year as a result of traffic accidents, which cost most countries three percent of their Gross Domestic Product (GDP) [22].

Every day, Brazil records 14 deaths and 190 accidents on federal highways. In 2018 alone, there were 69,206 accidents, 53,963 of which involved victims. These accidents resulted in 5,269 deaths in the year. In the 12 years analyzed by the Brazilian National Transport Confederation - CNT, Brazil had 1.7 million accidents on federal highways, with 751.7 thousand victims and 88.7 thousand deaths [3].

Among the actions aimed at preventing deaths and accidents in traffic, the use of ICTs (Information and Communication Technologies) has shown great promise to be an important tool, both in capturing statistical data and in helping to prevent these accidents. Several technologies are being developed to reduce and even extinguish the traffic problems that are so common in the world's metropolises. These new techniques could make cities smarter and help metropolises to overcome not only traffic problems, but also safety and urbanism [4]. This systematic mapping will show the use of ICTs in the scientific literature, focusing on IoT sensors and support infrastructures, in order to elucidate results or measure the technologies involved in the field of accident prevention.

II. RESEARCH METHODOLOGY

We will now describe the method used to compose this systematic mapping, its conceptual research structure and application model. For that, the protocol proposed by Petersen et al. [2] was used. A Systematic Literature Mapping - SLM seeks to analyze questions and answer them in order to add or index evidence found in the literature for the proposed themes. This is possible due to it being a process with strict criteria of an iterative nature. Its main objective is to give an overview in regard to a specific area, identifying the amount and character of the research, which allows bringing relevant results from the available works [5].

A review using systematic mapping requires a set of facts to determine the pathway. Therefore, a protocol is elaborated containing the research questions (RQ), inclusion criteria (IC), exclusion criteria (EC), definition of scientific databases and a research string containing keywords, thus generating a better data extraction process [6].

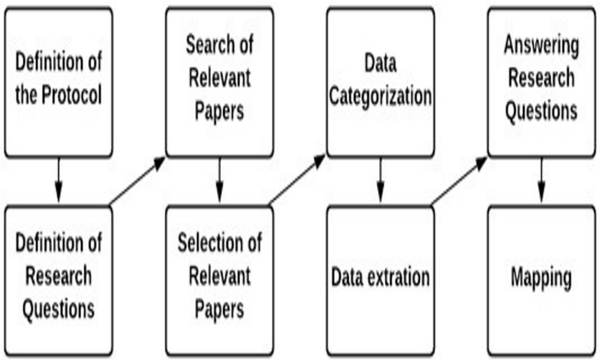

Fig. 1. Systematic Mapping Process. Source: Author

A. Research Questions

The following research questions (RQ) were defined for the systematic mapping study:

Main Question. Identify the current scenario and the technologies and technological concepts used in vehicular networks.

TRQ1. What are the most promising technologies for this implementation?

TRQ2. What are the challenges encountered in implementing this solution?

TRQ3. What type of infrastructure can support sensors?

TRQ4. What human factors influence this type of system?

TRQ5. What stage are these technologies at?

B. Motivation for Research Questions

RQ1..What are the most promising technologies for this implementation? The purpose of this question is to identify technologies that are already validated or have good evidence of success in the area of the proposed research. By answering this question, we will also be able to rule out outdated technologies.

RQ2.. What are the challenges encountered in implementing this solution? It is intended to identify challenges in different aspects, such as: physical characteristics of the communication channels, including their frequencies and signal coverage; performance and reliability of protocols and services, considering latency, errors and bandwidth, for example.
- Interference in the transmission frequency;
- Shaded or covered areas;
- Low latency in data transmission.

RQ3.. What type of infrastructure can support sensors?

Here we have the relative questions and correlated to the difficulties of RQ2, thus seeking among the selected articles the best indicators for hardware and software to support the sensors, expanding their signals, eliminating interference and reducing the latency to an acceptable limit.

RQ4.. What human factors influence this type of system? We seek answers to the main factors that threaten or limit the success of VANETs and collision detection systems, focusing mainly on those that are based on human and social interaction and on the possibility of actions that bring harm to the process.

RQ5.. At what stage are these technologies at? We seek here to verify the levels of availability and the extent to which these technologies can be improved or adapted to implement the search.

C. Search and Selection Strategy

We present here the inclusion and exclusion criteria and the search string used in the scientific databases, which helped to build a more efficient search, returning only relevant works for further in-depth analysis. The inclusion and exclusion criteria were:

IC1: Relevance to the theme;

IC2: Article-type document;

IC3: Publications between 2012 and 2022;
IC4: Book chapter.
EC1: Duplicate articles;
EC2: Jobs with limited or unavailable access;
EC3: Articles under review;
EC4: Short articles or expanded abstract.
These criteria were applied to the results of the search carried out in the following databases: IEEE Xplore, ACM Digital Library, Springer Link, Scopus, and Web of Science. The default search string used is presented in table.

TABLE I
GENERIC SEARCH STRING

((v2v OR "vehicle-to-vehicle" OR "vehicle to vehicle" OR v2i OR "vehicle-to-infrastructure" OR "vehicle to infrastructure") AND (IoT or "Internet of things") AND (collision or accident))

D. Conduction

A process of selection and screening of the articles found in selected scientific databases was carried out and duly analyzed according to the inclusion criteria. The search string returned a total of 1003 articles in the databases. The selection by database had the following distribution: IEEE Xplore brought 118 articles; Scopus had 288 articles; ACM Digital Library returned 114 articles; SpringerLink contributed 175 articles; and 308 articles in the Web Of Science.

Base	Search Result
IEEE Xplore	118
Scopus	288
ACM Digital Library	114
SpringerLink	175
Web Of Science	308
Total	**1003**

After applying the exclusion criteria related to the process of identifying papers and removing duplicate articles, a total of 834 were excluded from the research, leaving a total of 169 papers.

Of the 169 remaining papers, based on the criteria already available, 15 articles were selected for full reading since they met all the criteria established by the mapping protocol used.

E. RELATED WORKS

After analyzing and reading the articles, the mapping returned 15 works that have at their core several contributions regarding the topic addressed and that vary in different directions of the same proposal.

TABLE III
SELECTED AFTER EXCLUSION CRITERIA ANALYSIS

Base	Results Obtained	Final Results
IEEE Digital Library	118	25
Scopus	288	34
ACM Digital Library	114	24
SpringerLink	175	42
Web Of Science	308	44
Total	**1003**	**169**

In the work by Golestan et al. [17], it is highlighted that, in Vehicular Ad-hoc Networks (VANETs), one of the challenging issues is finding accurate location information. The authors introduced a new approach based on the idea of cooperative location. In the proposed scheme, different localization techniques were incorporated, along with data fusion, as well as vehicle-to-vehicle communication, to integrate available data and cooperatively improve the accuracy of vehicle location information. The simulation results show that the sharing of location information and the deployment of neighboring vehicles, not only ensure that nearby vehicles obtain more accurate location information, but also allow to obtain robust results regarding the greater accuracy of the sensors, or even help to find flaws.

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In the work proposed by Chen et al. [18], it is outlined the fact that in recent years, vehicular networks have become increasingly larger, heterogeneous and dynamic, making it difficult to meet the strict requirements of latency, high reliability, security and massive connections for next generation networks (6G). Recently, deep learning (DL) has emerged as a powerful artificial intelligence (AI) technique capable of optimizing the efficiency and adaptability of vehicular and wireless communication. However, it is important to consider that the rapid increase in the absolute number of vehicles on the roads is leading to an increase in car accidents, many of which are attributable to drivers interacting with their cell phones. To address potentially dangerous driver behavior, this study applies deep learning approaches to image recognition to develop an AI-based system that can detect potentially dangerous driving behaviors. Several convolutional neural network (CNN) based techniques including VGG16, VGG19, Densenet and Openpose were compared in terms of their ability to detect and identify problematic driving.

Hakeem et al. [19] exhibit a work that brings us to the considerations or concepts of the vast majority of technologies that can or have unique purposes to the theme of this map- ping. Dealing with issues such as interoperability, security, zones of signal amplitude and old and new technologies for convergence, the authors show us the various aspects of V2V networks and how they must work to be successful, as well as the technologies conducive to that matter. Issues such as security have always been a relative negative point in these projects involving sensors and their data transmission requirements, issues that many authors leave in the background so that there can be a dedication to the central problem that is usually the need for a low response time or latency in the communication between vehicles. The authors bring us comparisons of techniques involving 3GPP17 signals and signals involving 5G with V2X platforms, even showing their differences for the LTE V2X platform.

According to Yu et al. [7] most studies related to VANET technologies such as V2I present results based on the concept that all drivers will strictly follow the recommendations offered by auxiliary systems and almost never consider how different drivers can react in different ways to the most varied situations. Given this, a promising method was proposed for verifying the behavior of drivers at intersections with and without connected vehicle technologies. In this way, one can understand how drivers react to these technologies and envision what would be necessary for the same drivers to be encouraged to follow these suggestions. The desired result would be an increase in road and highway safety, taking into account that drivers often need to make decisions in a short amount of time.

In the study by Maglogiannis et al. [8] it is mentioned that accidents can be avoided and the levels of attention of drivers can be increased when vehicular wireless networks are implemented. A greater propensity of drivers to follow the rules of the road is mentioned, in turn having a better response when it comes to emergencies or situations where quick decisions must be taken. The authors propose a system with the objective of making VANETs safer and more efficient through the use of data transmission devices that are responsible for sending the information to the next vehicle and an LCD unit that is responsible for presenting the results to the drivers. Through experiments, the authors found that, for the current and future support of vehicles and transport networks, it is necessary for VANETs to be self-adaptive to failures and possible threats, in addition to being resilient.

Deng [9] argues that currently the Internet of Vehicles - IoV provides Internet connectivity for vehicles that are within the coverage of networks, but full-time connectivity is not guaranteed due to the limited number of Road Side Units (RSUs), one of the main forms of V2I technology. The author mentions that very busy highways are experiencing Internet connectivity problems which in turn results in less information being exchanged between vehicles and therefore hinders the achievement of some of the goals of VANETs. To deal with these problems, a dynamic positioning scheme of the RSUs on the highways is proposed so that the maximum of its extension is covered without losing connectivity. The dynamic positioning takes into account the traffic density and the distance between the RSUs and cellular antennas that can be used as infrastructure for communication in networks.

According to Huang et al. [10], a very important point that is often neglected by studies related to new IoT technologies and their operating scheme, is the download of information and the quality of service (QoS), to deal with these issues Huang proposed a system for the download of information in VANETs, DIVINE, whose main objective is the transfer of information to the RSUs as quickly as possible, as well as being responsible for deciding which data will be streamed through V2V or V2I taking into account details such as, type of information and its priority, so that the most important information reaches the right places in the fastest way and it becomes possible to make a more accurate and safe decision, thus ensuring the QoS is assured.

For Saleem et al. [10], some information technologies began to be implemented in vehicles and their networks as soon as organizations began to observe their advantages. Some of these best known technologies are 5G, the Internet of things (IoT) and Artificial Intelligence (AI). With this in mind, [11] proposed a system aimed at detecting abnormal behavior in vehicles on the road, such behavior can be exemplified through sudden stops or driving outside traffic regulations. The system uses 5G and IoT to maintain a network of information about vehicles on the road and thus analyze and refine information related to the location and intentions of drivers. This becomes possible through algorithms and with the aid of technologies such as cameras and sensors that would capture the driver's movement, the lane in which the vehicle is and its speed, in this way the system can define whether the vehicle is behaving abnormally and if you have broken any road regulations.

According to Choi et al. [13], using a Random Forest

(RF) encoder-decoder architecture and long short-term memory (LSTM), the authors proposed a grid prediction model that employs RF to predict the intent of surrounding vehicles (SV) to change lanes and establish the horizontal location of the grid. The trajectory of the SV is then predicted, and the vertical location of the grid is determined using the LSTM encoder-decoder architecture. The authors used a car equipped with a V2V communication device, camera sensor and LIDAR to record the dataset that would be used to train the proposed prediction model. The suggested model, which uses the grid created in this way to predict the trajectory of the SV, is advantageous for collision warning systems (CWS). The effectiveness of the CWS is based on how well the lateral position is predicted. Maglogiannis et al. [14] provides a comparison of the various V2X communication methods utilizing industry standard hardware in a realistic highway environment. 4G Cellular Vehicle to Everything (C-V2X) technologies on long range communication interfaces (Uu) and short range automotive communication interface (C-V2X PC5) and intelligent transportation systems (ITS-G5) were compared for various Key Performance Indicators (KPIs), including PDR, packet loss, unidirectional end to end (E2E) latency, and signal strength. Several configuration parameters, including the operating frequency channel in the 5.9 GHz band for the short range technologies, packet transmission interval and packet size, were considered for the evaluation of the KPIs. Test cases were used to evaluate the performance of V2X technologies, including the functionality of V2I and V2V communication links, the impact of software-based security on short-range communication technologies, and the functionality of V2X technologies in infrastructures between countries. They evaluated the technologies under identical conditions, taking into account transmission-related factors (simultaneous transmissions of various V2X technologies, packet sizes, transmission intervals), environmental factors of the highway (traffic density, obstacles, street curvatures) and climate factors.

They did this using their internally developed CAMINO V2X communication management framework. The results indicate that, for the vast majority of tests, the C-V2X PC5 offers a greater range than the ITS-G5. On the other hand, due to the way the two technologies used different channel access techniques, the ITS- G5 offers lower latency than the C-V2X PC5. However, both solutions provide latency below the 100ms threshold required for ITS security services and applications. The results also demonstrated that many times there is no packet loss on the 4G link for long distance communication.

In Torres et al. [15], the authors presented a Long Range (LoRa) analysis in contrast to the much used Dedicated Short Range Communication (DSRC). According to [9] although LoRa is declared a solution for the Internet of Things in general, its functionality in V2V communication is still very little studied. His analysis, therefore, seeks to address the gap when it comes to V2V and V2I applications in the performance of using LoRa . When creating tests with the stop of two vehicles, it was denoted that even with the limited transmission capacity and small size of transmitted messages, LoRa presents great versatility even in a dense urban environment. Its simple hardware and enormous applicability makes the use of LoRa a viable and satisfactory option.

In Mehmood et al. [16] paper, with the intention of meeting the need for a routing protocol that meets the needs of growing vehicle technologies, the authors propose the use of an intelligent algorithm, Naive Bayes, which practices probabilistic estimation. for traffic flow in order to form clustering stability in ANTSC named VANETs. The machine learning algorithm, Naive Bayes, is classified as supervised learning, as it is established from predictions of pre-established observations. The vehicle density, direction, distance and its connectivity are also parameters for the choice. The clustering model consists of initialization, join, cluster head selection algorithm, short-term disconnection of cluster head, exit procedure, merge procedure, no merger, exit procedure of all cluster member vehicles and procedure to give up the cluster head function. Always using the highest density flow aiming at greater cluster stability, it was found that the algorithm proposed by them when compared to other algorithms surpasses them in stability capacity and longevity of both the cluster and the cluster head. Abbas et al. [20] developed work on V2V and V2I communication based on the IEEE 802.11p protocol, which uses legacy CSMA/CA techniques to moderate gain control [12]. As the contention-based CSMA technique was not primarily aimed at VANETs with fast mobility, special V2V traffic may cause uncertain transmission latencies and may not be able to handle the timeliness and reliability requirements of ITS applications. In contrast, V2V communication, which allows direct communication on close associated links, offers an optimistic solution for stable VANET connections. Compared to ad-hoc V2V solutions, V2V links can easily achieve reliable message delivery and organized resource deployment, promoting the widespread existence of a centralized intelligent V2X infrastructure [15]. However, the presence of the V2V link, complemented by a central V2X structure, will offer direct propagation of nearby messages, significantly reducing energy consumption and latency, therefore suitable for V2V communications. latency based. Therefore, the authors of the study [20] indicate that the cellular network based on V2V is an optimistic solution to achieve highly stable and efficient vehicle communications.

Xu et al. [21] said the Internet of vehicles (IoV) arises to be an improvement in the increasingly crowded traffic conditions. In IoV, the rise of smart vehicle applications produces computationally intensive tasks for vehicles. However, it is difficult for vehicles to meticulously meet the demands required by the tasks due to the limited computing capacity implanted in them. To face this challenge, vehicle-to-everything communication (V2X) is a promising technology to support edge computing transmission tasks. By employing vehicle-infrastructure communication (V2I) and vehicle-to- vehicle communication (V2V), the source vehicle searches for viable routes to offload the computation tasks. to the border node (EN). In the article by [21], they propose a computation offloading method that employs V2X technology for data transmission in edge computing, called V2X-COM. Technically, the routing of computing tasks is determined first. Next, the genetic unsupervised classification algorithm III (NSGA-III) is adopted to generate balanced unloading strategies. Furthermore, simple additive weighting (SAW) and multi-criteria decision making (MCDM) are employed to search for the ideal offloading strategy. Finally, experimental evaluations are carried out to prove the validity of the V2X- COM.

F. RESULTS AND DISCUSSION

Based on the research and articles collected for this mapping, it was possible to generate a graph that shows the number of works published on the researched topic, as shown in Figure 2: Through the graph shown in Figure 2, it is possible to see the difference in the amount of research and articles written in the last 4 years compared to the previous years, this is due to an exponential increase in interest in VANETs technologies, their evolution and its possible applications in the various technological means involved, mainly in terms of sensors and edge equipment.

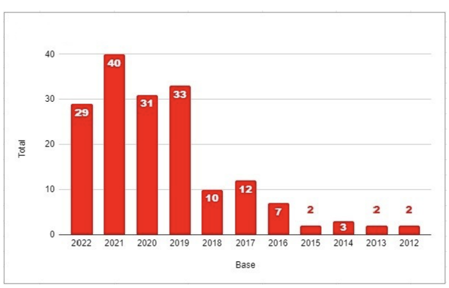

Fig. 2. Publications chart per year

In Table IV and Table V we can see the result of the research questions, the questions that motivated the creation of systematic mapping.

Among the selected articles, approximately 60% did not have an answer to question IV (What are the human factors that influence this type of system) and 14% could not answer question II (What are the challenges encountered in the implementation of this solution). All other questions had answers in 100% of the articles.

Table IV presents the answers to the first three research questions: RQ1. What are the most promising technologies for this implementation? RQ2. What are the challenges encountered in implementing this solution? RQ3. What type of infrastructure can support sensors?

With regard to (RQ1), the authors mainly cited IoT and 5G technologies, showing that both are in full development and will be the future metric, with their high availability, versatility and low energy consumption. Mobile technologies have, within the scope of networks, greater bandwidth and lower latency. These technologies, combined with the concept of Road Side Units (RSUs), form the new trend for vehicular networks.

The main challenges found in the researched articles turned out to be communication problems, either due to the low latency of the signals due to irregular terrain or in shaded areas, external factors such as the quality of the equipment used both in the vehicles and in the fixed infrastructures, they also become a barrier to be overcome, since a low reliability of the systems involved becomes a highly negative point in VANETs. The Information shock on very busy roads due to the large amount of transmissions taking place at the same time is another future challenge to be overcome, as current technologies are still unable to meet the needs of complex vehicular networks. Table V presents the answers to research questions 4 and 5, which are respectively: RQ4. What human factors influence this type of of system?

TABLE IV
RESEARCH QUESTIONS: Q1, Q2, AND Q3

	Q1 - Technologies	Q2 - Challenges	Q3 - Type of infrastructure
[4]	DSRC, RSU, HMI	Drivers compliance with recommendations	RSU (Roadsite Units)
[6]	Arduino Nano, LEDs, IoT sensors.	Equipment quality	V2V, CSP
[7]	RSU, UAVs	Limited connectivity	RSU.
[3]	Divine	Response time	V2V, RSU
[8]	5G, IA, IoT.	Not Mentioned	Video detection
[9]	SDNi-MEC	How to find the best paths to VANETs, how to have a reliable transmission	Celular network, RSU
[10]	Lidar	Occasional failure in SV recognition in areas where V2V communication is not possible	V2V communication device, camera sensor.
[11]	ITS-G5, C-V2X PC5.	Collisions between multiple transmissions or limitations on the hardware or firmware side of the ITS-G5 commercial module	V2I, RSU
[12]	LoRa, SF7 e sf12	Equipment reception limits according to distance and geology	V2V, V2I, CAMINO Framework
[13]	ANTSC	Process of cluster head selection and their stability	WAVE, RSU, OBU.
[14]	VANET‘s	Inaccurate location information	V2V, fusion of data, radio and distance measurement
[15]	AI, 6G, IOT, Deep Learning	Not Mentioned	Multiple convolutional neural network (CNN)-based techniques including VGG16, VGG19, Densenet, and Openpose
[16]	5G-NewRadio	Communications and mobility challenges.	V2X, 3GPP, DSRC, LTE-V2X, 5G-V2X
[17]	Resource Management Scheme	Track fast channel diversity due to high mobility and density	V2I,V2V
[18]	IoV, Mobile edge comp., V2X-COM, NSGA-III	Compute tasks and alleviate the unbearable latency caused by the relatively long distance between vehicles and the cloud	V2X, smart cameras,actuators

Most articles do not mention the human importance in rela-

TABLE V
RESEARCH QUESTIONS: Q4 AND Q5

	Q4 - Impact of human factors	Q5 - Stage of evaluated technologies
[4]	Drivers compliance	Functional under development
[6]	Driving behaviour	Tested and approved
[7]	Not Mentioned	Development
[3]	Driving speed	Functional under development
[8]	Drivers behaviour	Functional
[9]	Not Mentioned	Tested
[10]	Driving behaviour	Tested
[11]	Not Mentioned	Development
[12]	Not Mentioned	Functional under development
[13]	Using smartphones while driving and other problematics behaviors	Development
[14]	Not Mentioned	Development
[15]	Not Mentioned	Functional under development

tion to technology, which is a point to be considered, however those that did, have a common point that are the individual characteristics of the driver and that can affect the performance of the technologies involved. The tendency to accept or not the suggestions delivered by the available equipment, the way of behavior on the road, the use of electronic devices while driving, drivers with problematic safety behaviors and at what speed they drive the vehicle, make any scenario available unstable, as technologies need to be consciously and safely integrated into their daily lives. QP5. What stage are these technologies at? Regarding question V, only 26.7% of the articles analyzed technologies that were only in the development phase, while 46.6% of the articles cited technologies in a functional state and the others still in a test state 26.7%, among these articles mention was also made of some technologies that are considered promising for multiple areas of technology such as AI and 5G and 6G communication technologies, most of which are already in a functional state.

In Figure 2, the articles that were found through the search were cataloged and listed according to their year of publication and their research base, with 2022 being the year in which most articles were published with a total of 23.4% of all articles and the scientific research base Web of Science being the largest supplier of them with a total of 25.7%.

III. CONCLUSION

There are many challenges encountered in the implementation of real-time systems, particularly those involving high-speed data transactions and those which result in the physical integrity of the elements involved.

In recent years, with the development of intelligent vehicles and wireless sensor network technologies, road safety research has attracted a lot of attention on ad hoc vehicular networks (VANETs). We can exemplify by these surveys, models of detection of events on the road, where vehicles involved can transmit information to other vehicles or people about congestion, accidents or geographically interrupted terrain. However, the mobile vehicle network has a large transmission delay, which poses several challenges to real-time communication.

Vehicle-to-infrastructure (V2I) communications are the emerging paradigm for Intelligent Transportation System (ITS) used to increase traffic efficiency and reliability of timely data delivery. Despite the technological advances and the social needs involved, great advances are still needed in the area of IoT and sensor-based vehicular networks, while the same ones based on their creation proposal have latency and signal interruption failures, on the other hand the introduction of an adequate infrastructure based on real-time responses and the expansion of its service area emerges as a great model of support and complement to the lack of sensor responses, once well conducted, both technologies can together find the solutions for the limitations encountered, we can verify in this work that several technologies have been developed both at the hardware and software levels.

The future creation of specific protocols and/or adapted for VANETs will have a high relevance with the technologies employed, as they can help this type of network in a more synchronous way with Edge Computing structures. With the help of new microchips, 5G or even 6G, mobile technologies and developed protocols will make it possible for VANETs networks to become a primordial technology in the cities of the future. Benchmark tests and simulations, combined with the efficiency of new edge hardware, will provide answers to all the gaps still found at the present time.

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