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Roadside Units for Vehicle-to-Infrastructure Communication: an Overview

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Abstract— Over the past few years, the level of motorization has increased significantly as well as the number of accidents all over the world. Many countries have developed strategies to ensure road safety but the problem remains, and road fatalities keep increasing. Some African countries like Kenya have recently integrated Intelligent Transport Systems (ITS) to mitigate the road traffic issues such as congestion, especially in the city of Nairobi. Other countries proposed to implement Vehicle-to-Infrastructure (V2I) technology which is a subset of ITS and which seems to be a good solution to reduce road accidents. The implementation of this technology is done by the installation of roadside units (RSUs) on the road network which is said to be very expensive in terms of deployment and operation and maintenance cost. This work aims at presenting the utilization of roadside units for V2I communication. RSUs communicate with vehicles equipped with an onboard unit (OBU) and the communication between the two must be established with quality of service guaranteed. This paper focuses on roadside units functionalities and some related works on their deployment scheme.

***Keywords*—**Roadside Unit, Vehicle-to-infrastructure, onboard unit, road safety.

I. Introduction

INTELLIGENT transport systems are defined as applications used in the domain of transport to ensure road safety and mobility. Many researchers have worked in this field to mitigate the issue of road accidents and congestion [1]. According to the World Health Organisation (WHO), 1.35 million people die every year in road accidents and 20 to 50 million people suffer from injuries. In addition, studies have proven that road accidents cost countries 3% of their gross domestic product [2]. The benefits of ITS rely on the cooperative Intelligent Transportation System (C-ITS) which include Vehicle-to-Infrastructure (V2I), vehicle-to-Vehicle (V2V), Infrastructure-to Infrastructure (I2I), and Infrastructure-to-Vehicle (I2V) communications [1]. Two types of communication enable the C-ITS technology such as Dedicated Short Range Communication (DSRC) with the deployment of roadside units (RSUs) and Long-Term Evolution (LTE) with the utilization of eNode B as shown in Fig. 1 [3]. This paper focuses on V2I communication which is based on DSRC technology. RSUs are wireless communication devices used to collect traffic data from their coverage areas and transmit them to the traffic control center. They also serve as an information source for intelligent vehicles to collect current and future traffic information in a V2I communication system [4]. Many countries in the world have tried to reduce the percentage of deaths and injuries due to road accidents. The European countries are classified as the top countries in the world that have the safest roads. They have succeeded in reducing road accident deaths by 23% from 2010 to 2019 [5]. In Africa, some countries like Kenya have implemented ITS technology to mitigate the issue of traffic congestion in Nairobi city [6]. The rest of the paper is organized as follows; in section II, we present the functionalities of an RSU. In section III, we classify RSUs and present a review on their deployment sheme. Lastly, section IV conclude the article with some research gaps and future scope.

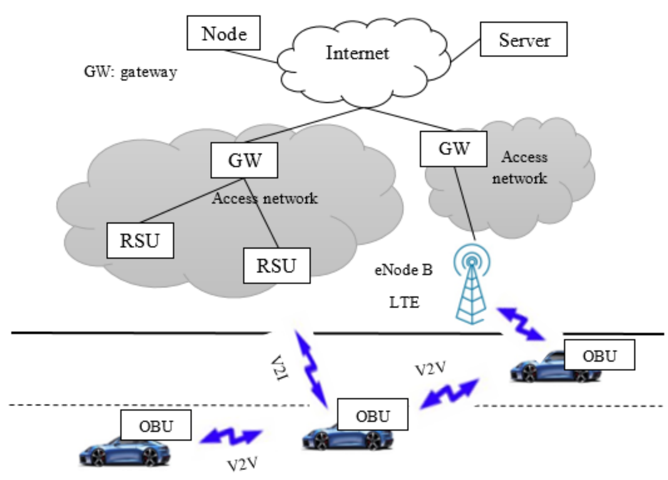

Fig. 1. Vehicle-to-Infrastructure network architecture

II. Functionalities of RSU

The information received by intelligent vehicles from RSUs can influence their decisions but is not considered to be an actuation. The information recorded by roadside units is the vehicle's speed, travel times, vehicle density, etc [7]. Roadside units are required to work on a frequency of 5.9 GHz as a DSRC infrastructure [8] [9]. DSRC is a technology defined under the IEEE 801.11p standard [10]. RSUs need to be configured by a transportation manager to transmit and receive messages [11]. The RSU can immediately forward a message and periodically transmit a message that has been stored. These messages can be

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signed or not by the source. The various scenarios are as follow [12]:

- Unsigned messages from the source and immediately forwarded by the RSU: The RSU receives unsigned or unencrypted messages from the back office and local devices and needs to sign or encrypt them before forwarding them to OnBoard Units (OBUs).
- Signed messages from the source and immediately forwarded by the RSU: The RSU receives signed or encrypted messages from the back office and local devices and needs to transmit them to OBUs without processing any additional security.
- Unsigned messages stored in the RSU, and sent periodically: The RSU sings or encrypts stored messages before transmitting them periodically to OBUs on the behalf of the source.
- Singed messages stored in the RSU, and sent periodically: The RSU periodically transmits signed and stored messages to OBUs on the behalf of the source. Those messages may be encrypted by the RSU.

Also, the RSU can receive messages from OBUs and forward them to the back office or local devices. This action depends on the content of the messages. If the messages are encrypted, the RSU will first decrypt them before forwarding them [11]. Furthermore, RSUs are wireless devices with high constraints in terms of deployment, operation and maintenance cost, energy efficiency, communication (high), storage (moderate), and processing (low) [7]. The RSU Working Group [12], presented a physical architecture of an RSU mounted on a mast arm of a traffic signal as elaborated in Fig. 2.

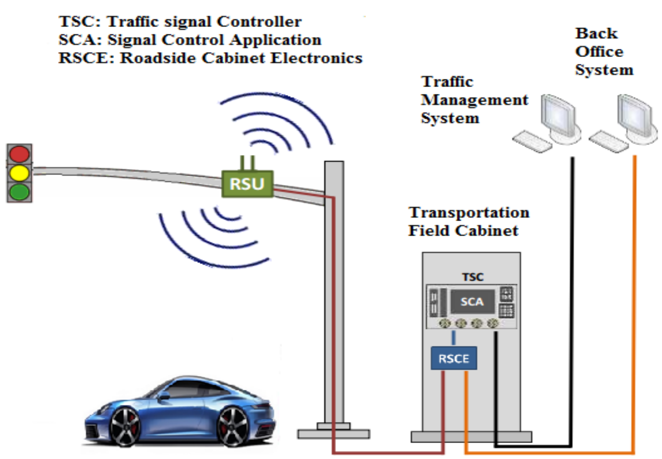

Fig. 2. RSU mounted on a mast arm of a traffic signal [12]

In this architecture, the Transport Field Cabinet System (TFCS) has two components that are the Traffic Signal Controller (TSC) which is in charge of running the application program(s) such as the Signal Control Application (SCA) (for the operation of an intersection) and the Roadside Cabinet Electronics (RSCE) for the integration of the RSU into the (TFCS). The Traffic Management System (TMS) is used by the transportation manager to configure, monitor, control, and collect data from the TFCS.

I. Passschier et al. [13] presented the high-level architecture and the detailed architecture of RSUs. In that design, it was assumed that the sensor information was used for three applications (Traffic management, shockwave damping, and merging assistant). The communication manager was in charge to enable communication with cooperative vehicles. Each component had a specific role and more information can be found in [8].

III. CLASSIFICATION AND DEPLOYMENT OF RSU

RSUs can be classified into two categories: fixed RSU and mobile RSU [14].

A. Fixed RSUs

Fixed RSUs are wireless communication devices with a static nature. Many works have been done to find an optimal RSU deployment scheme. M. Fogue et al. [15], proposed to use a genetic algorithm to determine the optimal location of RSUs by increasing the probability that emerging services can receive warning messages. L. Xue et al. [16], proposed a Connectivity-oriented Maximum Coverage RSU deployment Scheme (CMCS) to maximize the V2I communication performance in an urban area with a less number of fixed RSUs. The authors proved with this method that seven or eight RSUs can be deployed and achieve a better packet loss ratio for the transmission ranges of 400 meters and 500 meters for all vehicle densities. The minimum packet loss ratio obtained for the transmission ranges of 300m, 400m, and 500m was 3.60% and the maximum value was 31.81%. The researchers observed that for the same transmission range (except for 400m and 500m), the packet loss ratio decreased when the traffic density increases (a large vehicle density lead to minimum message forwarding performances due to collision and other factors). Also, the delay increased when the transmission range increased, but this variation depended on the vehicle density. They also noticed that the vehicle coverage was not much affected by the transmission (over 100m). S. Zhang et al. [17], proposed to use hybrid simulated annealing and particle swarm optimization algorithm (SAPSO) using vehicle speeds for a non-full coverage area (NCA). One of their results was that when the value of the NCA length increased, the minimum value of the objective function increased nonlinearly. Also, they discovered that their solution was highly performant and robust when the speed of the vehicles was high. J. Tao et al. [18], developed a method call the traffic-Aware Power Control (TAPC) for a cluster-based RSU deployment (CRD) scheme to minimize the RSU energy consumption and to maximize the performance of the network. Also, they proposed the Data-Driven Message Propagation algorithm (DDMP) to improve the performance of message propagation in RSUs for highways. Their results revealed that the network connectivity was much better and the energy consumption minimized when RSUs performed the TAPC method every 30 minutes. For a 100 MB packet size and a transmission rate of 20 MB/s, the transmission time was smaller in a DDMP scenario. B. Zhang et al. [19], proposed an algorithm based on the RSU energy efficiency with a constraint of coverage. Their results proved it is possible to have an optimal RSU deployment scheme with minimal transmission power. Y. Ni et al. [20], designed a utility-based

RSU deployment algorithm (URDA) for Internet of Vehicle (IoV) networks by considering the transmission delay and the service task assignment of IoV. The proposed URDA algorithm was found to be optimal if the deployment cost was low. Z. Wang, et al. [21], introduced the notion of centrality in an RSU deployment for 2-D urban and suburban areas. The objective was to maximize the centrality of all RSU positions which is to determine the importance of a candidate RSU position by considering two parameters such as the degree centrality and the closeness centrality. The authors defined the degree centrality as the degree of a node to be directly connected to other nodes and the closeness centrality as the total distance of a node to all other nodes. They compared their solution to a random deployment approach and found that their results were better in terms of coverage ratio time. X. Cao et al. [22], considered the deployment cost and the vehicle access network latency as parameters to design an RSU deployment scheme based on large vehicle data. From their solution they concluded that for a small amount of RSU they can achieve a high coverage and low latency.

The authors of the above-related works proposed various methods and algorithms to find an optimal fixed RSU deployment based on different parameters. They mostly did their deployment on road intersections or roadsides. Nevertheless, other authors have worked on the deployment of mobile RSUs to ensure high connectivity and coverage performances as explained in the section below.

B. Mobile RSUs

Mobile RSUs are wireless communication devices with a dynamics nature. Their effectiveness has been demonstrated by S. Ercan et al. [23] who did an analytical study of the deployment of 5% of mobile RSUs and validated that it can effectively double the communication probability. J. Heo et al. [24] replaced a fixed RSU with a mobile RSU and confirmed that both of them can perform the same task. Many authors have suggested using unmanned aerial vehicles (UAVs) or cars to serve as mobile RSUs. In this section, related works on UAVs will first be presented and then related works on cars as mobile RSUs will follow.

F. Outay et al. [25] presented the application of UAVs and their challenges. They mentioned that UAVs can be applied as infrastructure for accident investigations and improve the communication network. Similar work can also be found in [26]. Furthermore, S. A. Hadiwardoyo et al. worked on the deployment of UAVs for an area with fewer infrastructures [27]. They measured the received signal sent by UAVs to cars to determine the optimal location of UAVs by using particle swarm optimization (PSO) algorithm and genetic algorithm (GA) and found that PSO gives better results. Other authors designed strategies to integrate UAVs to assist fixed RSUs in data collection and dissemination. F. Zeng et al. [28], did the deployment of UAVs for highways and intersections. Their experiments were based on the prediction of vehicle mobility and the scheduling of 2 dimensional UAV's movements during data dissemination by using the recursive least squares algorithm and the maximum vehicle coverage algorithm respectively. Their objective was to maximize the total throughput and minimize the transmission delay. Also, E. Barka et al. [29] worked on the same line as [28] and resulted in the deployment of a network with a high packet delivery ratio. A hybrid gray wolf whale optimization algorithm was used by X. Du et al. [30] to plan the path of UAVs for data collection for each fixed RSU. The algorithm was validated to be stable, fast, and accurate. Other algorithms were used like GA and harmony search (HS) to determine the overall shortest path of UAVs to gather data from fixed RSUs. They assumed that one UAV cannot visit all fixed RSU, each UAV should travel the same distance and have a constraint of energy. The results revealed that HS is performant than GA when the problem becomes more complex. It is important to highlight that UAVs have some security challenges because they interchange very sensitive data dealing with road safety measures among others. To overcome this issue, Nico Saputro et al. [31] designed a secure protocol to control mobile RSU when they relay information. In addition, S. Jobaer [32] designed a secure routing protocol for UAVs to assist fixed RSUs. The objective was to prevent congestion.

Moreover, cars can be used like mobile RSUs as mentioned before, most of the researchers proposed to use parked cars as RSUs to improve the network connectivity in areas where other RSUs cannot cover. Some self-organizing strategies have been proposed in [33]-[35] to enable a parked car to decide whether it will be an RSU or not depending on its environment and its neighboring fixed RSUs.

IV. Conclusion

A roadside unit is a very important device for vehicle-to-infrastructure communication networks. In the recent decade, many works have been done to design an optimal deployment scheme of RSUs due to their high cost of installation, operation, and maintenance. In this paper, an overview of the functionalities of RSUs and related works on their deployment was presented. RSUs can be classified into two main categories: fixed RSU and mobile RSU. From the above-related works, mobile RSUs seem to be more suitable for road management and safety because they enhance network connectivity, are cost-effective, and they offer a large coverage. Nevertheless, they are very complex in terms of deployment because their deployment must follow the regulation of the aviation authority (for UAVs for example), various routing scenarios must be considered; scheduling of collected data, and dissemination path depending on the tasks assigned, self-organization for cars as mobile RSUs. Moreover, UAVs are proposed to be deployed to assist fixed RSUs in relaying information to vehicles and other RSUs. This solution can be well explored to improve RSU-to RSU communication.

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