RSU placement considering V2X services requirements and available radio resources

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***Abstract*—Connected, cooperative and automated mobility (CCAM) is a growing field as the services required by connected vehicles increase in quantity and complexity. To be able to be connected, vehicles need network infrastructure to communicate with. Roadside Units (RSUs) are communication devices that are placed beside highways and roads and offer connectivity and processing services to the vehicles. The 3rd Generation Partnership Project (3GPP) has developed some standards which specify the characteristics of the services, as well as the spectral bands used to offer vehicle to everything (V2X) connectivity. In this paper, we study the optimal placement of RSUs in a V2X network for different service requirements and channel quality scenarios, considering the 3GPP standards. We formulate an Integer Linear Programming (ILP) model to minimize the number of RSUs needed and solve it for different traffic and channel conditions given by the 3GPP specifications. Results offer the number of required RSUs and their placement for vehicular access networks deployments.**

Keywords— Network Planning, Internet of Vehicles (IoV), Roadside Unit (RSU), Connected and cooperative and automated mobility (CCAM), Vehicle to Everything (V2X).

I. Introduction

In connected vehicle networks, Roadside Units (RSUs) provide essential infrastructure support. These units enable vehicles to communicate with each other when direct communication is not possible and with the surrounding environment. RSUs are useful for efficient traffic management, enhancing road safety, and enabling emerging technologies such as autonomous driving. They serve as communication hubs, relaying critical information and helping vehicles make real-time decisions, contributing to a safer and more connected transportation ecosystem. When planning vehicular networks, the problem of how and where to place the RSUs arises. This RSU placement problem has been studied by research works such as [1], which focuses on balancing the average data delivery delay in Vehicular Ad-hoc Networks (VANETs) and the number of vehicles to be served by each RSUs, and to do so implements a genetic algorithm. The authors of [2] implemented a multiobjective evolutionary algorithm for RSU placement to optimize the cost and quality of service offered by the network. The objective of [3] is to minimize the expected vehicle tasks offloading delay treating vehicle positions and tasks as arbitrary stochastic variables by integrating stochastic simulation, an artificial neural network and a meta-heuristic algorithm. An overlap based greedy method is proposed in [4] to study the effects of different parameters such as radius and overlap rate on distribution results.

In this paper, we consider three 3GPP standards which define the requirements of V2X services depending on their category [5], as well as the description of Radio Access Network (RAN) aspects [6], [7] and the radio transmission and reception features of user equipment [7]. We combine the information from the standards with real traffic data of Spain [8], and solve an ILP model to optimize the RSU locations and estimate the required deployment considering different real traffic and bandwidth conditions. In contrast with previous past works, this paper is the only one (to the best of our knowledge) that solves an ILP model considering different values extracted from the current 3GPP standards for service requirements and radio characteristics of the frequency bands for V2X. The main objective of this paper is to offer a quantitative idea of the required RSUs considering the current and future V2X networks technical aspects.

II. RSU Placement Model

A. Estimation of maximum distance between RSUs and UEs.

Since there are limited available spectrum resources for the communication between the RSUs and the connected cars (user equipment, UEs), it is necessary to perform an estimation of how many vehicles, depending on their implemented service requirements, can be served by each RSU. If either the number of vehicles in a highway or their service requirements grow, a single RSU will be able to serve less vehicles, therefore the solution is to deploy more RSUs, lowering the maximum distance allowed between vehicles and RSUs. The technical service requirements of V2X applications are presented in the 3GPP standard for 5G "Service requirements for enhanced V2X

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scenarios" [5]. In this standard, the typical data rates for V2X applications, which are vehicles platooning, advanced driving, extended sensors and remote driving, are specified in Tables 5.2-1, 5.3-1, 5.4-1 and 5.5-1 of that document, respectively. For this study we consider these data rates, which require from 10 to 1000 Mbps. Likewise, the characteristics of the spectral bands used for V2X are described in [6], and we have selected the n79 band of NR-V2X to perform our tests, given that it has the largest bandwidth (600 MHz, according to table 6.2.6-1). Moreover, the standard [7] states that the maximum aggregated bandwidth is 200 MHz for the n79 band (table 5.5A.1-1), hence we assume that each RSU has an available bandwidth of 200 MHz for communication with vehicles. To compute the channel capacity, we use the Shannon-Hartley theorem given by Equation (1), where *C* is the channel capacity in Mbps, *B* is the bandwidth in MHz, and *S/N* is the signal to noise ratio (SNR).

$$C = B\log_2(1+\frac{S}{N}) \quad (1)$$

The load of an RSU can increase, either because there are more vehicles within its range or because more sophisticated services are required by them. For a given channel capacity, to keep offering services to all vehicles, it is necessary to deploy more RSUs and decrease the transmission power, in such a way that each RSU is connected only to the number of vehicles it is capable to serve. To get an approximate estimate, we assume that we know beforehand the rate of vehicles in highways, as well as their speed, and by combining these data with the channel capacity and the required data rate per vehicle, we can compute with Equation (2) the maximum distance $D_{data\ rate}$ (in km) from an RSU to a vehicle to offer a specific data rate.

$$D_{data\ rate} = \frac{Cv}{2Rr} \quad (2)$$

where *C* is the channel capacity in Mbps, *v* is the vehicle´s speed in km/h, *R* is the data rate required by each vehicle in Mbps/vehicle, and *r* is the vehicle rate in vehicles/h.

Equation (2) establishes a limitation in distance regarding the data rate that should be offered to each vehicle, but in case that this required data rate is low enough, the distance will be bounded by the limiting range of the RSU given by its signal power. The effective distance limitation will be given by the minimum value among the data rate limitation and the range limitation, according to (3).

$$Dmax = \min\,(D_{data\ rate}, D_{range}) \quad (3)$$

B. ILP model for RSU placement

To optimize the deployment cost of the access network we propose an ILP model which minimizes the number of RSUs. The symbols used in this model are described in Table 1.

TABLE 1: MODEL NOTATION

Symbol	Meaning
P	Number of potential locations for placing RSUs.
U	Number of users.
$Dmax$	Maximum distance between a point in the highway and its nearest RSU.
d_{ij}	Distance in kms between point i and point j. $i, j \in [1, P]$.
y_j	Binary variable indicating if there is an RSU located at point *j*.
x_{ij}	Binary variable. $x_{ij} = 1$ indicates that the point i can communicate with an RSU located at point *j*.

The objective function of the model is given by Equation (4). Constraint (5) states that every point in the highways has at least one RSU to connect with. With (6) we make sure that every connection point actually has an RSU installed in it. And (7) sets that the maximum distance between every point and its reachable RSUs is below the threshold defined in (3).

$$Minimize \sum_{i=1}^{P} y_i \quad (4)$$

$$\sum_{j=1}^{P} x_{ij} \geq 1 \ \ \forall i \in [1, P] \quad (5)$$

$$x_{ij} \leq y_j \quad \forall i, j \in [1, P] \quad (6)$$

$$x_{ij} d_{ij} \leq Dmax \quad \forall i, j \in [1, P] \quad (7)$$

III. CASE STUDY: DEPLOYMENT IN VALLADOLID PROVINCE

The model proposed and described in Section II was tested under the case study of the highways of Valladolid province, in Spain. We extracted the location (latitude and longitude) of the kilometric points of the province's highways from [9], and then made a linear interpolation adding three new points between each contiguous point, in such a way that we have now approximately four points by kilometer and a potential location around each 250 meters.

We assume that both velocity and vehicle rates are known and constant. We set a fixed value of 100 km/h for all vehicles, and for the vehicle rate per hour we made tests with different values around the typical ranges in [8], where real data of Spain's highways traffic is shown. Data rates per vehicle are within the range specified in [5], and we considered an RSU range of 2500 m taken from a datasheet of a commercial RSU model [10]. In this study, we consider *potential* locations with a separation of 250 m. Thus, the RSUs finally established in a same highway will be separated, at least, by that distance. Since this distance is 0.1 times the RSU range (2500 m), the possibility of deploying RSUs closer than that has not been considered.

TABLE 2: VALUES CONSIDERED FOR TESTS

Parameter	Values
Vehicles velocity (km/h)	100
Vehicle rate (vehicles/h) [8]	100, 200 400, 800, 1600, 3200
Data rate (Mbps/vehicle) [5]	10, 50, 100, 200, 500, 800, 1000
Maximum RSU range (km) [10]	2.5
SNR (dB)	10, 20, 30

Fig. 1 shows the number of required RSUs for different combinations of vehicle and data rates, all of them considering a SNR of 30 dB. For low values of vehicles and data rate (lower left corner), the required number of RSUs is the same, because in these cases this number depends only on the RSU range (2500 m). Therefore, for the first CCAM services implemented (those ones with lower requirements) the reach range of commercial RSUs will be the limiting factor. The black color represents cases where it is not possible to serve all the required demand without installing RSUs with less than 250 meters between them. If more vehicles implement more demanding services, more RSUs should be deployed. Here, operators should decide between planning the initial RSU network assuming low demanding services and then add more RSUs at intermediate points when required (note that this is not the optimal configuration) or placing more RSUs thinking in future services.

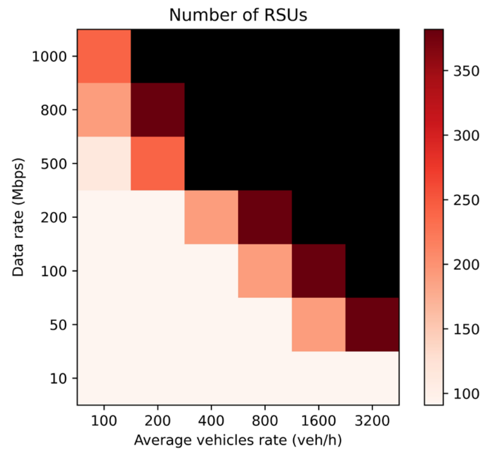

Fig. 1: Required RSUs for SNR=30dB

Fig. 2 shows the outcome of the model with a fixed vehicle rate of 200 vehicles per hour and different SNR values (10, 20 and 30 dB). Similar to Fig. 1, the maximum physical reach of each RSU imposes a minimum number of required RSUs. On the other hand, with SNR of 10, 20, and 30 dB, the service can be guaranteed up to 500, 800 and 1000 Mbps per vehicle respectively, given that at these values the minimum distance given by the potential points is met and increasing the requirements yields to a lowering of coverage. Lower values of SNR imply the need of deploying more RSUs. The difference between the three possibilities shows the great influence of the quality of channels in the solution of the RSU planning problem.

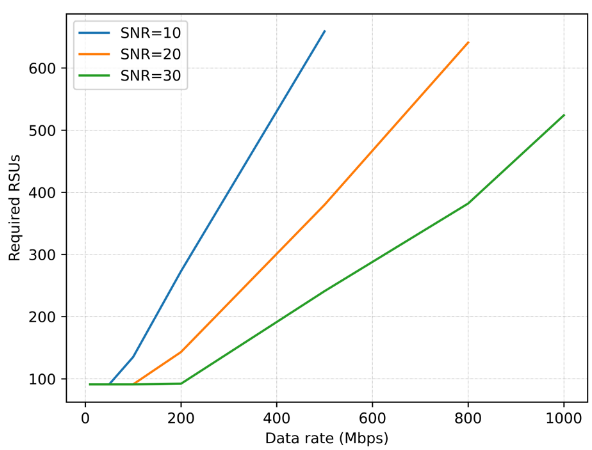

Fig. 2. Required RSUs for different SNR values (r =200 vehicles/hour).

An example of RSUs distribution in Valladolid province is shown in Fig. 3. The red triangles represent the location of RSUs, and the small black points represent potential locations. This example corresponds to a scenario with 200 Mbps/vehicle, 800 vehicles/hour, and SNR=30. With these conditions 191 RSUs are required according to our model.

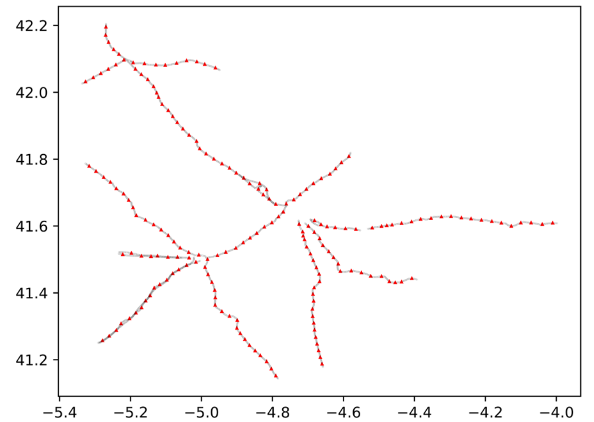

Fig. 3. Distribution for R=200 Mbps/vehic., r=800 vehic/h and SNR=30 dB.

IV. Conclusion

In this paper we consider current 3GPP standards for V2X networks. Using this information, we implemented an ILP model for minimizing the number of RSUs to meet the user requirements under different conditions of vehicle rate, data rate per vehicle, and SNR. Results offer a quantitative idea of the required RSUs to fulfill the requirements according to 3GPP standards for V2X services. With the outcomes of this research, network operators can dimension the required investment given different expected traffic conditions. Since the ILP model proposed here cannot be solved in polynomial time, for bigger scenarios, another solution like heuristics and clustering methods are necessary. Also, in this model we assume uniform conditions for vehicle rates in all highways. For future works we intend to improve the mentioned aspects of the model.

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