A Modeling of Road-Side Unit (RSU) Deployment for Efficient WiFi Offloading in Urban Areas

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Abstract: Wi-Fi offloading has been proposed to mitigate the data explosion resulting from increased vehicular application and services—Wi-Fi offloading means using Wi-Fi to offload the data initially targeted for cellular networks. In the C-V2X vehicle network, Wi-Fi can be delivered using the Road-Side Units (RSU) as Access Point (AP). The main concern is how many RSU -Wi-Fi APs- are needed to deliver the services for the more significant number of users without exceeding the communication delay demand and ensuring the users' satisfaction. Therefore, this paper wants to investigate the minimum required number of RSU for efficient Wi-Fi offloading in urban areas using the Minimum weighted vertex cover Algorithm. First, we find the graph representation of the target city map, then apply an MWVC algorithm solver to find the RSU Deployment. We will use both network and traffic simulators.

1. Introduction

There has been an enormous evolution in vehicular networks to provide safety and internet-based applications in recent years. In order to provide these applications, a reliable and robust wireless communication network is an essential requirement. Wireless communication is considered one of the pillars of autonomous driving and an Intelligent Transportation system[1]. The vehicular network was firstly developed for vehicles to communicate with each other (V2V) and with infrastructure(V2I) using ad-hoc network protocol like the Dedicated Short-Range Communication (DSRC) [2]. The DSRC was introduced mainly to provide safety message services for end-users. However, cellular communication has been currently introduced due to challenges like high mobility of vehicles, quality of service (QoS), high data rate, and lower latency for services proposed in vehicular networks. Cellular networks provide ubiquitous coverage and high bandwidth to improve reliability and efficiency, leading to a high data rate, low latency, and delivery of the internet of vehicles [2] [3].

With The significant development in the cellular networks, C-V2X has also evolved to support various applications with restricted performance in capacity, latency, and reliability requirements. Because of the high cost of the cellular network, in addition to the rapid increase in the number of connected devices, Wi-Fi AP can be deployed around the city for data offloading to ensure non-intermittent connectivity and maintain the QoS for broadband services of vehicular Networks[4]. The Wi-Fi APs run the free unlicensed IEEE 802.11. Despite the Wi-Fi short-range communication paradigm, it has proven effective with mobility in urban areas[5].

The limited coverage area of Wi-Fi hotspots - represented by the Road-side Unit (RSU) in the vehicular network - is challenging for the vehicular Wi-Fi offloading scenario. Even though we can distribute as many RSU to guarantee an optimal Wi-Fi offloading efficiency, it is not realistic and costly for Mobile network operators. Therefore, in this paper, we want to provide a modeling of RSU Deployment for efficient Wi-Fi offloading considering the Urban areas scenarios, including the effect of non-line of sight propagation generated by the buildings. For modeling, we will consider the graph theory for the mathematical representation of the map and the minimum vertex cover to find the minimum number of RSU that can provide sufficient Wi-Fi offloading efficiency.

The rest of this paper is organized as follows: Section 2 presents related work. Section 3 provides background and motivation. In Sec. 4, we describe the problem and propose our solution. Furthermore, the conclusion and future work will be in Sec. 5.

2. Related Work

In their survey about the cellular communication usage in the V2X communication[1][2][3] mentioned that cellular communication, especially the 5G; is going to offer significant benefits to the future automotive drive system. Also, in the V2X context, it will enhance the safety and infotainment applications. Although DSRC can provide reliable V2I and V2V communications, the achievable data rate may not satisfy many emerging applications such as video and image transmission and autonomous driving. So, they suggested using 5G in addition to the DSRC network. In Refs. [6][7], they discussed the usage of a central controller for collab-

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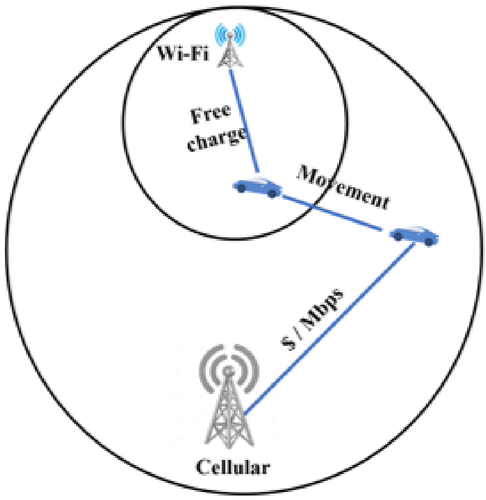


Fig. 1: Wi-Fi Offloading

orative offloading from the core network (cellular) to other wireless networks (Wi-Fi and DSRC). Reference [6] has proposed the Hybrid-awareness Path Collaboration (HPC) algorithms for the offloading mechanism. The HPC allows the controller to select suitable paths based on the round-trip time, packet loss rate, and path bandwidth. In contrast, Ref. [7] proposed a V2X resource allocation formulation to let the LTE and Wi-Fi work simultaneously.

In Ref. [4], the research objective is to maximize the number of vehicle users by offloading some communication data to RSUs so that the system can serve more vehicles moreover to maximize user satisfaction by offering slight delays at a lower cost. They developed a linear decay user satisfaction model where the vehicle will gain the utility for every bit of downloaded data. However, the utility decays with time to reflect the user ' s time sensitivity for the downloading data and the reduction in utility due to the cost of retrieving data from the cellular. In Ref. [5], a Wi-Fi offloading mechanism is proposed based on Auction-Game Offloading (AGO) and Congestion Game Offloading (CGO) mechanisms to improve the offloading performance. In addition to the prediction method to help the intelligent offloading decision-making, they used an urban area map with planned Wi-Fi AP location deployed by the mobile network operators (MNO). The Wi-Fi offloading process is affected by the vehicle ' s high mobility and the Wi-Fi short coverage area. Therefore, RSUs need to be deployed appropriately to cover a wide area to ensure an adequate Wi-Fi offloading performance. In their article, Ref. [8] discussed three different RSUs deployment policies, the minimum cost in which the authority wants to reduce the total cost and not consider the coverage area. The second approach is distributing the RSUs Uniform on the map like a Mesh. Finally, the Downtown-based (D-RSU), where the places with high traffic density will have fewer RSUs, and vice versa, because they assume that in the density traffic v2v communication will deliver reliable communication.

In Ref. [9], they discussed the RSU Deployment problem to find the number of RSUs that covers all points of interest (PoI). They considered RSU data storage capacities and communication ranges and developed a capacity-based adaptive clustering algorithm. They assumed an adaptive communication range of the RSU between 0.5R 1.5R. The RSU Deployment problem is considered an NP-hard optimization problem and can be solved using heuristics or approximation algorithms. These famous algorithms are the Minimum Vertex Cover, the Minimum Spanning Tree, genetic algorithms, etc. In their research, Ref. [10] used the Maximum Coverage with Time Threshold Problem (MCTTP) and the Global Search Genetic Algorithm to find an RSU Deployment in an urban area for the VANET system and compared their method to the greedy algorithm. Reference [11] developed an RSU deployment model for file downloading in synthetic scenarios. They modeled the encounter-time between the vehicles and the RSU as a time-continuous two-state Markov chain. Finally, They found the file downloading delay and the successful download ratio. As seen in Refs. [7][8][9], their RSU deployment methods consider only one communication access network using the Dedicated Short Range Communication protocol (DSRC), and they do not consider the case of a heterogeneous network of both cellular and or Wi-Fi Offloading scenarios. Consequently, in our work, we model an RSU-deployment problem using the minimum weighted vertex cover (MWVC), where the weighted vertices represent the intersections and edges represent the communication range between two vertices, in urban scenarios for Wi-Fi offloading scenario in the presence of LTE network as the leading access network.

3. Problem Definition

Our main objective is to provide the minimum number of RSUs placement while ensuring the application delay is less than the threshold delay with an adequate Wi-Fi offloading efficiency. We consider the following assumption: the LTE eNodeB is the leading access network. The vehicle is connected through the LTE network until it gets to the area covered by an RSU connection that runs the IEEE802.11 Wi-Fi protocol. The vehicles use the Wi-Fi network for downloading or uploading multimedia applications like VoIP and Video streaming applications. All RSUs are connected and the server using the evolved Packet Data Gateway (ePDG). For initial distribution positions, we consider intersections as the RSUs position candidates; then, for final placement, we reduce the delay constraint and deployment cost by modeling the location problem and solving it. Herein we give our mathematical modeling of the RSUs deployment problem, followed by the complexity details.

3.1 Optimization Problem Modelling

The RSU deployment problem is a combination problem where we select **k** positions out of total **m** positions see

Ref. 2. Let $I = 1, 2, 3, ..., n$, be the candidate positions to deploy the RSUs. a_i denotes the RSU_i deployment cost; r and R are the radio range for the RSU and eNodeB respectively. T_{th} will be the threshold delay for an application, P represents the total number of transferred packets, while P_{off} will represent the number of offloaded packets. These variables are provided in Table 1.

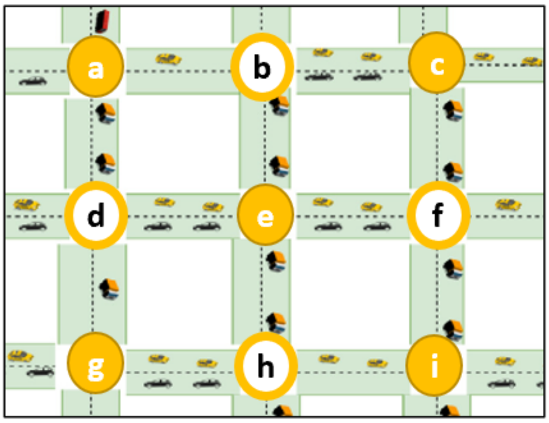


Fig. 2: n=9, k=5 (a,c,e,g,i)

Table 1: Variable Notations.

Variables	Notation
The numbers of candidate position for RSU	n
the number of deistinict Apllications	m
Deployment cost to build the RSU	c_i
decision to deploy RSU_i or not	y_i
Radio range of RSU	r
Radio range of eNodeB	R
Minimum delay to send msg from vehicle to server	t
Application's delay threshold	T_{th}
Number of transferred packets	P
Number of Offloaded packets	P_{off}

To solve the deployment problem of RSUs, we model it using the objective function illustrated in Eq. (1). We aim to minimize the RSU deployment cost and the application delay. The sub-function F_1 represents the minimum delay function, and t_j is the time delay to send a packet of application j between the vehicle and the server. The value of t_j should be less or equal to the value of the application threshold delay. In addition, F_2 represents the minimum cost for the RSUs.

$$Min\ F = \beta F_1 + \alpha F_2 \tag{1}$$

$$F_1 = min \sum_{j=1}^{m} t_j \qquad t_j <= T_{th} \tag{2}$$

$$F_2 = min \sum_{i=1}^{n} c_i y_i \qquad y_i \in 0, 1 \tag{3}$$

where:
$F_1 \equiv Application\ delay\ function$
$F_2 \equiv RSUs\ installation\ cost\ function$
$\beta, \alpha \equiv weights$

3.2 Problem complexity

The RSU deployment problem is an NP-hard optimization problem, and it requires huge computation capacities to find the optimal solution. The complexity of finding the RSU deployment problem can be represented as follows:

$$\sum_{k=1}^{n} C_n^k \tag{4}$$

We need to find the number of RSUs deployed and the positions to deploy them. So, we need to find k RSUs from the n possible solutions ($k <= n$). Due to the problem, we use the heuristic method to get a solution to solve the problem. The heuristic algorithm does not give an exact solution, and there is no guarantee for the worst case. However, it is a quick sort algorithm and is good in a realistic scenario. We utilize a known Minimum weighted vertex cover (MWVC) algorithm to get the solution. Next, we will explain the details of our proposed solution.

4. Proposed Method

In our work, we use the map of the city, road traffic information, the communication range of the RSU and the LTE networks, and the deployment cost for the RSU as given information. Considering the application delay, we try to find an acceptable deployment strategy to perform a Wi-Fi offloading using road and communication traffic and network simulators. To do that, we propose three steps, as shown in Fig 2.

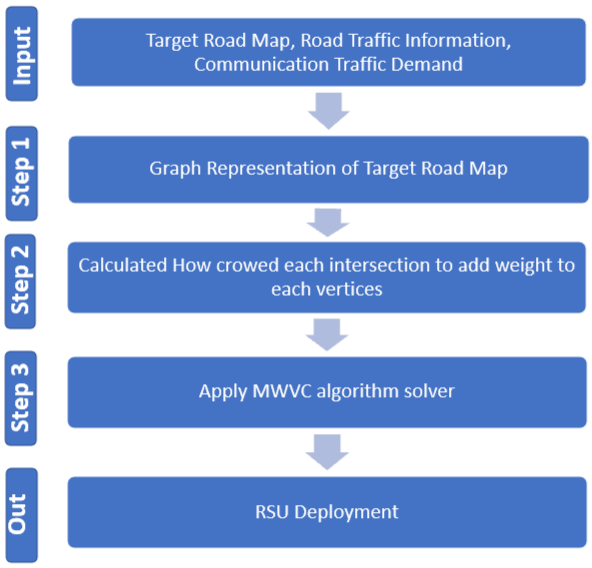
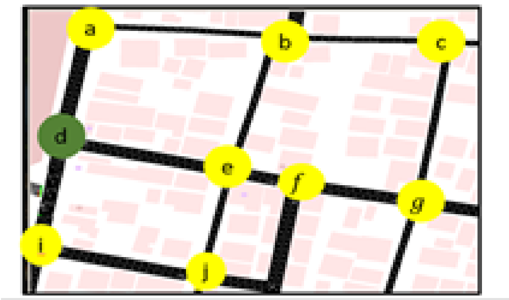


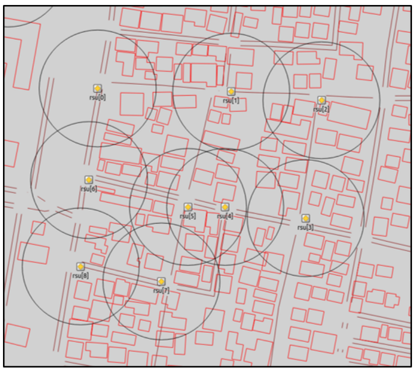
Fig. 3: Proposed Solution Steps

4.1 Graph Representation of Target Road Map

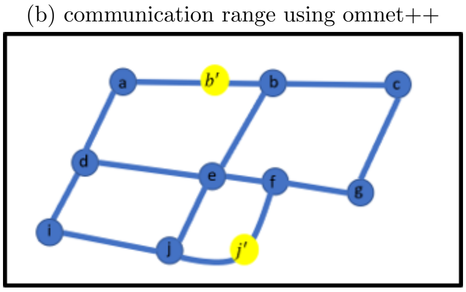
To find the graph representation of a given map, we define each intersection as a vertex, and the signal range is an edge between any two vertices. We consider each intersection as a candidate initial position for the RSU because the density in intersections is usually higher. Then, select the minimum number of RSU (k) that covers most vehicle trajectories. We also examine the connectivity of the Wi-Fi between any two adjacent intersections with a communication traffic simulator software, and we add pseudo nodes in case there is no connectivity between the nodes with a standard Wi-Fi signal. The connectivity can be affected by distance and the effect of high buildings and non-line of sight signals. Then we add pseudo vertices to the target map Fig. 3. Then to solve the deployment problem, we use a known Minimum Vertex Cover Problem.



(a) City map



(b) communication range using omnet++



(c) Graph represenation

Fig. 4: City map and its graph representation

4.2 Minimum Weighted Vertex Cover (MWVC)

The Minimum Vertex Cover (MVC) algorithm for a given undirected graph $G = (V, E)$, is the minimum sized vertex cover where a vertex cover is subset $S \subseteq V$ such that every edge in G has at least one endpoint in S[12]. Furthermore, in the MWVC problem, each vertex has a weight, and the goal of the minimum weighted vertex cover problem introduced to find a vertex cover of minimum weight.

Input: $G(V, E)$
Output: $Z = \sum_{v_i \in V_c} W_i V_i$
while $E \neq \phi$ *do*
  Step 1:
    for $i \leftarrow 1$ *to* n
      for $j \leftarrow 1$ *to* n
        $d(v_i) = \sum_j a_{ij}$
  Step 2:
    for $i \leftarrow 1$ *to* n
      for $j \leftarrow 1$ *to* n
        $s(v_i) = \sum_{v_i \in N_{v_i}} d_G(v_j)$
  Step 3:
    for $i \leftarrow 1$ *to* n
      $r(v_i) = \dfrac{s(v_i)d(v_i)}{w(v_i)}$
  Step 4:
    Add the vertex v_i, having the maximum value of $r(v_i)$, into the vertex cover V_c.
    $V_c \leftarrow V_c \bigcup v_i$.
  Step 5:
    delete $N[v], v \in V_c$, *from* G
end while
  for $i \leftarrow 1$ *to* n
    if $(v_i \in V_c)$
      $v_i = 1$
    else
      $v_i = 0$
    end

Fig. 5: The proposed algorithm

4.2.1 MWVC Algorithm Solver

In [13], they proposed an algorithm to solve the MWVC problem, which is based on finding a vertex cover of minimum weight. In their Support Ratio algorithm (SRA), an undirected graph $G = (V, E)$ with a weight function where $w : V \rightarrow R$ associated with each vertex of $v \in V$, a set $S \subseteq V$ is a minimum weighted vertex cover of G if :

- For each edge $(v, u) \in E$, at least one of the nodes $(u), (v) \in S$
- S should has the smallest weight in E, $\sum_{v \in V} w(v)$ is minimum.

According to their SRA, the adjacency matrix is created as integer programming with binary variables. To find the adjacency matrix, if an edge (v_i, v_j) is in E, then $a_{ij} = 1$ else $a_{ij} = 0$. Then the adjacency matrix is given as the input of the program. The algorithm is shown in Fig. 5.

They used random weights to evaluate their algorithm in three sets and compared it with other heuristics algorithms. However, we will generate the weight for each vertices using the information of communication demand.

4.2.2 Vertex weight

As mentioned before, the purpose of MWVC problem is to find the vertex cover of minimum weight. Therefore, to find the weight for each vertex, we assume that the weight $w(v_i)$ is in reverse proportion to the communication demand (packets transferred) on each intersection.

$$w(v_i) \; \alpha \; \frac{1}{comm.\ demand\ of\ each\ intersection} \tag{5}$$

Using the network traffic simulator, we find the communication demand at each intersection by finding the number of packets transferred from each RSU located in that intersection.

5. Conclusion and future work

This work proposes a graph modeling for the city map to find the minimum number of RSU placements which will provide sufficient wifi offloading using Minimum weighted vertex cover optimization algorithms. First, our model considers the intersections as initial location candidates. Then, it optimizes the number of final RSUs locations using the Minimum Weighted Vertex Cover algorithm. In contrast to the existing work that deploys RSUs considering only one access network, our solution provides modeling for RSU running the wifi while LTE is considered the leading network. We plan to evaluate our method using the traffic and network simulators to find the offloading efficiency in future work.

References

[1] Storck, C. R. and Duarte-Figueiredo, F.: A survey of 5G technology evolution, standards, and infrastructure associated with vehicle-to-everything communications by internet of vehicles, *IEEE access*, Vol. 8, pp. 117593–117614 (2020).

[2] Takakusaki, M., Tang, S., Ueno, T., Ogishi, T. and Obana, S.: Fast and Reliable Dissemination of Road and Traffic Information by Combining Cellular V2X and DSRC, *2019 IEEE Globecom Workshops (GC Wkshps)*, IEEE, pp. 1–6 (2019).

[3] Abboud, K., Omar, H. A. and Zhuang, W.: Interworking of DSRC and cellular network technologies for V2X communications: A survey, *IEEE transactions on vehicular technology*, Vol. 65, No. 12, pp. 9457–9470 (2016).

[4] Wang, N. and Wu, J.: Opportunistic WiFi offloading in a vehicular environment: Waiting or downloading now?, *IEEE INFOCOM 2016-The 35th Annual IEEE International Conference on Computer Communications*, IEEE, pp. 1–9 (2016).

[5] Cheng, N., Lu, N., Zhang, N., Zhang, X., Shen, X. S. and Mark, J. W.: Opportunistic WiFi offloading in vehicular environment: A game-theory approach, *IEEE Transactions on Intelligent Transportation Systems*, Vol. 17, No. 7, pp. 1944–1955 (2016).

[6] Quan, W., Wang, K., Liu, Y., Cheng, N., Zhang, H. and Shen, X. S.: Software-defined collaborative offloading for heterogeneous vehicular networks, *Wireless Communications and Mobile Computing*, Vol. 2018 (2018).

[7] Huang, W., Ding, L., Meng, D., Hwang, J.-N., Xu, Y. and Zhang, W.: QoE-based resource allocation for heterogeneous multi-radio communication in software-defined vehicle networks, *IEEE Access*, Vol. 6, pp. 3387–3399 (2018).

[8] Barrachina, J., Garrido, P., Fogue, M., Martinez, F. J., Cano, J.-C., Calafate, C. T. and Manzoni, P.: Road side unit deployment: A density-based approach, *IEEE Intelligent Transportation Systems Magazine*, Vol. 5, No. 3, pp. 30–39 (2013).

[9] Xu, X., Cao, X., Wolffe, G. and Du, J.: Intelligent Roadside Unit Deployment in Vehicular Network, *2021 IEEE International Conference on Electro Information Technology (EIT)*, IEEE, pp. 178–183 (2021).

[10] Cavalcante, E. S., Aquino, A. L., Pappa, G. L. and Loureiro, A. A.: Roadside unit deployment for information dissemination in a VANET: An evolutionary approach, *Proceedings of the 14th annual conference companion on Genetic and evolutionary computation*, pp. 27–34 (2012).

[11] Liu, Y., Niu, J., Ma, J. and Wang, W.: File downloading oriented roadside units deployment for vehicular networks, *Journal of Systems Architecture*, Vol. 59, No. 10, pp. 938–946 (2013).

[12] Cai, S., Su, K., Luo, C. and Sattar, A.: NuMVC: An efficient local search algorithm for minimum vertex cover, *Journal of Artificial Intelligence Research*, Vol. 46, pp. 687–716 (2013).

[13] Balaji, S., Swaminathan, V. and Kannan, K.: An effective algorithm for minimum weighted vertex cover problem, *International Journal of Computational and Mathematical Sciences*, Vol. 4, No. 1, pp. 34–38 (2010).