# Resource Management in LADNs Supporting 5G V2X Communications

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***Abstract*—*Local access data network* (LADN) is a promising paradigm to reduce latency, enable lowering energy consumption, and improve *quality of service* (QoS) for the Fifth Generation (5G) *radio access network* (RAN) supporting *vehicle to everything* (V2X) communications. To achieve optimum resource allocation and save energy by minimizing the activation of LADN servers in Cloud-RAN, some *remote radio heads* (RRHs) can be turned on or off depending on the traffic demand. In this paper, we investigate the problem of how to realize effective resource management in 5G RAN supporting V2X communications. More precisely, we first propose a formulation of the resource management problem as an optimization problem with the objective of minimizing the number of RRHs to be turned on subject to the uplink bandwidth constraints. We then use a fully-fledged professional software to solve our optimization problem and propose a solution with heuristic algorithms to deal with the complexity of the problem for large scenarios. Moreover, we analyze the impact of the density of vehicles on the computation time and the influence of the uplink data rate and vehicle densities on the number of active RRHs. Our numerical results show that our proposed model can efficiently utilize the resources and provide optimum vehicles-to-RRHs associations which lead to energy-savings. For instance, to serve 100 vehicles with aggregated uplink data rate equal to 100 [*Mbps*], the optimal associations save about 70% of the energy comparing to the strongest-signal associations. Furthermore, we obtain optimal results for the small size problem in reasonable computation times, which are around 50 [*ms*].**

***Keywords*-5G, LADN (local access data network), optimization, resource management, V2X communications.**

## I. INTRODUCTION

The Fifth Generation (5G) *radio access network* (RAN) is expected to provide ultra-high data rate, tremendous connectivity of *user equipment* (UE) and ultra-low latency. The Third Generation Partnership Project (3GPP) specifies service requirements to enhance *quality of service* (QoS) for 5G RAN supporting *vehicle to everything* (V2X) scenarios including vehicle platooning, remote driving, automated cooperative driving, collective perception of the environment, and cooperative collision avoidance [1].

*Local access data network* (LADN) is a promising paradigm to meet the 5G V2X service requirements, i.e., the maximum latency should be $10 \sim 25$ $[ms]$ and the minimum availability should be $90 \sim 99.99\%$, and to realize high-efficiency V2X communications. LADN enables reduction of the latency, minimization of the energy consumption, and improvement of the QoS for 5G networks. It achieves the aforementioned service requirements by pushing the computing and networking services to the close proximity of UEs. LADN can be defined as a *mobile edge computing* (MEC) paradigm in 3GPP 5G that has a distributed computing environment bringing the network capabilities closer to UE which leads to deploying services with minimum delay [2].

Figure 1 illustrates an overview of LADN, where it is deployed near the edge and close to the UEs, while the UEs are located at the LADN service area. Furthermore, the gNBs are located in the vicinity of the edge and the *road-side units* (RSUs) are deployed closer to the UEs, while the *remote radio heads* (RRHs) are identical with remote antennas of RSUs.

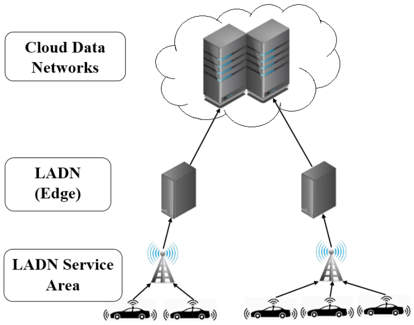

Fig. 1. Overview of the architecture of a local access data network (LADN).

In 5G RAN supporting V2X applications, the key problem which significantly affects the network functionality is how to allocate the available radio resource (i.e., *resource blocks*, RBs) efficiently in LADN [3]. To optimize resource management and save energy, some RRHs could be turned on or off depending on the traffic demand [4]. An appropriate assignment must be done between UEs and RRHs, concerning *inter-cell interference* (ICI) and *signal-to-interference-plus-noise ratio* (SINR) management. ICI management plays a key role in ensuring a satisfactory link quality while SINR between UEs and RRHS determines the *channel quality indicator* (CQI). It is used to build a mapping table which leads to UEs-to-RRHs associations. Optimal UE-to-RRH associations produce less intense traffic in vehicular networks which lead to minimization in the number of active RRHs and results in optimized resource management.

Resource allocation for 5G V2X communications and vehicular networks has been examined in several research publications. Authors in [5] proposed a joint computation and *ultra-reliable and low-latency communication* (URLLC) resource allocation strategy for MEC-based V2X communications considering the significance of reliability and delay in vehicular networks. The joint power consumption optimization problem is formulated with the aim of reducing the inter-cell interference and maximizing the throughput while satisfying the reliability and network stability. The work in [6] proposed the notion of a virtual base station which is formed by allocating virtualized network resources and formulated the energy-efficient optimization problem using an integer linear program (ILP) with the objective of minimizing total energy consumption in *Cloud-RAN* (C-RAN). Novel energy-saving schemes were proposed for both the network planning stage and traffic engineering stage with a solution algorithm aimed to minimize the number of active *baseband process units* (BBUs). In [7], the authors formulated a joint optimization problem of selecting the active RRHs and coordinate beamforming among the active RRHs for the C-RAN with the objective of minimizing the overall power consumption of RRHs and the corresponding front-haul links while guaranteeing the QoS requirements represented by traffic delay constraints. The minimization of power consumption is formulated as a stochastic optimization problem considering random traffic arrivals and time-varying channel conditions. The work in [8] proposed a joint design optimization problem with the objective of maximizing the number of supported users through user admission control while satisfying the QoS constraints exemplified by SINR values of all served UEs where the considered set of UEs is divided into multiple non-overlapping multicast subsets.

We investigate in this paper the problem of how to perform effective resource management in LADN to optimize the resource utilization and energy-savings while guaranteeing QoS requirements for V2X communications represented by uplink data rates, SINR values, and available uplink resource blocks. We propose a mathematical formulation of the problem of resource management as an optimization problem with the goal function of minimizing the number of active RRHs. In particular, given a number of RRHs with available uplink RBs and a number of vehicles with required RBs for sending data, we need to determine the optimal vehicle-to-RRH association and the state of particular RRHs in order to minimize the number of active RRHs while satisfying the constraints on the number of RBs and data rate.

The remainder of this paper is organized as follows. In section II, the system model and the optimization problem are formulated to optimize resource management including the calculations of SINR, ICI, and required RBs. Additionally, the heuristic algorithms are defined in this section. In section III, the numerical results are presented. Finally, the conclusion is drawn and the future work is pointed out in section IV.

## II. System Model

### A. Problem Formulation

In our model of the system under study, as shown in Figure 2, we consider a network topology consisting of LADN, RRH, and vehicles. LADN is deployed near the gNB and vehicles need to send sensor information to LADN, such that a local digital map could be built. This implies that the uplink traffic (i.e., communication offloading) is sent to RRH. In particular, we investigate a scenario which consists of a set of RRHs ($n = 1, 2, \ldots, N$) and a set of vehicles ($v = 1, 2, \ldots, V$). Each RRH $n$ has a number of available RBs per time slot and we denote the maximum number of RBs for RRH $n$ by $MRB_n$. Each vehicle $v$ — if it is associated with RRH $n$ — will require a number of RBs per time slot for sending sensing data and we denote it by $R_{n,v}$. The required number of RBs depends on the vehicle's SINR values.

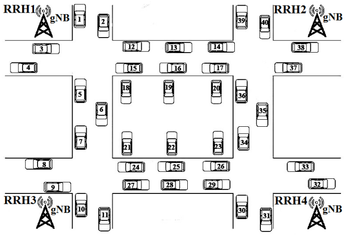

Fig. 2. A small example of V2X network topology.

Table I summarizes the mathematical notations used in this paper.

TABLE I
MATHEMATICAL NOTATION

| **Symbol** | **Meaning** |
|---|---|
| $P_v$ | Transmission power of vehicle $v$ |
| $d_{n,v}$ | Distance between vehicle $v$ and RRH $n$ |
| $\alpha$ | Attenuation factor: calculated from COST 231–Hata Model [9] |
| $N_{OC}$ | Power spectral density of white noise source |
| $I_{\text{sum}}$ | Aggregated uplink ICI representing interference power level of RRHs |
| $I_n$ | Mean value of uplink ICI for RRH $n$ |
| $C$ | RRH coverage (in kilometers) |
| $r$ | Distance from transmitter to receiver (in kilometers) |
| $\theta$ | Vehicle's angle to direct line connecting target RRH to interfering RRH |
| $N$ | The number of RRHs |
| $V$ | The number of vehicles |
| $MRB_n$ | Available uplink RBs per time slot for RRH $n$ |
| $R_{n,v}$ | Required RBs per time slot for sending data |
| $UL\_DR_v$ | Required uplink data rate of vehicle $v$ |
| $x_n$ | Decision variable to turn on/off the RRH $n$ |
| $y_n^v$ | Decision variable indicating whether vehicle $v$ is associated to RRH $n$ or not |

SINR is calculated from the transmit power of the vehicle $v$ and the interference power level of other interfering RRHs in the network. SINR values can be obtained as

$$SINR_{n,v} = \frac{P_v d_{n,v}^{-\alpha}}{N_{OC} + I_{\text{sum}}} \tag{1}$$

Assuming that the network model is fully loaded with traffic, omnidirectional antennas are used, and a regular coverage pattern takes place, the uplink ICI from the RRH $n$ can be approximated with a log-normal distribution by analytically determining the statistical parameters [11]. Therefore, the aggregated uplink ICI, $I_{\text{sum}}$, is approximated with another log-normal distribution and can be calculated as

$$I_{\text{sum}} = (\text{number of RRHs}) \times I_n \tag{2}$$

where: $I_n$ is the mean value of the uplink ICI of the interfering RRH $n$ and can be computed as[1]

$$I_n = \int_0^1 \int_0^{2\pi} \frac{P_v C^{-(\alpha+1)} r^{\alpha+1}}{\pi(\sqrt{r^2+4+4r\cos\theta})^{\alpha}} \mathrm{d}r\mathrm{d}\theta \tag{3}$$

RB data rate is calculated according to the SINR range, CQI index, and the efficiency from the mapping table (Table II) considering, for the sake of simplicity, that both the gNBs forming the networks and the UEs work in the *single-input-single-output* (SISO) mode [12]. The CQI index is calculated at the UE and reported back to gNB. The efficiency is used to calculate the data rate of an RB. Specifically, an RB per time slot of length 0.5 $[ms]$ consists of 12 sub-carriers (15 $[kHz]$) and each sub-carrier consists of 7 symbols. Accordingly, the data rate of an RB is calculated as

$$RB\_data\_rate \text{ [bits per 0.5 ms]} = 12 \times 7 \times \text{efficiency} \tag{4}$$

TABLE II
MAPPING TABLE [12]

| **CQI index** | **Modulation order** | **SINR range [*dB*]** | **Efficiency [*bps/Hz*]** | **RB data rate [*kbps*]** |
|---|---|---|---|---|
| 1 | QPSK | -9.5 $<$ SINR $\leq$ -6.7 | 0.1523 | 25.59 |
| 2 | QPSK | -6.7 $<$ SINR $\leq$ -4.1 | 0.2344 | 39.38 |
| 3 | QPSK | -4.1 $<$ SINR $\leq$ -1.8 | 0.3770 | 63.34 |
| 4 | QPSK | -1.8 $<$ SINR $\leq$ 0.4 | 0.6016 | 101.07 |
| 5 | QPSK | 0.4 $<$ SINR $\leq$ 2.5 | 0.8770 | 147.34 |
| 6 | QPSK | 2.5 $<$ SINR $\leq$ 4.5 | 1.1758 | 197.53 |
| 7 | 16QAM | 4.5 $<$ SINR $\leq$ 6.5 | 1.4766 | 248.07 |
| 8 | 16QAM | 6.5 $<$ SINR $\leq$ 8.5 | 1.9141 | 321.57 |
| 9 | 16QAM | 8.5 $<$ SINR $\leq$ 10.3 | 2.4063 | 404.26 |
| 10 | 64QAM | 10.3 $<$ SINR $\leq$ 12.3 | 2.7305 | 458.72 |
| 11 | 64QAM | 12.3 $<$ SINR $\leq$ 14.2 | 3.3223 | 558.15 |
| 12 | 64QAM | 14.2 $<$ SINR $\leq$ 15.9 | 3.9023 | 655.59 |
| 13 | 64QAM | 15.9 $<$ SINR $\leq$ 17.8 | 4.5234 | 759.93 |
| 14 | 64QAM | 17.8 $<$ SINR $\leq$ 19.8 | 5.1152 | 859.35 |
| 15 | 64QAM | SINR $\geq$ 19.8 | 5.5547 | 933.19 |

We calculate the number of the required RBs to serve the requested uplink data rate from each vehicle, $R_{n,v}$, depending on the required uplink data rate $UL\_DR_v$ (i.e., a calculation task required from each vehicle). We use the following formula.

$$R_{n,v} = UL\_DR_v / RB\_data\_rate \tag{5}$$

To minimize the number of active RRHs while satisfying the constraints on $R_{n,v}$ and $MRB_n$, we need to determine $y_n^v$ which denotes whether the vehicle $v$ is associated to RRH $n$ or not and determine $x_n$ which indicates whether to turn the RRH $n$ on or off. We formulate the optimization problem as:

$$\min \sum_{n=1}^{N} x_n \tag{6}$$

$$\text{s.t.} \quad MRB_n - \sum_{v=1}^{V} y_n^v R_{n,v} \geq 0 \quad n = 1, \ldots, N \tag{7}$$

$$\sum_{n=1}^{N} y_n^v = 1 \quad v = 1, \ldots, V \tag{8}$$

$$y_n^v \geq 0 \quad n = 1, \ldots, N \quad v = 1, \ldots, V \tag{9}$$

$$x_n \geq y_n^v \quad n = 1, \ldots, N \quad v = 1, \ldots, V \tag{10}$$

$$x_n, \; y_n^v \in \{0, 1\} \tag{11}$$

The aforementioned objective function is subject to the following constraints: the constraint (7) ensures that the number of required RBs per time slot to uplink data from vehicle $v$ to the RRH $n$ should not exceed the number of available uplink RBs at the RRH $n$. The constraint (8) says that each vehicle $v$ should be associated to one and only one RRH, and the constraints (9)–(10) indicate the lower and the upper bounds of the decision variables, which are binary (11).

### *B. Heuristic Algorithms*

To deal with the complexity of our optimization problem for the big size scenario, we apply heuristic algorithms. The heuristic algorithms generally produce good and fast solutions but without the guarantee of finding the minimum value. Since our optimization problem is structurally similar to the Bin-Packing problem[2], known to be NP-complete, we propose applying the following heuristic algorithms [10] (implemented in MATLAB): First-Fit (FF), Best-Fit (BF), First-Fit-Decreasing (FFD), and Best-Fit-Decreasing (BFD).

In the First-Fit Algorithm, we assign each vehicle to the first RRH that has sufficient capacity, i.e., available RBs, and then we update the remaining capacity of RRHs. For the First-Fit-Decreasing Algorithm, we first sort the required RBs by each vehicle in the decreasing order and then we apply the First-Fit Algorithm. Furthermore, in the Best-Fit Algorithm, we find the RRH whose remaining capacity matches the size of required RBs best and assign the vehicle to that RRH, (i.e., we assign the vehicle to the best RRH that has the least capacity). For the Best-Fit-Decreasing Algorithm, we first sort the required RBs by each vehicle in the decreasing order and then we apply the Best-Fit Algorithm.

## III. RESULTS AND EVALUATION

In this section, we evaluate our resource management problem under three scenarios of V2X network topology with different sizes, i.e., a small size scenario (10, 20, 30, 40 and 50 vehicles, with setting the number of RRHs to 4 and to fixed locations), a medium size scenario (100, 200, 300 and 400 vehicles, with setting the number of RRHs to 40 and to random locations), and a big size scenario (1000, 2000,

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[1] In this paper we focus on the optimization problem rather than on interference and SINR. For further details we refer the reader to [11].

[2] Where we have items with different volumes and the goal is to assign those items into a minimum number of bins of limited capacities.

3000, 4000 and 5000 vehicles, with setting the number of RRHs to 400 and to random locations). First, we compare the optimal and the default associations of the vehicles. Then, we compare the optimal solutions with the solutions obtained by implementing the aforementioned heuristic algorithms. Furthermore, we analyze the impact of the required data rate and vehicle densities on the number of RRHs to be turned on. Finally, we examine the impact of the density of the vehicles on the computation time of the optimal and heuristic solutions.

For the evaluation purpose, we assume that all vehicles have the same transmit power, namely $P_v = 23\ [dBm]$, and the same uplink data rate, namely $UL\_DR_v = 1\ [Mbps]$.

Table III lists the parameter values which are used in the calculations and the evaluations. The values are assumed according to the service requirements for 5G V2X services and to guarantee QoS requirements of V2X communications exemplified by SINR values, $MRB_n$ and $UL\_DR_v$.

TABLE III
EVALUATION PARAMETERS

| **Parameter** | **Value** |
|---|---|
| $N_{OC}$ | -174 $[dBm/Hz]$ |
| $\alpha$ | 3.5 |
| $C$ | 1 $[km]$ |
| $r$ | $0-1\ [km]$ |
| $\theta$ | $0-2\pi$ |
| $P_v$ | 23 $[dBm]$ |
| $MRB_n$ | 50 $[RBs]$ |
| $UL\_DR_v$ | 1 $[Mbps]$ |

## A. *Optimal vs. Default Associations*

To investigate the key performance on how much energy is saved by our proposed model, in this section we compare the optimal vs. strongest-signal associations of vehicles. The optimal association is obtained from the optimal solution of our resource management problem and the strongest-signal association is obtained according to the default association, where the vehicles are associated with the serving RRH depending on the distances of the vehicles from each RRH and on the SINR values of each vehicle. Thus, in the strongest-signal association, the vehicle with the higher SINR value will be connected to the nearest RRH.

Figure 3 shows the optimal association vs. the default association. We can observe that as the number of vehicles increases, so the optimal association is turning on less number of RRHs to serve the tasks of the vehicles than the strongest-signal association which leads to energy-saving. Especially for the medium size scenario, the energy saved by the optimal association ranges from 45% up to about 70%. Furthermore, we can notice that for the scenarios consisting of 10, 20, and 30 vehicles, the energy saved by the optimal association is 25% and 50%. For the scenarios consisting of 40 and 50 vehicles, both associations use the same number of RRHs. We note that in the default association the number of used RBs exceeds the maximum number of the available uplink RBs for the scenario of 50 vehicles, where the number of used RBs for the first RRH is equal to 58, i.e., a number of used RBs is larger than the maximum number of the available uplink RBs which is equal to 50 RBs.

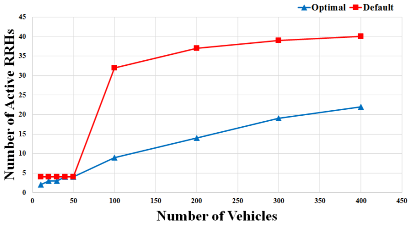

Fig. 3. Comparison of optimal vs. default associations.

Table IV illustrates a comparison between the total number of active RRHs and the total number of RBs used for both the optimal and the default associations. We can notice that the default association turns on more RRHs than the optimal association, although it uses fewer RBs comparing to the optimal association. Therefore, the default association consumes more energy than the optimal association, especially for the medium size scenario. Particularly for the scenario consisting of 100 vehicles with aggregated uplink data rate equal to 100 $[Mbps]$, the strongest-signal association turns on 32 RRHs comparing to 9 RRHs that are turned on by the optimal association. Furthermore, for the scenario consisting of 400 vehicles with aggregated uplink data rate equal to 400 $[Mbps]$, we can observe that the default association consumes about 80% more energy than the optimal association. Both associations use almost the same number of RBs (i.e., there are about 12% less RBs used by default association in comparison to a number of RBs used by optimal association). Thus, optimal associations minimize energy consumption and efficiently utilize the resources.

TABLE IV
COMPARISON OF OPTIMAL VS. DEFAULT ASSOCIATIONS

| **Number of vehicles** | **Number of active RRHs** | | **Number of used RBs** | |
|---|---|---|---|---|
| | **Optimal** | **Default** | **Optimal** | **Default** |
| 10 | 2 | 4 | 88 | 40 |
| 20 | 3 | 4 | 120 | 80 |
| 30 | 3 | 4 | 116 | 92 |
| 40 | 4 | 4 | 174 | 114 |
| 50 | 4 | 4 | 195 | 174 |
| 100 | 9 | 32 | 427 | 252 |
| 200 | 14 | 37 | 665 | 521 |
| 300 | 19 | 39 | 930 | 777 |
| 400 | 22 | 40 | 1091 | 964 |

## B. *Optimal vs. Heuristic Solutions*

In this subsection, we compare the optimal solutions obtained from solving the resource management problem for both small and medium scenarios by using CPLEX solver [13] with the solutions obtained by implementing the above-mentioned four heuristic algorithms using MATLAB. More precisely, we compare the total number of active RRHs and used RBs. Furthermore, we analyze the solutions obtained by implementing the heuristic algorithms for the big size scenario.

Table V shows the total number of the active RRHs and the RBs used by all active RRHs. We can observe that the number of RRHs turned on by the heuristic algorithms is competitive to that of the CPLEX. Despite the fact that heuristic and optimal solutions provide similar results, we notice the differences in the number of RBs used by each active RRH and in the number of vehicles served per each active RRH. Additionally, we observe that the FF and BF algorithms produce the same results in terms of the total number of used RBs and the total number of served vehicles, while the results obtained by applying the FFD and BFD algorithms are the same. Moreover, optimal solutions provide a balanced utilization of the RBs by each active RRH which leads to efficient utilization of RRHs capacities. Furthermore, we notice that the optimal solutions provide an efficient association of vehicles among each active RRH, especially for the scenario consisting of 30 vehicles, where we can see that each of the 3 active RRHs serves 10 vehicles. Thus, optimal vehicles-to-RRHs assignments lead to efficient resource management and less traffic.

TABLE V
COMPARISON OF OPTIMAL VS. HEURISTIC SOLUTIONS

| Number of vehicles | Number of active RRHs | | Number of used RBs | |
|---|---|---|---|---|
| | Optimal | Heuristic | Optimal | Heuristic |
| 10 | 2 | 2 | 88 | 88 |
| 20 | 3 | 3 | 120 | 120 |
| 30 | 3 | 3 | 116 | 116 |
| 40 | 4 | 4 | 174 | 174 |
| 50 | 4 | 4 | 195 | 195 |
| 100 | 9 | 9 | 427 | 427 |
| 200 | 14 | 14 | 665 | 665 |
| 300 | 19 | 19 | 930 | 930 |
| 400 | 22 | 22 | 1091 | 1091 |

To deal with the complex scenario of our optimization problem, i.e., a big size scenario, we propose applying the aforementioned heuristic algorithms (implemented in MATLAB): that is FF, BF, FFD, and BFD for solving the complex scenario.

Table VI shows the results obtained from solving the optimization problem for the big size scenario by applying the above-mentioned heuristic algorithms. The maximum number of the RRHs that are turned on depends on the number of vehicles and their aggregated uplink data rate, and the total number of used RBs depends on the number of vehicles and their association to the serving RRH.

TABLE VI
NUMBER OF TURNED ON RRHS FOR BIG SIZE SCENARIO

| Vehicles | Uplink data rate | Number of turned on RRHs | | | |
|---|---|---|---|---|---|
| | | FF | BF | FFD | BFD |
| 1000 | 1000 $[Mbps]$ | 41 | 41 | 41 | 41 |
| 2000 | 2000 $[Mbps]$ | 83 | 83 | 82 | 82 |
| 3000 | 3000 $[Mbps]$ | 123 | 123 | 123 | 123 |
| 4000 | 4000 $[Mbps]$ | 165 | 165 | 164 | 164 |
| 5000 | 5000 $[Mbps]$ | 207 | 207 | 205 | 205 |

### *C. Impact of Required Data Rate*

In this subsection, we analyze the impact of the required data rate by each vehicle on the number of active RRHs. The total number of active RRHs depends on the aggregated uplink data rate requested by the vehicles and their association to the serving RRH. Additionally, the total number of RBs used by each active RRH depends on optimum resource management and vehicle-to-RRH associations.

Figure 4 shows the impact of the required uplink data rate on the number of RRHs to be turned on. Intuitively, as the required data rate increases, so is the number of active RRHs. Additionally, the labeled numbers above the curve represent the number of active RRHs. As we can see, 2 RRHs are turned on to serve 10 vehicles with an aggregated uplink data rate equal to 10 $[Mbps]$. For the scenarios consisting of 30 vehicles, 3 RRHs are turned on to serve the vehicles with aggregated uplink data rates equal to 30 $[Mbps]$. For the scenarios consisting of 400 vehicles, 22 RRHs are turned on to serve the vehicles with aggregated uplink data rates equal to 400 $[Mbps]$. To serve vehicles with uplink data rates vary from 10 to 1000 $[Mbps]$, we observe that the number of active RRHs is varying from 2 to 41. This implies that although the required data rate increases by 100 times, the number of active RRHs increases by about 20 times due to the optimal resource allocation and vehicle-to-RRH associations which lead to less active RRHs and save energy.

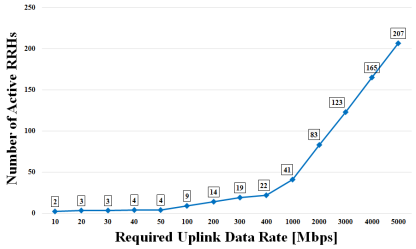

Fig. 4. Required data rate vs. turned on RRHs.

### *D. Impact of Vehicles Density*

In this subsection, we investigate the impact of the density of the vehicles on the number of active RRHs. The maximum number of the RRHs that are turned on depends on the number of vehicles and their optimal association to the serving RRH. Furthermore, the number of vehicles served by each active RRH depends on the RBs requested by each vehicle.

Figure 5 shows the impact of the number of vehicles on the number of RRHs to be turned on. Intuitively, as the number of vehicles increases, so is the number of active RRHs. As we can notice, for the scenarios consisting of 10 up to 1000 vehicles, the number of active RRHs varies from 2 to 41, due to the optimum assignments between the vehicles and the RRHs. Especially for the scenario consisting of 30 vehicles, we observe that the number of served vehicles is the same per each active RRH, i.e., each active RRH serves 10 vehicles. This implies that optimal vehicle-to-RRH association leads to efficient utilization of RBs and energy-saving by minimizing the number of RRHs to be turned on.

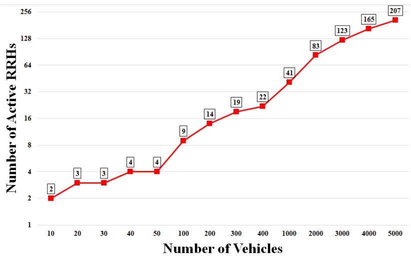

Fig. 5. Number of vehicles vs. turned on RRHs.

### *E. Impact on Computation Time*

In this subsection, we compare the execution times of solving the optimization problem and running each of the heuristic algorithms for the small, medium, and big size scenarios. We run each implementation for 10 times and calculate the average elapsed time.

Figure 6 shows the impact of the number of vehicles on the computation time measured in seconds. We compare the elapsed time of solving the resource management problem by implementing the optimal and heuristic solutions. We can notice that the obtained optimal results for the small size problem can be achieved in a reasonable execution time, which is around 50 $[ms]$. Additionally, we can notice that the elapsed time for the scenario consisting of 100 vehicles is longer than the elapsed time for the scenarios consisting of 200 and 300 vehicles. This occurs due to the fact that CPLEX solver has a choice of algorithms for solving linear programming problems and the execution time will depend not only on the problem size but also on the selected algorithm. For the big size scenario, values of computation time are not available due to memory shortage (a typical phenomenon for big instances). Furthermore, we can observe that the heuristic algorithms provide competitive solutions to the optimal ones in an acceptable execution time (which is faster than the ones obtained from the optimal solutions by CPLEX solver).

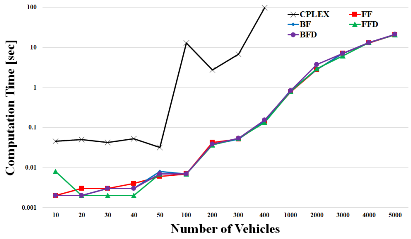

Fig. 6. Number of vehicles vs. computation time.

## IV. CONCLUSION

In this work, we investigate the problem of resource management in 5G LADN supporting V2X communications. The resource management problem is mathematically formulated as an optimization problem based on integer linear programming and then solved by using a professional solver. In the following, heuristic algorithms are applied to provide solution methods for big instances. As expected, the obtained optimal results for the small size scenario are achieved in reasonable execution times, while the heuristic algorithms run efficiently even on big problem instances and produce solutions that approximate the optimal ones in acceptable execution times of seconds. Our numerical results show that LADN is suitable for V2X applications and provides dynamic resource management depending on the traffic demand while reducing energy consumption. Therefore, our proposed model can efficiently utilize the resources and save energy while guaranteeing the QoS requirements.

For future work, we intend to further consider additional constraints (e.g., mobility) to make the model more realistic. Additionally, we plan to investigate the impacts of more factors (e.g., CQI distribution and power of RRH) on the model performance. We also plan to work with non-regular environments (e.g., existing town street networks). Furthermore, we intend to analyze the queuing model when LADN is located in the vicinity of both RSUs and gNBs by determining the optimal ratio of the sensing data transferred to gNB.

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