Joint Placement and Sleep Scheduling of Grid-Connected Solar Powered Road Side Units in Vehicular Networks

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***Abstract*—With the emerging demand for vehicular safety and comfort, research in vehicular ad hoc networks (VANETs) has received more importance lately. Road side units (RSUs) being a key element for communication in VANETs, optimal placement of RSUs has become a challenge to ensure ubiquitous connectivity and lower deployment cost. With the emphasis on minimizing carbon footprint, energy aware strategies in placement are necessary. A direction orthogonal to it is sleep scheduling of RSUs to minimize their energy consumption. Taking these into account, we aim to perform optimal placement of RSUs with sleep scheduling where RSUs are powered by conventional grid and solar power. This is done by jointly optimizing the total number of RSUs deployed, the operational expenditure and the conventional grid energy consumed. We use Rainbow Ranking algorithm to place and schedule RSUs for a given scenario. Our results show that this kind of joint optimization leads to an overall energy aware RSU placement with lower overall cost.**

***Index Terms*—VANET, RSU placement, Sleep scheduling, Energy efficiency, Rainbow product ranking.**

I. Introduction

Vehicular ad hoc networks (VANETs) have recently emerged as a research area with a large number of applications ranging from road safety to infotainment. Such networks comprise of vehicles participating as nodes and static units as gateways [1], [2]. A typical VANET scenario consists of a set of moving vehicles communicating among themselves as well as with stationary radio units placed along the road called Road Side Units (RSUs). The vehicles are equipped with radio devices called On-Board Units (OBUs) which help them to communicate with other vehicles, known as Vehicle-to-Vehicle (V2V) communication, as well as with RSUs, known as Vehicle-to-Infrastructure (V2I) communication.

Applications in VANETs require continuous connectivity at all times and to provide such ubiquitous connectivity, it is required to have maximal coverage in a given area. RSUs in a VANET scenario help the vehicles to have such a continuous end-to-end connectivity. For providing maximal coverage, it is required to place large number of RSUs on a given road. Deployment and maintenance of RSUs being a costly affair, it will incur high cost [3], [4].

Lately, environmental concerns arising from the impact of using non-renewable energy sources have opened up a new dimension in the study of VANETs. Providing ubiquitous connectivity by placing many RSUs not only increases deployment cost but also increases the amount of energy consumed. Since the energy is obtained using scarce energy sources like fossil fuels, it leads to an increase in harmful emissions and leaves a large carbon footprint [5]. Hence, it is of utmost importance to determine ways to place RSUs such that total cost incurred and total energy consumed is minimized without affecting the coverage criteria.

Use of renewable energy sources such as solar and wind energy are now seen as alternatives to conventional power sources. Although these energy sources help in reducing the total carbon footprint, their discontinuous availability leads to the need for conventional grid power as an alternative supply of energy. In this direction, it has been proposed to use sleep scheduling strategies for RSUs to reduce the energy consumption and also reduce the dependency on grid power [6], [7]. The RSUs transition through various power states (sleep, idle and active) according to the vehicular demands. During high traffic density, the RSUs are mostly active whereas, in case of low density scenario, RSUs whose non-participation does not impact the system performance, can transition to sleep state. This reduces the energy consumption compared to the situation where no such energy aware mechanisms are used.

In this paper, we propose an RSU placement strategy on a one-dimensional (1-D) road such that, the total energy consumed is minimized without violating the coverage constraint. We couple this with a sleep scheduling scheme that helps in determining the RSUs which are required to be active thus, reducing the total energy consumed as well as the total grid energy usage. Given a set of candidate locations and vehicle distribution of a 1-D road scenario, we use the rainbow product ranking algorithm [8] to find out a subset of candidate locations where RSUs are required to be placed and also schedule them according to changing vehicle density. In our scenario, we relate the coverage constraint with the Packet Delivery Ratio (PDR) which is the fraction of packets reaching RSUs within a certain delay bound. A candidate location is chosen for placement of RSU if the minimum necessary PDR constraint is not met. The results show that using our approach the optimal subset of candidate locations can be obtained where placement of RSUs will not only meet the required PDR but will also reduce the total amount of energy consumed with a guarantee on minimum grid energy usage.

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II. Related Work

RSUs play an important role in ensuring ubiquitous connectivity in a VANET environment. Deployment of RSUs combined with its energy consumption is expensive. Thus, it is important to have an intelligent placement of RSUs in a given area such that the total energy consumption is reduced without impacting the coverage requirement. Various works exist in the literature which have dealt with the problem of placement of RSUs [3], [4], [9], [10] and also on minimizing total energy consumption by RSUs using scheduling techniques [6], [7]. So far, these two aspects have been dealt separately. For placement of RSUs, only the cost for deployment has been considered as a contribution to the total cost. Energy consumption at RSUs has been dealt in separately.

With respect to RSU placement, in [11], the authors have suggested a technique by evaluating graph centrality. In [9], the authors have derived the inter-RSU separation for an estimated delay bound for a 1-D low vehicle density scenario. An RSU placement strategy that maximizes the aggregate throughput and also reduces the total deployment cost have been suggested in [4] and [10]. In [4], the authors have taken into account the impact of interference at the radio, vehicle population distribution and vehicle speeds in the formulation, whereas in [10], the authors try to maximize the system throughput by formulating a max flow problem. In all the above strategies, RSU placement has been dealt only with the aim of either increasing the aggregate throughput or meeting a given delay bound with a decrease in the total deployment cost.

In [5], the authors have suggested an $M/G/1/k$ queuing model for an RSU to estimate the energy consumption, average packet delay, and required battery capacity. They have considered wind energy as the renewal energy source and have proposed a rudimentary online scheduling algorithm for RSUs. The work considers RSUs to be already placed but is silent about delay or coverage requirements. To further reduce the energy consumed by RSUs, sleep scheduling of the RSUs has been suggested. Mostofi et al, in [6] have suggested an ON/OFF sleep scheduling technique for RSUs deployed beforehand in a given region for an energy efficient vehicular network scenario. It takes into account the energy consumed during OFF/ON transitions which the authors use to compute a lower bound on energy usage of the RSUs. This is used for comparisons with the energy consumed when using the proposed online scheduling algorithm. The proposed schedule is shown only for a single RSU and hence applicable for single hop communications but does not reveal anything about multi hop communication.

In [7], the author has proposed an online scheduling of RSUs based on coverage requirement and vehicle density to minimize the energy consumption. However, the author does not impose any delay requirement or pose any hop bound on the given scenario which has uniformly deployed RSUs. The authors in [3] have proposed a joint optimization strategy for the configuring and placing RSUs using Integer Linear Programming (ILP) where they have considered variations in antenna types, transmit power levels of RSUs, and their installation cost in a two-dimensional network scenario to achieve a user specified coverage criteria. With different traffic realizations and coverage constraints, the algorithm gives a different placement strategy every time.

In this paper, we aim to place RSUs in a given 1-D scenario such that the deployment cost, the operational cost, and the overall energy consumed is reduced with a guarantee to achieve a certain PDR. We intend to use a combination of solar and grid energy sources at the RSUs and propose a sleep scheduling algorithm to further reduce the total energy consumed with an assurance of maximal usage of solar power over grid power. To the best of our knowledge, there are no existing studies on joint optimization of deployment cost, operational expenditure, and conventional grid energy consumed by the RSUs.

III. System Model

We consider a 1-D road scenario where vehicles have bi-directional movement and the OBUs on the vehicles periodically broadcast information to the neighbouring vehicles [9]. A packet generated can reach any of the RSUs deployed along the side of the roads in this setting. The transmission of the packets is via either a direct link with the RSU (V2I) when the vehicle is within its transmission range or by multi-hop propagation (V2V). We limit our analysis to an uplink scenario where packets will be transmitted from the OBUs. We aim to place RSUs and schedule them based on the traffic conditions so as to ensure a high energy efficiency of the system.

A. *Road and mobility model*

We consider that vehicles arrive at the given road according to a Poisson distribution and the distribution of the number of vehicles in a road is also Poisson. We also make the assumption that the distance between any two vehicles is exponentially distributed and that the average vehicle density is maintained. We neglect the width of the road in comparison to its length and take the difference in the X-coordinate, assumed to be along the length of the road, as a measure of separation between any two entities [4].

B. *RSU model*

A set of candidate locations chosen for placement of RSUs are considered. Among these candidate locations, a subset is chosen for deploying RSUs ensuring that minimal energy is utilized while not compromising on the PDR. We define a road segment as the region between any two candidate locations. The RSUs are placed at the end of segments and the length of each segment is at least twice the reception range of the RSU. Each RSU is powered by two sources of energy namely, a fixed power line using the conventional grid energy and Photo Voltaic (PV) cells to utilize the solar energy. The PV cells charge a battery which in turn powers the RSU. The PV cells are operational during day time when the charging of the battery happens. For operating the RSUs at night the stored energy from the battery is utilized. Since PV cells have low efficiency and are affected by fluctuating insolation due to varying weather conditions [12], grid power is used to ensure that the RSU is always operational when necessary, i.e., when the battery is unable to power it. The PV cells themselves are constrained in the power output they can provide based on the position of the sun and the weather condition. With respect to the battery, it has its operating limits whereby, it cannot be used when the available charge present in it falls below a certain threshold value to ensure its longevity.

C. Radio model

We assume here that both the RSUs and the OBUs use 802.11p MAC to utilize the DSRC channels allocated at 5.9 GHz [13] and have same transmission and reception ranges. The signal propagation is assumed to be a two-ray path loss model. The OBUs are assumed to have a single packet queue containing the high priority control channel packets. The dissemination of the information is by broadcast so that an OBU can transmit a packet to all radio units within its transmission range. In the RSU, its radio unit has an option to enter a sleep mode during which it does not participate in the communication with the OBUs and this sleep interval is fixed after which it will transition out of sleep state to active state.

D. Routing

When an OBU broadcasts a packet, the one hop neighbours broadcast it further and so on. Thus, by using multi-hop propagation an OBU can communicate with an RSU which is not within its transmission range or line of sight. A blind forwarding by all the OBUs can create an implosion of packets. To overcome this issue we use a modified broadcasting scheme that uses the location and direction of propagation information of the OBUs to ensure that only a certain fraction of the one-hop neighbours will be able to forward the packet [14]. Since the packets are time sensitive, they have a hop bound and a delay bound associated with them. Exceeding these bounds make the packet information invalid and cause the packet to be dropped.

E. Scheduling

The scheduling of the RSUs is done to minimize the energy usage [6], [7]. This is motivated by the fact that with the knowledge of variations in traffic conditions for a given scenario, an RSU can be set to sleep mode iff the OBUs can still be serviced as per the PDR requirements. One can see the importance of this when in a sparse traffic scenario less RSUs are required than when the traffic density is more. Based on the historic traffic data of the scenario, a static schedule is computed which dictates when an RSU is to be placed in sleep mode.

IV. Problem Formulation

A typical road scenario in VANETs is characterized by variations in the traffic patterns over time. We consider k different time slots given by $T = < t_1, t_2, ..., t_k >$ for placement and scheduling of RSUs where $\forall\, i$, $t_i = \tau$ and τ is the duration of each slot. Each slot here captures a snapshot of the particular road scenario at different time intervals. There are m different candidate RSU locations represented as $R = < R_1, R_2, ..., R_m >$. Let V_i be the set of all vehicles that would have entered the system in a given time slot i. Each vehicle broadcasts packets and the number of packets broadcast in duration t is given by the function $\Phi(t)$. Thus, in our scenario the number of packets sent by each OBU in every time slot is $\Phi(\tau)$. Thus, given the traffic variations apriori for each of the time slots, we aim to determine here, the candidate locations where an RSU would have to be deployed for each time slot beforehand. We place an RSU in those candidate locations where an RSU is required for at least one time slot and later scheduled.

Candidate locations for RSUs are characterized by the following matrices: battery state B, a charging profile I, the power source it is using S, whether it is on or off O, and the number of packets n, it services in each of the time slots. Consider the j^{th} candidate RSU location in the i^{th} time slot. Its charging profile is given by the matrix entry $I_{j,i}$ which determines the amount of solar energy an RSUs battery will receive from its PV cell if placed there. $S_{j,i}$ represents the power source it is using where 1 indicates solar power while 0 indicates grid power. RSU can be active or in sleep mode based on $O_{j,i}$ where a value of 1 indicates it is active and 0 indicates that it is in the sleep state. The battery state, indicated by variable $B_{j,i}$ gives the amount of energy stored in the battery. If in the i^{th} time slot, $n_{j,i}$ packets are incident on the j^{th} candidate RSU location, we impose the following constraints on the battery state

$$B_{j,i+1} = B_{j,i} + I_{j,i} - S_{j,i}(O_{j,i}\Delta E_{j,i} + f_{j,i}\Delta E_s) \quad (1)$$

where $\Delta E_{j,i}$ indicates the energy expended by the RSU in servicing the packets of the OBUs, ΔE_s is the transition energy needed to wake up the radio unit from sleep mode or transition to sleep mode and $f_{j,i}$ indicates if the RSU underwent such a transition from previous time slot. $\Delta E_{j,i}$ is given by the following equation:

$$\Delta E_{j,i} = n_{j,i} t_t P_{rx} + (\tau - n_{j,i} t_t) P_{res} \quad (2)$$

Here we consider the energy consumed by the radio unit in the RSU to be composed of energy consumed during packet reception P_{rx} for the duration $n_{j,i}t_t$. The rest of the time in that slot is spent at idle power P_{res}. Here t_t represents the transmission delay.

We add the following constraints to relate the various parameters:

$$\frac{\sum_j n_{j,i} O_{j,i}}{\sum_{V_i} \Phi(\tau)} \geq \zeta \quad \forall\, i \quad (3)$$

$$f_{j,i} = \begin{cases} 1 & \text{if } O_{j,i} \neq O_{j,i-1} \\ 0 & \text{otherwise} \end{cases} \quad \forall\, i, j \quad (4)$$

$$S_{j,i} = \begin{cases} 1 & \text{if } B_{j,i} > \delta \\ 0 & \text{otherwise} \end{cases} \quad \forall\, i, j \quad (5)$$

$$B_{j,i} \geq 0 \quad \forall\, i, j \quad (6)$$

$$B_{j,i} \leq B_{max} \quad \forall\, i,j \tag{7}$$

$$\sum_j n_{j,i} = \sum_j n_{j,i} O_{j,i} \quad \forall\, i \tag{8}$$

Equation (3) constraints the PDR to at least a minimum value ζ. Equation (4) tells us when to factor in the transition energy based on the wake/sleep state of the RSU. The available battery capacity is restricted to a minimum value as represented by equation (5), i.e, an RSU can use the battery power only if the battery has minimum remaining capacity δ else it has to use the grid power. The constraint of non-negative available capacity for any given battery is given by equation (6) while (8) ensures that if an RSU is in sleep mode, then no packet must be processed by it.

We can also relate the total number of packets generated by OBUs and received at RSUs at a time instant i as follows:

$$\sum_j n_{j,i} \leq \sum_{V_i} \Phi(\tau) \quad \forall\, i \tag{9}$$

Equation (9) ensures that the total number of packets received at active RSUs is at most equal to the total number of packets generated.

A. Objectives

Our aim is to have an energy aware placement and scheduling of the RSUs so as to minimize the energy consumption while trying to ensure that PDR is not negatively impacted. In our setting we try to minimize the following three objectives:

- The number of RSUs deployed in the system.
- The fraction of grid energy consumed to the total energy consumed by the RSUs.
- The operational expenditure (OPEX) incurred due to the power consumption at an RSU.

Let $O' = \{j \mid \max_i O_{i,j} > 0\}$. O' represents the set of candidate RSU locations which was used in some time slot and therefore where an RSU has to be deployed. Since a large number of RSUs will lead to high energy consumption and high deployment cost, minimizing the total number of RSUs deployed is justified. The OPEX of the deployment is given by

$$E_c = \sum_i \sum_j (\Delta E_{j,i} + f_{j,i}\Delta E_s)((1 - S_{j,i})c_g + S_{j,i}c_s) \tag{10}$$

where, c_s represents the cost of a unit of solar energy while c_g represents the cost of a unit of grid energy.

We represent our objectives by the following expressions:

$$min \; ||O'|| \tag{11}$$

$$min \; \frac{\sum_i \sum_j (\Delta E_{j,i} + f_i \Delta E_s)(1 - S_{j,i})}{\sum_i \sum_j \Delta E_{j,i}} \tag{12}$$

$$min \; E_c \tag{13}$$

Expression (11) represents the number of RSUs deployed. Expression (12) represents the fraction of grid energy used to the total energy consumed by the RSUs in the given scenario. Our primary objective is to minimize the OPEX which is given by expression (13). Because of the multiple objectives and the combinatorial nature of the given problem, a multi-criteria knapsack problem can be reduced to the given scenario in polynomial steps. Since, multi-criteria knapsack is NP-hard [15], the given problem is also NP-hard. Hence, we use a heuristic Rainbow Product Ranking algorithm to get the near optimal solution in polynomial time.

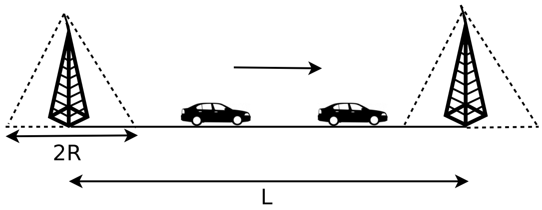

Fig. 1. 1-D road with two RSUs

B. Rainbow Product Ranking Algorithm

The Rainbow Product Ranking (RPR) algorithm is used to rank objects according to their attributes [8]. Given N candidate query points with M attributes, it gives a strategy to choose the near optimal candidates based on a required criteria.

The RPR algorithm is a multi-attribute sorting approach for finding the best item from a given item set. The approach involves a filtering process followed by skyline generation and finally ranking. Filtering is done using a user specified attribute to obtain acceptable set of candidates. A skyline is defined as the set of best possible candidate points obtained by comparing every pair of candidate points' attributes and forming an ordering of data points. The skylines are built until all the candidates are exhausted. Out of these skylines the best candidate solution is chosen by ranking within the skylines using another user specified attribute. As our aim is to choose a candidate location from a set of given candidates that must satisfy multiple objectives, we use RPR algorithm as a heuristic to solve the optimization problem framed.

In our case, the objectives are modified and taken as the attributes. PDR within the delay bound is used for screening the candidate locations which are to be used for building the skyline. For each screened candidate location, the energy consumed, the fraction of grid energy used and a variable to check whether the candidate location was used in the previous time slot are computed and are used as attributes in the RPR scheme. Energy consumption of the candidates is used for ordering them and the one with the least energy value is chosen as the optimal candidate. Thus, in a given time slot skylines are repeatedly computed until the set of candidate locations obtained can satisfy the required PDR. The algorithm is used is shown in Algorithm 1. After obtaining the optimal locations, the aggregate energy consumed and the fraction of grid energy used is estimated. The optimal candidate locations obtained are stored for applying the algorithm in next time slot.

The PDR, the energy consumed, and the fraction of grid energy for a candidate RSU location are obtained by simulat-

Algorithm 1 Candidate location selection in particular a time slot

Input:
U : set of all candidate locations
min_pdr: minimum PDR necessary
Output:
U': optimal candidate locations

$PDR(u, U')$: PDR obtained when RSU is placed at location u taking into consideration U'
$energy(u, U')$: energy consumed at location u taking into consideration U'
$gridFraction(u, U')$: factional grid energy usage taking into consideration U'
$placed(u)$: indicates if location u is used in previous time slot
s : optimal candidate location given by $Rainbow\_product\_ranking()$
M : set with tuple for a candidate location with its attribute
Set $all\_coverage\_in\_bound \leftarrow false$;
Set $U' \leftarrow \phi$
while $((!\ all\_coverage\_in\_bound) \wedge (U \neq \phi))$ **do**
  $S = \{u \mid u \in U \wedge PDR(u, U') < min\_pdr\}$
  if $S == \phi$ **then**
    $all\_coverage\_in\_bound \leftarrow true$
    stop
  end if
  for all $u \in S$ **do**
    $M \leftarrow M \cup \{< u, energy(u, U'), gridFraction(u, U'), placed(u, U') >\}$
  end for
  $s \leftarrow Rainbow\_product\_ranking(S, M)$
  $U' \leftarrow U' \cup \{s\}$
  $U \leftarrow U - \{s\}$
end while

ing individually both the road segments formed between it and the nearest used candidate location on either sides as shown in Figure 1. We extrapolate this model to our scenario by approximating the road segment between any two candidate locations to behave similarly. In the algorithm, a candidate location is said to satisfy the minimum PDR requirement only if the PDR obtained for both the road segments on either side of it is grater than the minimum PDR. Thus, by using Algorithm 1 over all time slots, for a given PDR and the set of candidate locations, we compute the optimal locations where an RSU has to be deployed and its schedule.

Building skyline for N candidate locations with M attributes incurs a complexity of $O(MN^2)$. The algorithm mentioned above builds skyline for at most N candidate locations leading to an overall complexity of $O(MN^3)$. Over all k time slots, we compute optimal candidate locations and schedule with complexity $O(kMN^3)$. Thus, this heuristic provides a near optimal solution for the above optimisation problem in polynomial time.

V. Simulation Results and Discussion

TABLE I
System Parameters [12], [16], [17]

Radio power during reception	P_{rx}	10.0 W
Radio power during idle state	P_{res}	9.0 W
Min contention window	G_{min}	15 ms
Max contention window	G_{max}	1023 ms
Packet length	P	200 $bytes$
Bandwidth	B	6 $Mbps$
Transmitter range	R	1 km
Hop limit	H	5
Average OBU packet generation rate	λ	1 s^{-1}
Switching energy	ΔE_s	50 J
Grid energy cost	c_g	0.06\$$kW^{-1}h^{-1}$
Solar energy cost	c_s	0.001\$$kW^{-1}h^{-1}$
Battery value	B_{max}	240Whr
min battery value	δ	12Whr
PV panel output		40W

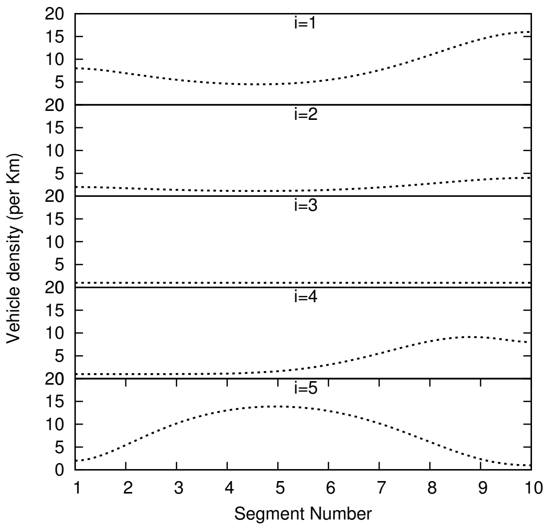

Fig. 2. Density variation with segment number

Our simulations have been carried out using ns-2 [18] which has been modified to work for 802.11p network settings using [19]. We experiment on a road scenario of length 20 km and consider 11 uniformly spaced candidate locations forming 10 road segments. We have considered traffic scenarios for 5 different time slots each of 300 seconds as given in Figure 2. With respect to the vehicle mobility, we allow for vehicles to overtake each other to allow for exponential distribution of inter-vehicle separation as per the system model. Each data point of Figures 4, 5, 6 and 7 is obtained by 100 simulation rounds. The traffic variations are captured at different time slots for each of the road segments. The solar energy obtained by using the PV cells varies according to Figure 3 and is calculated by using [20]. We assume that at the start of simulation the battery capacity is zero. All the other required parameters are given in Table I. We have compared the results obtained from our proposed method with two different placement strategies, viz, uniform placement of RSUs and exhaustive search and

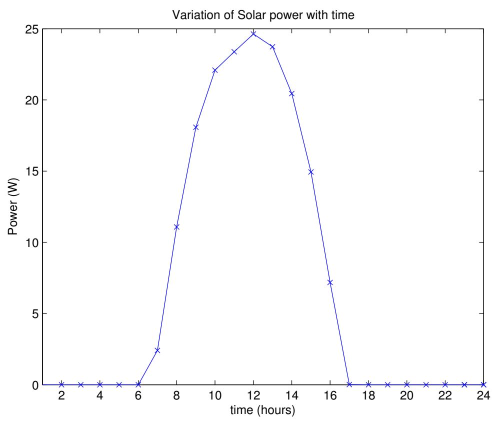

Fig. 3. Solar power variation with time

placement. In exhaustive search, for each time slot, the best RSU configuration is chosen as a subset of candidate location such that when RSUs are placed, least amount of energy is consumed while adhering to the minimum PDR requirement. Due to the multihop communication scenario and the fact that the separation between two candidate locations is greater than the transmission range, we expect a low PDR as shown in [21].

The variation of total energy consumed by the different placement strategies for various PDR values is shown in Figure 4. From the graph it is seen that the total energy consumed when RSUs are placed uniformly is much higher and remains constant throughout the simulation period. In the proposed method, energy consumed is lesser and nears the values obtained through the exhaustive search. This behaviour is attributed to the reduction in energy consumption in the proposed method due to efficient sleep scheduling of the RSUs. Sleep scheduling ensures that those RSUs which do not impact the PDR are turned off. This fact is further strengthened by the graph shown in Figure 5 which shows the variation of total operational cost incurred using the different placement strategies.

In Figure 6, using our placement strategy the OPEX incurred for various modes of power consumption by RSUs is shown. The cost has been considered to be a logarithmic value to represent the variations in energy consumed when RSUs are solely solar powered, grid powered and powered by both. With solar power, the OPEX becomes negligible as once deployed the cost incurred is only due to the PV cells' maintenance. But due to discontinuous availability of solar power, it is required to have an alternative source of power for the RSUs which is the conventional grid energy and from the graph in Figure 6 we find that the cost incurred is substantially less than using only grid power as the power source.

The proposed joint optimization method not only reduces the energy consumed but also reduces the total number of RSUs which are required to be deployed. Figure 7 depicts the number of RSUs necessary to satisfy the required PDR for various placement strategies. With the uniform placement, irrespective of the PDR the RSU requirement remains the same. But with sleep scheduling the number of RSUs needed is lesser. It is seen that the best case has the lesser number of RSUs needed but because the proposed strategy jointly optimizes energy with number of RSUs deployed, we can see that for certain PDR the number of RSUs needed is lesser but looses out on the energy consumption as seen from the previous plots. However, above a certain PDR the proposed method behaves similar to uniform placement.

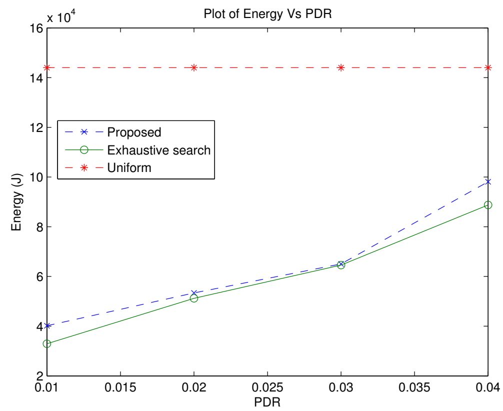

Fig. 4. Energy variation with required PDR values

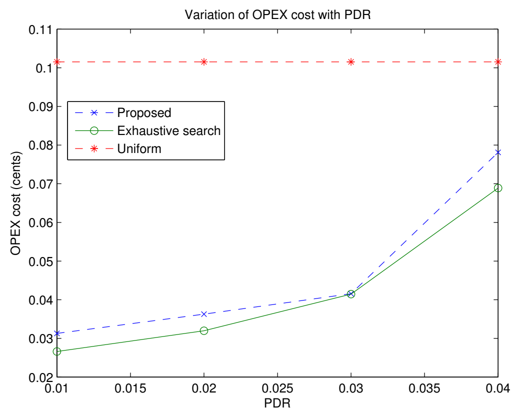

Fig. 5. Variation in OPEX with required PDR values

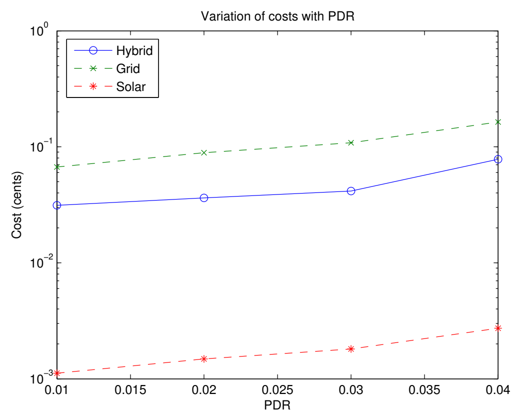

Fig. 6. Variation in cost incurred using different power sources

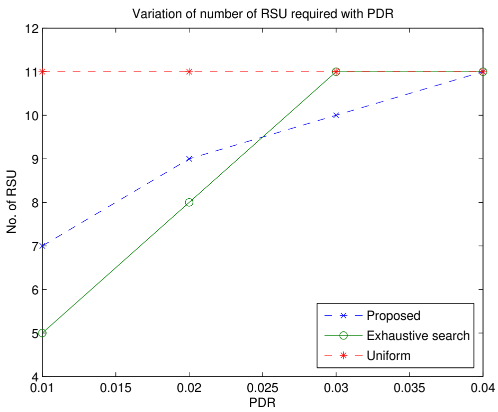

Fig. 7. Variation in PDR with number of RSUs

VI. Conclusion

In this paper, we have proposed a joint optimization strategy to optimize the number of RSUs deployed, the total energy consumed, and the fraction of grid energy used by RSUs in a given vehicular network scenario. We have emphasized on the fact that an optimal placement of RSUs with an efficient sleep scheduling technique leads to an overall decrease in deployment cost as well as the operational expenditure. The Rainbow Product Ranking algorithm has been used to achieve the near optimal placement by solving the multi-objective optimization problem. We have compared the energy consumed for the required PDR using the proposed strategy with uniform placement and exhaustive search strategy. We have found that the proposed strategy performs much better in terms of energy consumed as well as total operational expenditure as compared to uniform placement and nears the exhaustive search strategy. Results also show that the number of RSUs required to be deployed also decreases by using the proposed strategy, leading to an overall low cost placement.

VII. Acknowledgement

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