JOINT PLACEMENT AND SLEEP SCHEDULING OF GRID-CONNECTED SOLAR POWERED ROAD SIDE UNITS IN VEHICULAR NETWORKS

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis titled **Joint Placement and Sleep Scheduling of Grid-Connected Solar Powered Road Side Units in Vehicular Networks**, submitted by **Vageesh D C**, to the Indian Institute of Technology Madras, for the award of the degree of **Bachelor of Technology**, is a bona fide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: VANET; RSU placement; Sleep scheduling; Energy efficiency; Rainbow Product Ranking.

With the emerging demand for vehicular safety and comfort, research in vehicular ad hoc networks (VANETs) has received 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, the work aims 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. Rainbow Product Ranking (RPR) algorithm is used to place and schedule RSUs for a given scenario. The results show that this kind of joint optimization leads to an overall energy aware RSU placement with lower overall cost.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

1-D	one-dimensional
2-D	two-dimensional
DSRC	Dedicated Short Range Communication
ILP	Integer Linear Programming
ITS	Intelligent Transportation Systems
MAC	Medium Access Control
OBU	On Board Unit
OPEX	Operational Expenditure
PDR	Packet Delivery Ratio
PV	Photo Voltaic
RPR	Rainbow Product Ranking
RSU	Road Side Unit
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad Hoc Network

CHAPTER 1

Introduction

1.1 VANETs

With the ever increasing vehicular traffic, safety of the drivers and passengers is of utmost importance. In this regard, Vehicular ad hoc networks (VANETs) are envisioned as a system where vehicles would be aware of the surroundings and provide the driver with necessary inputs to take pre-emptive actions to ensure safety [1, 2]. The system is designed to detect key traffic events like overtaking, sudden braking and informing all neighbouring vehicles about the vehicle's state. Some of the other applications of VANETs include providing aid to the drivers via maps and directions and striving for passenger comfort by providing infotainment through streaming of audio-video content.

VANETs comprise of vehicles participating as nodes and static units as gateways. 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.

Thus, applications in VANETs require continuous connectivity at all times and to provide such ubiquitous connectivity, it is required to have maximal coverage for all vehicles 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].

1.2 Environmental Concerns

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 criterion.

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.

1.3 Contributions of the Work

This work proposes an RSU placement strategy on a one-dimensional (1-D) road such that, the total energy consumed is minimized without violating the coverage constraint. This is coupled 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, the RPR algorithm [8] is used to find out a subset of candidate locations where RSUs are required to be placed and also schedule them according to changing vehicle density. The coverage constraint is imposed using 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 the proposed 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.

1.4 Organization of the Report

The remainder of the report is organized as follows: Chapter 2 presents an overview of the literature survey. Chapter 3 describes the system model assumed for this work. Chapter 4 describes the problem formulation, and the placement and scheduling strategy. The simulation results with explanation are provided in Chapter 5. Concluding remarks and some possible directions for future work are described in Chapter 6.

CHAPTER 2

Related Work

2.1 VANETs

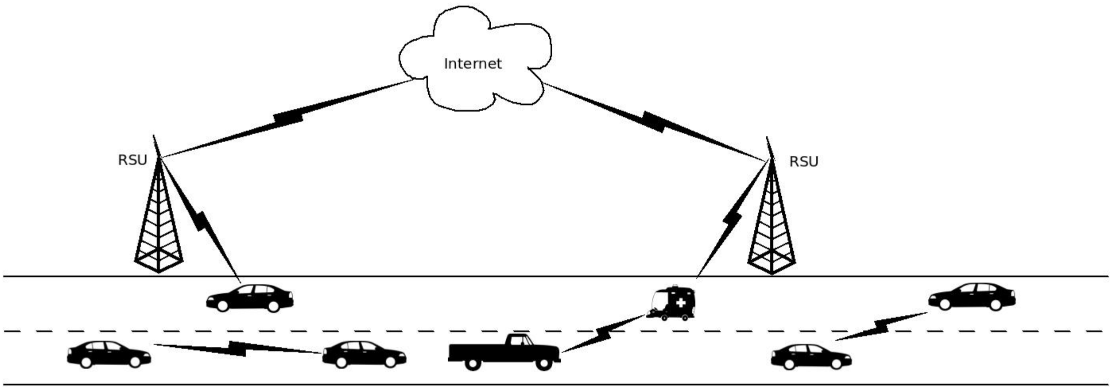

Figure 2.1: A typical VANET scenario

The idea of VANETs started with the notion of reducing the occurrence of accidents and ensuring smooth traffic. Initial designs looked at the feasibility of using off the shelf wifi radios to act as OBUs and RSUs to provide required content to the cars [9, 10]. Now they have evolved as part of ITS systems and several places like USA, Japan and Europe have proposed and developed standards for it. In USA, the main point of focus is on the IEEE 1609 protocol suite. In Europe, the ETSI ITS and ISO CALM have been studied and standardized, while in Japan, ARIB and ISO CALM are being standardized through the ISO TC 204 committee of Japan [1].

Currently, for V2V and V2I communication, IEEE 802.11p with IEEE 1609 suite is seen as a suitable candidate, given that they are customised for a vehicular network scenario especially to handle high mobility and ensure low latency connections [11, 12]. A separate band called the DSRC channel has been set aside for the use in VANETs and is designated as a licensed but free band. The current architecture of VANETs, incorporating the RSUs and the OBUs is shown in Fig 2.1.

2.2 RSU Placement

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, 13, 14] 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 [15], the authors have suggested a technique by evaluating graph centrality. In [13], 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 has been suggested in [4] and [14]. 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 [14], 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.

2.3 Scheduling

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 in a given region for an energy efficient vehicular network scenario. The scenario has RSUs deployed beforehand and takes into account the energy consumed during transitions from OFF-to-ON state. The authors [6] compute a lower bound on energy usage which is used for comparison with their proposed online scheduling algorithm. The proposed schedule is shown only for a single RSU and hence applicable for single hop communications and does not reveal anything about multi-hop communication.

In [7], the author has proposed an online scheduling of RSUs to minimize the energy consumption based on coverage requirement and vehicle density . 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 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 (2-D) network scenario to achieve a user specified coverage criteria. With different traffic realizations and coverage constraints, the above proposed ILP solution gives a different placement strategy every time.

This work aims 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. The work intends 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. During the writing of this report, there are no existing studies on joint optimization of deployment cost, operational expenditure, and conventional grid energy consumed by the RSUs.

CHAPTER 3

System Model

A 1-D road scenario is considered here where vehicles have bi-directional movement and the OBUs on the vehicles periodically broadcast information to the neighbouring vehicles [13]. 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). The analysis is limited to an uplink scenario where packets will be transmitted from the OBUs.

3.1 Road and Mobility Model

It is considered 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. It is assumed that the distance between any two vehicles is exponentially distributed and that the average vehicle density is maintained. The width of the road in comparison to its length is neglected and the difference in the X-coordinate, assumed to be along the length of the road, is taken as a measure of separation between any two entities [4].

3.2 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. A road segment is defined 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 an

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 [16], 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.

3.3 Radio Model

It is assumed here that both the RSUs and the OBUs use 802.11p MAC to utilize the DSRC channels allocated at 5.9 GHz [11] 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.

3.4 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 a modified broadcasting scheme is employed 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 [17]. 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.

3.5 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.

CHAPTER 4

Problem Formulation

A typical road scenario in VANETs is characterized by variations in the traffic patterns over time. In this setting, the traffic properties are assumed to be known apriori for a certain time duration. Using this data, RSU placement and the corresponding schedule is computed before hand after which the RSUs are deployed at the chosen locations. This duration is divided into k equal length time slots so as to adapt the schedule to varying traffic properties, given by $T = \{t_1, t_2, ..., t_k\}$ where $\forall\ i,\ t_i = \tau$. Here τ is the duration of the time 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 $R = \{R_1, R_2, ..., R_m\}$. Candidate RSU locations represent position where placing an RSU is feasible and they are determined before hand. Let V_i be the set of all vehicles that would have entered the system in a particular time slot i. Each OBU present in the vehicle broadcasts packets containing information regarding its mobility information. Let $\Phi(t)$ denote the rate at which the OBU generates packets in a time slot of length t. In this scenario the number of packets sent by each OBU in every time slot is the same and is given by $\Phi(\tau)$. The problem of placement and scheduling is solved together by first determining in each time slot those RSU candidate locations needed to satisfy the QoS constraints which forms the schedule. The RSUs are then placed in those candidate locations in which they are required in any one of the time slots.

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, the following constraints are imposed on the battery state

$$B_{j,i+1} = B_{j,i} + I_{j,i} - S_{j,i}(O_{j,i}\Delta E_{j,i} + f_{j,i}\Delta E_s) \tag{4.1}$$

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:

$$\Delta E_{j,i} = n_{j,i}t_t P_{rx} + (\tau - n_{j,i}t_t)P_{res} \tag{4.2}$$

Here the energy consumed by the radio unit in the RSU is considered 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.

The following constraints are added to relate the various parameters:

$$\frac{\sum_j n_{j,i}O_{j,i}}{|V_i|\Phi(\tau)} \geq \zeta \;\; \forall\, i \tag{4.3}$$

$$f_{j,i} = \begin{cases} 1 & \text{if } O_{j,i} \neq O_{j,i-1} \\ 0 & \text{otherwise} \end{cases} \;\; \forall\, i, j \tag{4.4}$$

$$S_{j,i} = \begin{cases} 1 & \text{if } B_{j,i} > \delta \\ 0 & \text{otherwise} \end{cases} \;\; \forall\, i, j \tag{4.5}$$

$$B_{j,i} \geq 0 \;\; \forall\, i, j \tag{4.6}$$

$$B_{j,i} \leq B_{max} \;\; \forall\, i, j \tag{4.7}$$

$$\sum_j n_{j,i} = \sum_j n_{j,i} O_{j,i} \;\; \forall\, i \tag{4.8}$$

Equation (4.3) constraints the average PDR for the system to at least a minimum value ζ. Equation (4.4) tells when to factor in the transition energy based on the wake/sleep state of the RSU. The transition energy is factored in if the RSU were to change its state from sleep to active or vice versa. The available battery capacity is restricted to a minimum value as represented by equation (4.5), i.e, an RSU can use the battery power only if the battery has minimum remaining capacity δ otherwise it has to use the grid power. The constraint of non-negative available capacity for any given battery is given by equation (4.6) while (4.8) ensures that if an RSU is in sleep mode, then no packet must be processed by it or in other words, packets are received only at the active RSUs.

The total number of packets generated by OBUs and received at RSUs at a time instant i are related as follows:

$$\sum_j n_{j,i} \le |V_i| \Phi(\tau) \;\; \forall\, i \tag{4.9}$$

Equation (4.9) ensures that the total number of packets received at active RSUs is at most equal to the total number of packets generated.

4.1 Objectives

The aim of the work 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 this setting, the following three objectives are minimized:

- 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 $O' = \{j \mid \underset{i}{max}\; O_{i,j} > 0\}$. 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

$$E_c = \sum_i \sum_j (\Delta E_{j,i} + f_{j,i}\Delta E_s)((1 - S_{j,i})c_g + S_{j,i}c_s) \tag{4.10}$$

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

The objectives are represented by the following expressions:

$$min\ |O'| \tag{4.11}$$

$$min\ \frac{\sum_i \sum_j (\Delta E_{j,i} + f_i \Delta E_s)(1 - S_{j,i})}{\sum_i \sum_j \Delta E_{j,i}} \tag{4.12}$$

$$min\ E_c \tag{4.13}$$

Expression (4.11) represents the number of RSUs deployed. Expression (4.12) represents the fraction of grid energy used to the total energy consumed by the RSUs in the given scenario. The primary objective is to minimize the OPEX which is given by expression (4.13). 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 [18], the given problem is also NP-hard. Hence, a heuristic, RPR algorithm is employed to get the near optimal solution in polynomial time.

4.2 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.

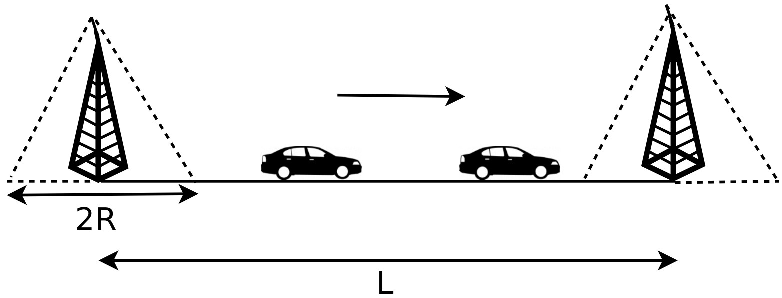

Figure 4.1: 1-D road with two RSUs

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. Since it is required to choose a candidate location from a set of given candidates that satisfies multiple objectives, RPR algorithm is used as a heuristic to solve the optimization problem framed.

In this 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. Algorithm 1 shows the usage of the RPR algorithm to obtain the optimal candidate locations. After obtaining those 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.

Algorithm 1 Candidate location selection in a particular 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

The PDR, the energy consumed, and the fraction of grid energy for a candidate RSU location are obtained by simulating individually both the road segments formed between it and the nearest used candidate location on either sides as shown in Figure 4.1.

This model is extrapolated to the current 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, the optimal locations where an RSU has to be deployed and its schedule is computed.

Building skyline for N candidate locations with M attributes incurs a run time 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, the optimal candidate locations and schedule is computed in $O(kMN^3)$ time. Thus, this heuristic provides a near optimal solution for the above optimisation problem in polynomial time.

CHAPTER 5

Simulation Results and Discussion

Our simulations have been carried out using ns-2 [19] which has been modified to work for 802.11p network settings using [20]. The model is experimented on a road scenario of length 20 km and consider 11 uniformly spaced candidate locations forming 10 road segments. Traffic scenarios for 5 different time slots each of 300 seconds have been considered as given in Figure 5.1. With respect to the vehicle mobility, vehicles are allowed to overtake each other to accommodate for exponential distribution of inter-vehicle separation as per the system model. Each data point of Figures 5.3, 5.4, 5.5, and 5.6 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 5.2 and is calculated by using [21]. It is assumed that at the start of simulation the battery capacity is zero. All the other required parameters are obtained from [16, 22, 23] and are given in Table 5.1. The results obtained from the proposed method is compared with two different placement strategies, viz, uniform placement of RSUs and exhaustive search and 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 large transmission range needed for VANETs, multi-hop communication scenario, and the fact that the separation between two candidate locations is greater than the transmission range, a low PDR is expected as shown in [24, 25].

The variation of total energy consumed by the different placement strategies for various PDR values is shown in Figure 5.3. 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

Table 5.1: System Parameters

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

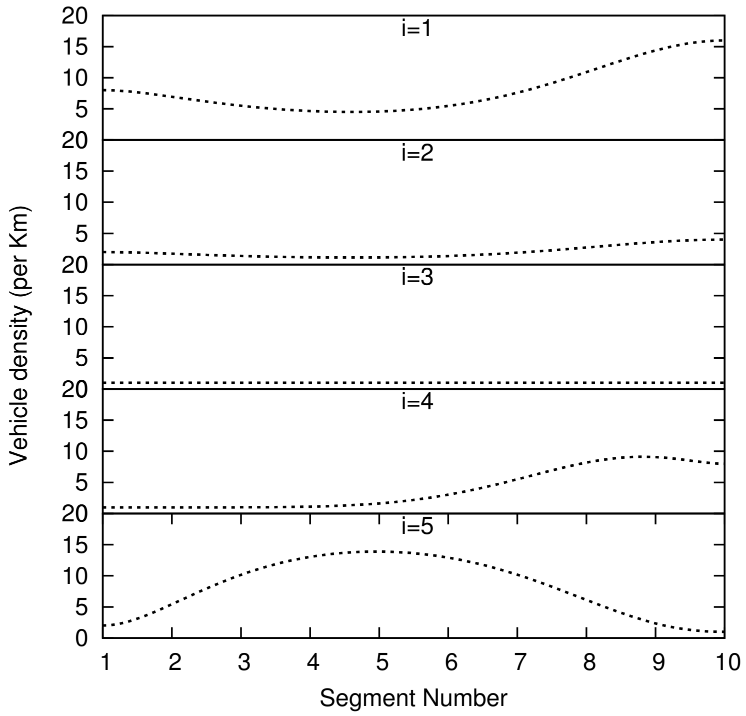

Figure 5.1: Density variation with segment number

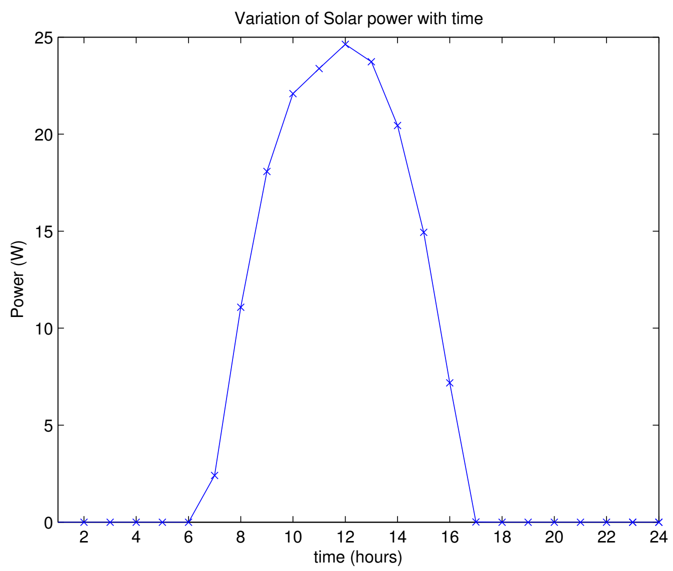

Figure 5.2: Solar power variation with time

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 5.4 which shows the variation of total operational cost incurred using the different placement strategies.

In Figure 5.5, using the proposed 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 5.5 it is found 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 5.6 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, one 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.

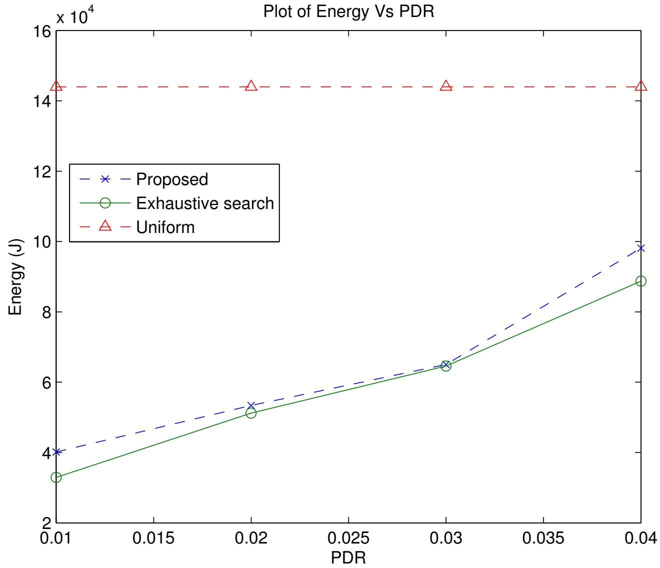

Figure 5.3: Energy variation with required PDR values

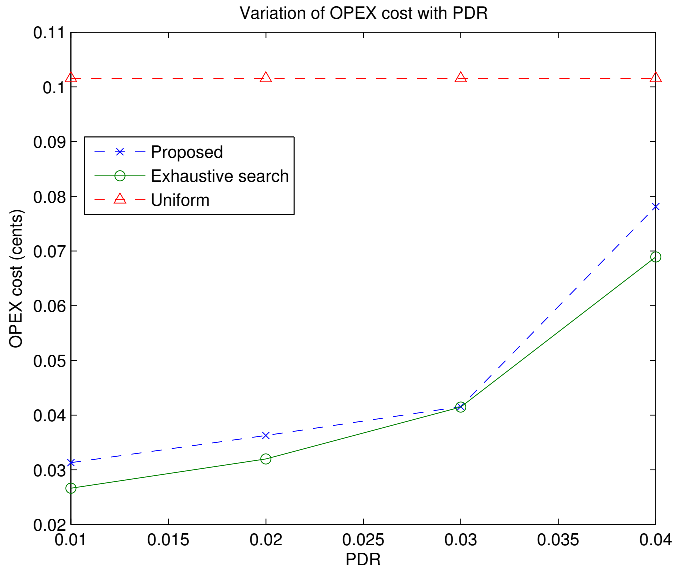

Figure 5.4: Variation in OPEX with required PDR values

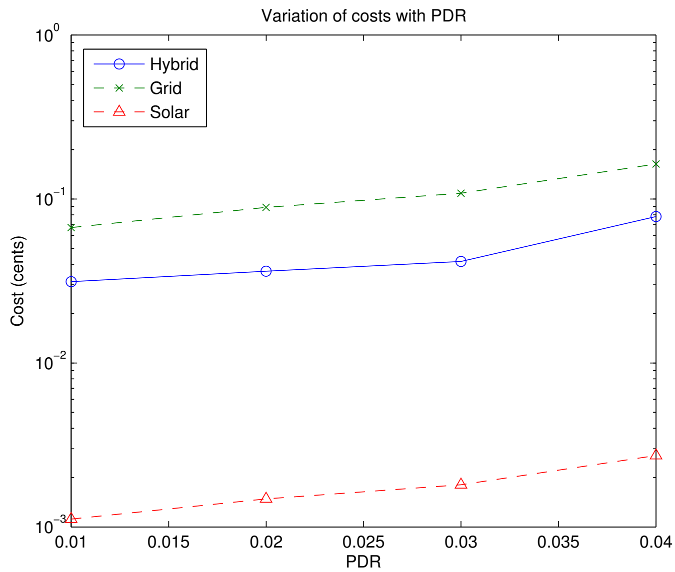

Figure 5.5: Variation in cost incurred using different power sources

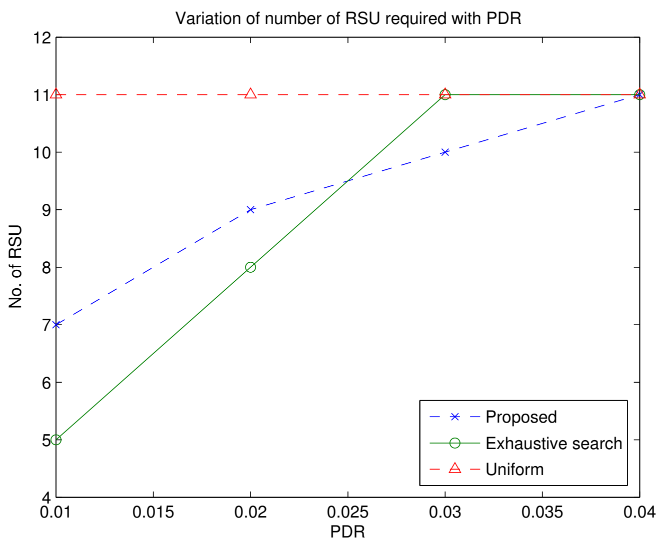

Figure 5.6: Variation in PDR with number of RSUs

CHAPTER 6

Conclusion and Future Work

This work has 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. The fact that an optimal placement of RSUs with an efficient sleep scheduling technique leading to an overall decrease in deployment cost as well as the operational expenditure has been emphasized. The RPR algorithm has been used to achieve the near optimal placement by solving the multi-objective optimization problem. The energy consumed for the required PDR using the proposed strategy has been compared with uniform placement and exhaustive search strategy. It is 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.

Several avenues can be explored to further the understanding of the current work. The derivation of closed form analytical expressions for PDR, connectivity and energy consumption for a multi-RSU scenario can be investigated. The optimality of proposed placement and scheduling can be explored on a 2-D traffic scenario and on various vehicle mobility patterns. The advantage of a dynamic schedule that adapts to the traffic demands can be examined.

REFERENCES

[1] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, "Vehicular Networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," *IEEE Communications Surveys Tutorials*, vol. 13, no. 4, pp. 584–616, 2011.

[2] H. Hartenstein and K. Laberteaux, "A tutorial survey on vehicular ad-hoc networks," *IEEE Communications Magazine*, vol. 46, no. 6, pp. 164–171, 2008.

[3] Y. Liang, H. Liu, and D. Rajan, "Optimal placement and configuration of roadside units in vehicular networks," in *Proceedings of the IEEE Vehicular Technology Conference - Spring*, 2012, pp. 1–6.

[4] T.-J. Wu, W. Liao, and C.-J. Chang, "A cost-effective strategy for road-side unit placement in vehicular networks," *IEEE Transactions on Communications*, vol. 60, no. 8, pp. 2295–2303, 2012.

[5] A. Muhtar, B. Qazi, S. Bhattacharya, and J. Elmirghani, "Greening vehicular networks with standalone wind powered RSUs: A performance case study," in *Proceedings of the IEEE International Conference on Communications*, 2013, pp. 4437–4442.

[6] S. Mostofi, A. Hammad, T. Todd, and G. Karakostas, "On/off sleep scheduling in energy efficient vehicular roadside infrastructure," in *Proceedings of the IEEE International Conference on Communications*, 2013, pp. 6266–6271.

[7] S.-I. Sou, "A power-saving model for roadside unit deployment in vehicular networks," *IEEE Communications Letters*, vol. 14, no. 7, pp. 623–625, 2010.

[8] Q. Feng, K. Hwang, and Y. Dai, "Rainbow product ranking for upgrading e-commerce," *IEEE Internet Computing*, vol. 13, no. 5, pp. 72–80, 2009.

[9] J. Ott and D. Kutscher, "Drive-thru Internet: IEEE 802.11b for "automobile" users," in *Proceedings of Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies (INFOCOM 2004)*, vol. 1, 2004, pp. 362–373.

[10] J. Eriksson, H. Balakrishnan, and S. Madden, "Cabernet: Vehicular content delivery using wifi," in *Proceedings of the 14th ACM International Conference on Mobile Computing and Networking (MobiCom '08)*, 2008, pp. 199–210.

[11] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in *Proceedings of the IEEE Vehicular Technology Conference - Spring*, 2008, pp. 2036–2040.

[12] "IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments," *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, pp. 1–51, 2010.

[13] A. Abdrabou and W. Zhuang, "Probabilistic delay control and road side unit placement for vehicular ad hoc networks with disrupted connectivity," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 1, pp. 129–139, 2011.

[14] F. Malandrino, C. Casetti, C. Chiasserini, and M. Fiore, "Content downloading in vehicular networks: What really matters," in *Proceedings of the IEEE INFOCOM*, 2011, pp. 426–430.

[15] A. Kchiche and F. Kamoun, "Centrality-based access-points deployment for vehicular networks," in *Proceedings of the IEEE International Conference on Telecommunications*, 2010, pp. 700–706.

[16] T. Todd, A. Sayegh, M. Smadi, and D. Zhao, "The need for access point power saving in solar powered WLAN mesh networks," *IEEE Network*, vol. 22, no. 3, pp. 4–10, 2008.

[17] C. E. Palazzi, M. Roccetti, and S. Ferretti, "An intervehicular communication architecture for safety and entertainment," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 1, pp. 90–99, 2010.

[18] K. Klamroth and M. M. Wiecek, "Dynamic programming approaches to the multiple criteria knapsack problem," *Naval Research Logistics*, pp. 57–76, 2000.

[19] L. Breslau, D. Estrin, K. Fall, S. Floyd, J. Heidemann, A. Helmy, P. Huang, S. McCanne, K. Varadhan, Y. Xu, and H. Yu, "Advances in network simulation," *Computer*, vol. 33, no. 5, pp. 59–67, 2000.

[20] Q. Chen, F. Schmidt-Eisenlohr, D. Jiang, M. Torrent-Moreno, L. Delgrossi, and H. Hartenstein, "Overhaul of IEEE 802.11 modeling and simulation in ns-2," in *Proceedings of the 10th ACM Symposium on Modeling, Analysis, and Simulation of Wireless and Mobile Systems*, 2007, pp. 159–168.

[21] N. R. E. Laboratory, "A performance calculator for grid-connected PV systems," http://rredc.nrel.gov/solar/calculators/pvwatts/version1, accessed: 2014-01-11.

[22] J. Webster, W.H. and N. P. Yao, "Progress and forecast in electric vehicle batteries," in *IEEE Vehicular Technology Conference*, vol. 30, 1980, pp. 221–227.

[23] S. Chiaravallot, F. , Idzikowski, and L. Budzisz, "Power consumption of WLAN network elements," http://www.tkn.tu-berlin.de/fileadmin/fg112/Papers/TR-WLAN-Power.pdf, accessed: 2014-01-11.

[24] M. Boban, O. Tonguz, and J. Barros, “Unicast communication in vehicular ad hoc networks: A reality check,” *IEEE Communications Letters*, vol. 13, no. 12, pp. 995–997, 2009.

[25] Y. P. Fallah, “Networking vehicles for safety: Embedding cyber networks in physical networks,” *ACM XRDS*, vol. 20, no. 3, pp. 52–58, 2014.