

Efficient Scheduling for VANET Considering Renewable Energy

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Abstract—The realization of intelligent transportation systems requires the use of specific networks such as Vehicular Ad Hoc Networks (VANETs). VANETs are used to connect vehicles with each other and with fixed infrastructure Road Side Units (RSUs). In powering the RSUs, renewable energy is a great alternative to conventional electric grid. This paper proposes an efficient scheduling algorithm for serving vehicles in a green vehicular network with the aim to maximize the number of served vehicles while maintaining a sustainable energy level. We define and compute four metrics, for each vehicle, of a substantial impact on both the quality of service (QoS) and the power to be consumed. The proposed scheme outperforms other scheduler in terms of the percentage of served vehicles under different arrival rates, various values of average vehicle velocities, variable data size and varying the amount of harvested energy.

Index Terms—VANET, scheduling, renewable energy.

I. INTRODUCTION

The integration of wireless communication devices into a transportation infrastructure enables passengers to benefit from various wireless services and to commute safely on road. To make the operation of transportation systems more intelligent, we need to incorporate a fully connected vehicular network in such a way to regulate vehicular traffic and to provide in-vehicle entertainment services. Vehicular Ad Hoc Networks (VANETs) have drawn increasing attention in both industry and research for its capability to achieve this goal. Vehicles in VANETs can communicate in two ways, either Vehicle-to-vehicle (V2V) via On-Board Units (OBU) or Vehicle-to-Infrastructure (V2I), or a combination of the both modes of communications, as shown in Fig. 1. V2I communication can be used to connect vehicles to broadband networks through fixed infrastructure Road Side Units (RSUs) deployed along the roadway, which serve as gateways to enable various entertainment services. In addition, they disseminate real-time information gathered from passing vehicles to enhance the road safety [1], [2].

Setting up such an infrastructure alongside a road for operation requires either the use of wired electrical power, which can be expensive or even unavailable especially in rural areas, or the use of sustainable power source such as solar energy. Due to the high cost resulting from powering RSUs with electrical grid, green energy sources have become a good alternative. Since the energy available for RSUs is limited, we need to optimize our use of this energy in such a way that extends their lifetime as well as achieves acceptable quality-of-

service (QoS). Hence, the design of energy-efficient scheduling algorithms for RSUs is very crucial in order for their sustainable operation. Various scheduling algorithms have been proposed to enhance the performance of VANETs, however, few of them were concerned with the use of renewable energy powered RSUs [3].

Recent research studies focus on presenting scheduling algorithms that can minimize RSUs deployment and operation cost. For instance, the authors in [4] proposed an RSU placement strategy to minimize the total energy consumption where RSUs are powered by both electric grid and solar power. Also, they proposed a sleep scheduling scheme which specifies the RSUs needed to be active. In the same context, the authors in [5] aimed to reduce the power consumption of RSUs by studying the ON/OFF sleep cycles of each RSU and formulated it as a scheduling problem. Adnan et al. [6] investigated the performance of wind-powered RSUs on the QoS for video-related applications with the introduction of RSU sleep cycles. In [7], the authors investigated the downlink communication for the purpose of minimizing energy cost of transmission. Specifically, they considered a low-complexity time slot assignment and balancing the energy cost load across multiple RSUs. Also, Wassim et al. [8] studied the downlink V2I communication with the use of green energy to power RSUs. They addressed both offline and online scenarios where their objective was to maximize the number of served vehicles under certain constraints.

In this paper we concern with downlink communication in V2I mode. We propose an energy-efficient scheduling algorithm to ensure an optimal performance for VANETs. In addition, we address the variation in both the required data size and the time instant to request these data. Online scenario is considered in our model where an RSU has no prior knowledge of vehicular inputs. We assume a distributed approach where each RSU operates independently without information exchange between each other. The RSU is only powered by batteries recharged from renewable energy sources such as solar energy. We aim to balance between maximizing the percentage of served vehicles and maintaining a stable level of energy consumption ensuring sustainable energy level for the RSU.

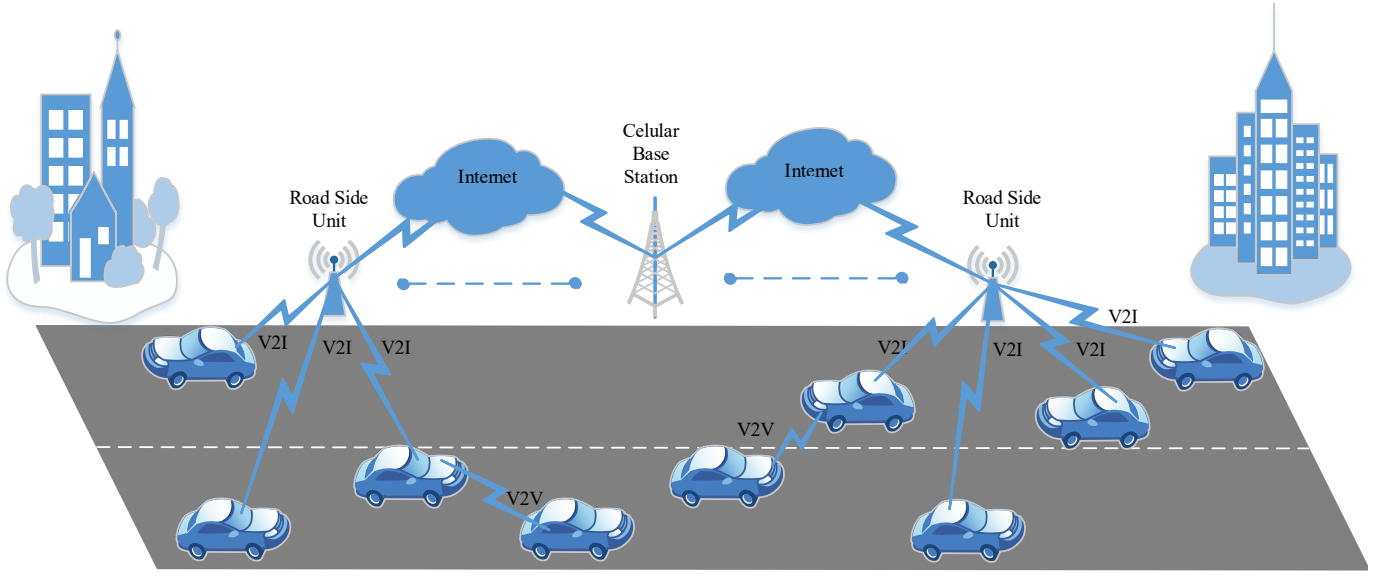


Fig. 1: VANET architecture.

II. SYSTEM MODEL

We consider an RSU to serve passing vehicles in a fixed, one-way segment as shown in Fig. 2. Although the figure shows vehicles move in a single direction, the proposed algorithm can be applied to bidirectional highway and can be extended to use multiple RSUs. The reason we consider only one RSU is because we concern with the distributed on-line scenario, where there is no communication among RSUs, and each RSU has no prior knowledge neither of the energy to be harvested nor the future vehicular inputs. The arrival of vehicles to the considered segment follows a Poisson distribution with parameter λ . Each vehicle arrives with a random speed following a truncated normal distribution between $[V_{min}; V_{max}]$, and it is assumed to maintain a fixed velocity throughout the road segment. The required data size of an arriving vehicle is uniformly distributed random variable between $[H_{min}; H_{max}]$, and it is assumed to be requested at any random position across the roadway. Harvested energy $h(t)$ is used to power the RSU at time t and it follows a uniform distribution in the range between $[0, h_{max}]$. The RSU is equipped with a battery of capacity k to store the harvested energy. We denote $S(t)$ the energy state of the RSU at time t .

We consider only the downlink communication (i.e., RSU-to-vehicle direction) between the RSU and the vehicles using only a single channel. We assume that time is divided into equal time slots of length τ . Each time slot is assigned to a vehicle by the RSU for communication at a constant data rate regardless of the vehicle's position. Accordingly, the power control is applied to RSU-to-vehicle link. As soon as any vehicle arrives, it sends its current position and speed information to the RSU. Based on each vehicle's position, the communication energy cost can be estimated. Consequently, the RSU assigns the time slots to each vehicle in such a way that optimize its energy consumption. Let $E(i, t)$ be the energy consumption for the communication between the RSU and a vehicle i at time t

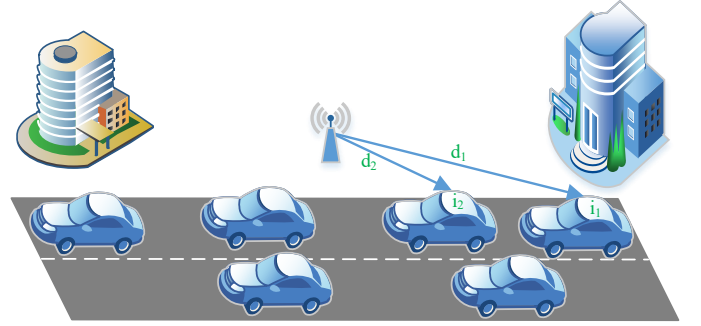


Fig. 2: System Model.

following a simplified path loss model [9], and is given by:

$$E(i, t) = P_{tx}(t) \tau = \frac{P_{rx}(i, t) \tau}{P_0 \left[\frac{d_0}{d(i, t)} \right]^\gamma} = \frac{N(2^{\frac{D}{B}} - 1) \tau}{P_0 \left[\frac{d_0}{d(i, t)} \right]^\gamma}, \quad (1)$$

where $P_{tx}(t)$ is the transmit power of the RSU at time slot t ; $P_{rx}(i, t)$ is the received power of vehicle i ; d_0 is a reference distance; P_0 is the path loss at the reference distance; $d(i, t)$ is the distance between the RSU and vehicle i at time slot t ; γ is the path loss exponent; N is the noise power; B is the bandwidth of the channel; and D is the data rate.

III. PROPOSED ALGORITHM

Our strategy in scheduling is based on choosing the most important metrics that affect on both power consumption of the RSU and the percentage of served vehicles. The first metric is the speed (M_{sd}), as a vehicle's speed increases the more weight it takes. Since fast vehicles last a shorter period of time within the coverage area compared to slow vehicles, it is expected that serving fast vehicles first would result in better throughput. The second metric is the distance (M_{dis}), when the distance between the RSU and vehicle i increases, it takes less weight. While

Algorithm 1: Metric Based Algorithm

Input: Vehicle arrival parameter, λ , and the set of time slots, $\{1, 2, \dots, T\}$

Output: The chosen vehicle to be served i_M

Data: The size of data is random and vehicles can request it at any random position within the coverage area

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1 for  $t \in \{1, 2, \dots, T\}$  do
2   Obtain the metric,  $M(i_u, t)$ , where  $i_u \in \{1, 2, \dots, U\}$ ,
   the vehicles with unsatisfied requirements at time  $t$ ,
   using Eqn.2 and Eqn.3.
3   Sort the obtained metrics into an ordered set
    $M_s = \{M_1(\hat{i}_1, t), \dots, M_U(\hat{i}_U, t)\}$  such that
    $M_{U-1}(\hat{i}_{U-1}, t) > M_U(\hat{i}_U, t)$ , where  $\hat{i}_k$  is the vehicle
   with  $k$ -th highest metric value.
   // Find the energy to be consumed,  $E$ , for each
   vehicle in  $I_u$  following the same order in  $M_s$ , using
   Eqn.1
4   Obtain the energy  $E$ 
5   for  $k \in \{1, 2, \dots, U\}$  do
6     if  $E(\hat{i}_k, t) < S(t)$  then
7        $i_M \leftarrow \hat{i}_k$ 
8        $S(t) \leftarrow S(t) + h(t) - E(i_M, t)$ 
9       break;

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the RSU communicates with each vehicle, it conducts power control to guarantee a fixed data rate at each vehicle. Hence, as we see in Fig. 2, the energy needed to serve the vehicle i_1 at distance d_1 is much greater than the required energy for vehicle i_2 at d_2 to be served. The third metric is the size of required data of each vehicle (M_{data}). When the requested data size increases, more time slots are needed to satisfy the vehicle requirement, and hence more power is required in order to fully serve this vehicle. Accordingly, we can conclude that if the data size of any vehicle increases, it will takes less weight. Finally, we take into consideration a vehicle's sojourn time (M_{time}), which means how much time the vehicle will reside in the RSU coverage area. A vehicle i takes less weight when its sojourn time within the coverage area increases. Vehicles with less sojourn time will leave the RSU area sooner than others. Hence, they need to be served promptly in order to increase the throughput. All of these metrics are normalized to be between 0 and 1 using the following equation then we add them together:

$$Normalized\ Metric = \frac{x_i - \min(x)}{\max(x) - \min(x)} \quad (2)$$

$$Total\ Metric = A \cdot M_{sd} + B \cdot M_{dis} + C \cdot M_{data} + D \cdot M_{time}, \quad (3)$$

where the parameters A , B , C and D are used to adjust the previously mentioned metrics and to prioritize some metrics upon another. The value of these parameters giving the best performance are obtained through multiple simulations. The proposed algorithm takes vehicles arrival rate as well as the

number of time slots, T , as input. The algorithm chooses the vehicle to be served according to the steps detailed in Algorithm 1. The algorithm starts by finding the set of vehicles requesting a service at time t , we denote this set by $I_u = \{i_1, i_2, \dots, i_U\}$, where U is the total number of vehicles with unsatisfied requests at time t . Then, we calculate their metrics using Eqn. 2 and Eqn. 3. For instance, to calculate the speed metric (M_{sd}) of a vehicle i_u traveling with velocity of 20 m/s, we substitute for the value of x_i in Eqn. 2 by 20 m/s and the values of $\max(x)$ and $\min(x)$ become the values of V_{max} and V_{min} , respectively. After obtaining all the predefined metrics for each vehicle, Eqn. 3 is used to determine the total metrics set, M . Then, we store these metrics into an ordered set $M_s = \{M_1, \dots, M_U\}$ such that $M_{U-1} > M_U$. Moreover, we find the energy to be consumed, E , in order to serve each vehicle in I_u following the same order in M_s . The vehicle with the highest metric value is served first if the RSU can afford its energy cost. In case that the energy communication cost, $E(i_u, t)$, of the vehicle of the highest metric value at time t is bigger than the remaining energy $S(t)$, we skip scheduling this vehicle and check the vehicle with the second highest metric value and so on. Finally, the energy storage of the RSU, S , is updated by subtracting the value of energy used to communicate with vehicle i_M alleviated by the harvested energy $h(t)$.

IV. PERFORMANCE EVALUATION

In this section, the performance of the proposed algorithm is evaluated. The vehicular inputs to our scheduler are generated randomly following a Poisson process of $\lambda = 2$ Veh./sec. Each vehicle has a download request of size H_i bits, which is randomly generated following a uniform distribution between $H_{min} = 2$ MB and $H_{max} = 10$ MB and is requested at any random position within the coverage area. The performance is studied over 80 seconds with time slot duration $\tau = 0.1$ s. A simplified path loss model with a path loss exponent of $\gamma = 3$ is adopted to estimate the value of energy cost based on vehicle position. The RSU is equipped with a battery of capacity k of 2500 energy units and recharged from renewable energy source, and the harvested energy follows a uniform distribution in the range between 0 and 6 energy units. The simulation input parameters are shown in Table I. We compare our algorithm with another scheduling algorithm proposed in [8] named Threshold Based Scheduling (TBS) which selects the vehicle by comparing the estimated energy cost of a transmission with the expected harvested energy and can be thought of choosing the vehicle with the lowest power consumption.

Fig. 3 shows the impact of traffic density on the percentage of served vehicles. It is clear that the percentage of served vehicles decreases as more vehicles arrive in the RSU's coverage area under all scheduling algorithms. As the arrival rate increases the chance of serving a certain vehicle will decrease. Fig. 3 also shows that the proposed algorithm outperforms TBS in terms of the percentage of served vehicles by average improvement of 4.83 - 17 %. Under TBS, the selection is based on choosing the vehicle whose power consumption is minimum so the RSU tends to choose the nearby vehicle first which lets some

TABLE I: Simulation Input Parameters

Parameter	Value
RSU Battery Capacity	2500 UE
RSU coverage area	400 m
Data rate (D)	1 Mbps
Channel bandwidth (B)	10 MHz
Simulation time	80 s
Time slot length (τ)	0.1 s
Vehicular arrival rate λ	2 Veh./sec
Min and Max vehicle speed [$V_{min}; V_{max}$]	[15; 35] m/s
Min and Max request size [$H_{min}; H_{max}$]	[2; 10] MB
Maximum harvested energy (h_{max})	6 UE
Path loss exponent (γ)	3
Reference distance (d_0)	1 m
Path loss at $d_0(P_0)$	1
Noise power at the receiver (N)	1 mW

of distant vehicles to depart the coverage area without being served.

Fig. 4 depicts the scheduling performance under different vehicles' average velocities. It is clear that as the average speed increases, the percentage of served vehicles decreases. As we have included the velocity metric in our scheme, our scheduling algorithm results in a superior performance in terms of served vehicles compared to TBS by average improvement of 5.27 - 12.28 %. When vehicles are moving at high speed, they will reside inside the RSU's communication range for a short time. Since we also have incorporated the time metric, our algorithm tends to choose the vehicles with high speed that will leave the coverage area first. As Fig. 4 shows, the proposed scheduling method does not be effected by high speed compared to TBS.

Fig. 5 plots the percentage of satisfied vehicles versus the average request data size. As the average request data size increases, the percentage of vehicles departing from RSU's coverage area being served decreases. Similar to the reasoning of Fig. 3, the proposed algorithm outperforms TBS in terms of average request size by average improvement of 4 - 14.6 %.

Fig. 6 studies the effect of increasing the amount of harvested energy on the percentage of served vehicles. Note that increasing the harvested energy dramatically increase the performance of the proposed scheme. Since the metrics of the proposed scheme tend to serve departing vehicles at far distance first, the proposed algorithm may lose some extra amount of energy compared to TBS. Hence, as we increase the harvested energy even by small amount, the proposed metrics tend to satisfy more vehicles and significantly increase the percentage of served vehicles by average improvement of up to 11.34 %.

V. CONCLUSION

In this paper, we developed an efficient scheduling algorithm to support the operation of a vehicular network. Our objective was to increase the percentage of served vehicles while

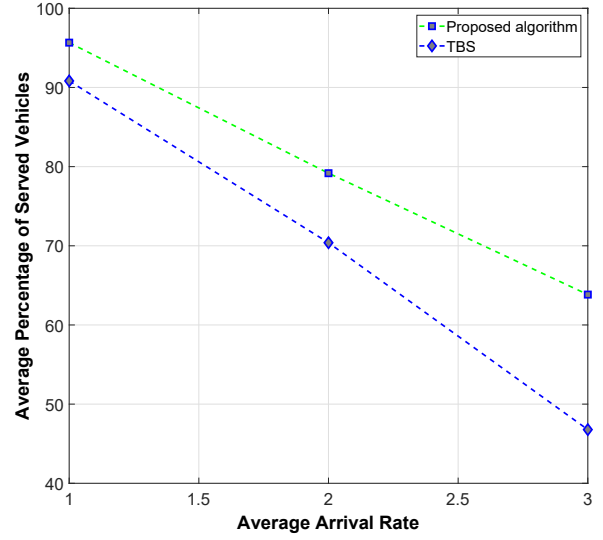


Fig. 3: Impact of Traffic density on the percentage of served vehicles.

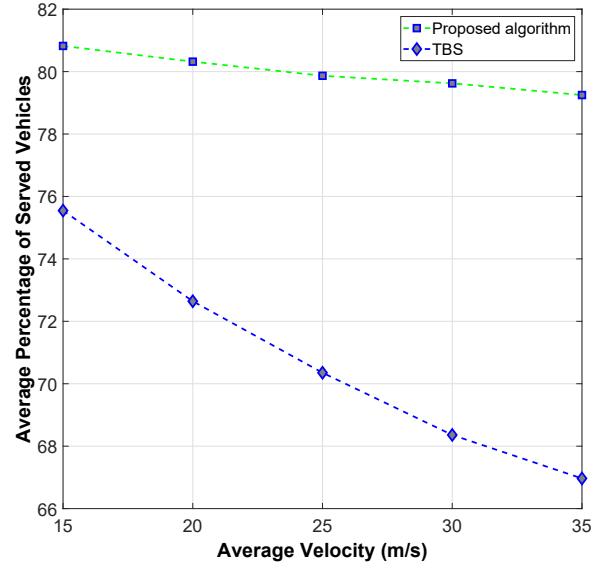


Fig. 4: Average velocity vs served vehicles.

maintaining a sustainable energy level. The idea behind our proposed algorithm is based on determining some metrics with a significant impact on both the quality of service and the power to be consumed. We defined and computed four metrics, for each vehicle, namely M_{sd} , M_{dis} , M_{data} and M_{time} . Then, we combined them together in one metric while prioritizing some metrics upon another. We evaluated and compared the performance of our proposed scheme with other scheduling algorithm. The proposed metrics outperformed the other scheduler in terms of the percentage of served vehicles under different arrival rates, various values of average vehicle velocities, variable data size and varying the amount of harvested energy.

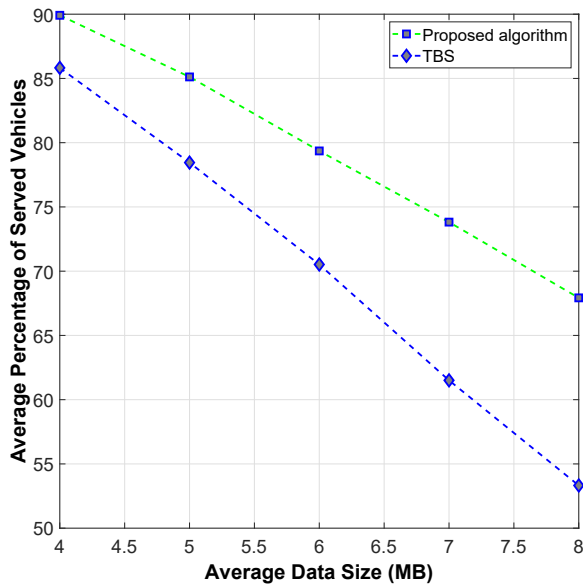


Fig. 5: The impact of data size on vehicles service.

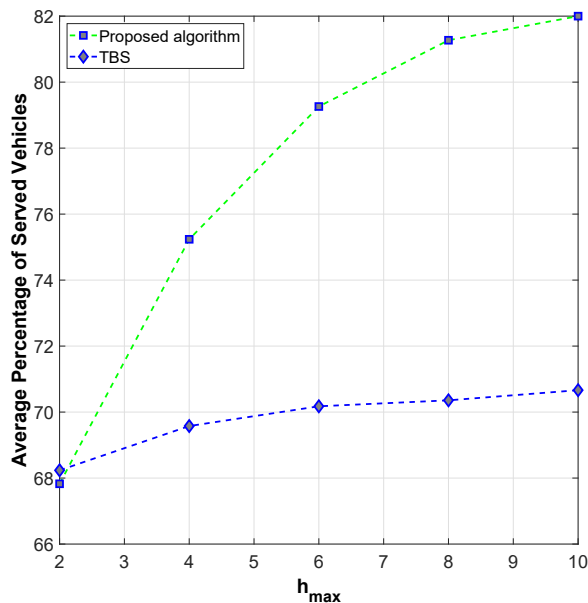


Fig. 6: Performance evaluation with the varying amount of harvested energy.

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current research interests are in the areas of wireless sensor networks, mobile networks, and vehicular ad hoc networks.



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