Optimizing the Power Utilization of Road Side Units in Vehicular Ad Hoc Network

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ABSTRACT

A Vehicular Ad Hoc network is a subclass of Mobile Ad hoc Networks, to provide communication among vehicles and nearby road side units (RSUs). The main goal of VANET is providing safety and comfort for passengers. In this paper, two metrics to measure the connectivity and power requirement of RSUs in VANET have been proposed for power utilization of RSUs in VANET. Based on the metrics two methods for efficient power saving in RSUs have also been proposed and tested experimentally in a simulated network.

Keywords

VANET, RSU, MANET

1. INTRODUCTION

A Vehicular Ad Hoc Network is a subclass of Mobile Ad Hoc Networks, to provide communication among vehicles and nearby RSUs. As GPS and navigation systems are becoming standard equipment in vehicles, it has been assumed that every car can obtain its current location as vehicles are installed with a pre-loaded digital map[1,5]. Navigation system describe the land attributes such as road topology, traffic lights and traffic statistics such as traffic density and average velocity at a certain time of the day. Wi-Fi enabled vehicles are expected to be on the road within the next 3-5 years[2]. Each vehicle equipped with VANET device will be a node in the Ad-hoc network and can receive & relay other messages through the wireless network. Accident warning, Road signal alarms (like left turn, right turn, Zigzag left or right etc.) and traffic view will give the driver essential data [12] to decide the best path along the way. With the increase of vehicles on roads in the recent years, driving becomes more challenging and dangerous.

Safety distance and reasonable speeds are hardly respected [12]. The leading car manufacturer decided to jointly work with Government agencies to develop solution aimed at helping drivers on the roads by anticipating dangerous events or bad traffic areas. One of the outcomes has been a novel type of wireless access called wireless access for vehicular environment (WAVE) used for vehicle to vehicle and vehicle to road-side communication.

Unlike other ad-hoc networks (e.g. sensor networks or MANET), VANET has its own unique characteristics. The most important among them is the rapidly and dynamically changing topology which leads to frequent communication disconnections between vehicles [4]. The mobility of nodes in VANET cannot be simply expressed by traditional models because the driving behavior of each vehicle can be affected by many factors including speed limit, neighboring vehicles, traffic lights and even pedestrians crossing the road [3]. The frequent network disconnection problem is the most important issue in designing VANET[7]. Another problem is the uneven deployment of vehicles on the roads, which makes route selection more complex. Due to the blocking of wireless signal by objects such as big building in the city, communication between vehicles must have line-of-sight in addition to being in range of one another[10].

However, safety applications cannot work properly in disconnected VANETs [12]. To reduce the disconnection problem it is proposed to deploy a number of low cost RSUs along the roads. In near future, thousands of RSUs can be deployed on road sections of urban and rural areas. RSUs require power to operate. A huge amount of power is consumed by these RSUs. RSUs may operate in two modes. They are active mode and passive mode. Active mode requires more power compared to passive mode. This paper deals with how to save power provided to the RSUs.

Consider that there are ‘N’ RSUs deployed in a road section of ‘R’ kms. Among these RSUs, ‘N_{act}’ RSUs are in the active mode while ‘$N - N_{act}$’ RSUs are in the passive mode. ‘N_{act}’ may be a controlled dynamically based on the traffic density of the road section. If ‘$N = N_{act}$’ then all the RSUs are in the active mode and provide maximum connectivity to the vehicles in the road sections ‘RS’ but consumes more power. If $N_{act} = 0$, then all the RSUs are in the passive mode and consumes less power but provide less connectivity to the vehicles in the road section. This paper proposes how to choose an optimal number, ‘N_{act}’ of active RSUs such that it maximizes the power consumed by the RSUs and provide connectivity to the vehicles in the road sections. For this purpose two indices namely Connectivity index C(R) to measure the network connectivity and Power Save index PS(R) to measure power saving have been proposed.

The remainder of this paper is organized as follows. Section II describes the properties and characteristics of vehicular ad hoc networks. Then study of network connectivity in VANETs is described in Section III. In Section IV and V, power saving model for RSUs in VANETs and simulation results are presented respectively. Section VI gives the conclusion.

2. VEHICULAR AD HOC NETWORKS

Vehicular ad hoc networks have been predicted to be useful in driver-safety and many commercial applications. For example, a vehicular network can be used to alert drivers to traffic accidents, potential traffic jams, road condition and much more providing increased convenience and efficiency. It can also be used to propagate emergency warning to drivers of preceding vehicles in case of any accident to avoid multi-car collisions on highways[14]. Considering all these applications FCC has allocated 75 MHz in 5.9 GHz [6, 12, 13] band for dedicated short range communications (vehicle-vehicle or vehicle-RSU) and IEEE is working on standard specifications for inter vehicle communication. VANETs are different than MANETs in many ways. For example Instead of random movement in MANETs, the movement of nodes in VANETs is constrained by the layout of roads. Normally radio range for VANETs is several hundred meters, typically between 250 and 300 meters. In a scenario when there are no radio obstacles, the nodes can communicate with others in the radio range. But in city environment, there would be radio obstacles because of tall buildings. Another difference is that in VANETs vehicles move with much greater speeds as compared to MANETs [9] therefore the topology in VANETs changes much more frequently. But on the other hand the vehicles mobility can be predicted based on the speed and direction as well as the layout of roads. The RSUs are installed along the road-side and consists of infrastructure that can connect the nearby vehicles. It is a challenging job where to keep these RSUs [1].

3. STUDY OF NETWORK CONNECTIVITY

3.1 Traffic Pattern

The traffic pattern can be grouped into four categories [12]:

1. Morning Rush Hour traffic (8.00 a.m. - 11 a.m.): During this time period, people come from their home to their workplace and hence it is more congested. In this time traffic density λ is approximately equal to 0.7 vehicle/meter. Hence, network connectivity between vehicles is very high.
2. Lunch Time traffic (11 a.m. - 2 p.m.): During this time period, it is observed that moderate traffic due to few persons go to their home for lunch. In this time traffic density λ is approximately equal to 0.025 vehicle/meter. Hence, network connectivity between vehicles is moderate.
3. Evening Rush Hour traffic (3 p.m. - 8 p.m.): The traffic in this time period is similar to that observed during the morning rush hours as people go back to their home. Hence, network connectivity between vehicles is very high. In this time traffic density λ is approximately equal to 0.7 vehicle/meter
4. Midnight traffic (11.30 p.m. - 4 a.m.): The traffic volume in this period is very low. Hence, network connectivity between vehicles is very low. In this time traffic density λ is approximately equal to 0.004 vehicle/meter

3.2 Derivation of Connectivity Index C(R)

In this paper, the distribution of the inter-vehicle spacing follows an exponential distribution. The validity of this assumption has been confirmed by the empirical measurements reported in [1]. Under this assumption, the overall number of vehicles in the road section can be determined by the traffic density λ.

The probability C(R) that all vehicles and RSUs located in an R km road section are fully connected. This index is used to measure network connectivity among the vehicles which are located in the road section.

The derivation of C(R) is described as follows: Consider a RSU device deployed at each end of a road section ‘RS’. Let ‘P(RS)’ be the probability that all vehicles located in the road section ‘RS’ are fully connected with the RSUs. Consider the VANET scenario illustrated in Figure 1, where ‘R’ kms road-section is divided into ‘m' sub sections by RSUs ‘U_1, U_2 … U_m’. The distance between any two RSUs are of same length and equal to ‘D’. The probability of connectivity index ‘C(R)’ can be computed by:

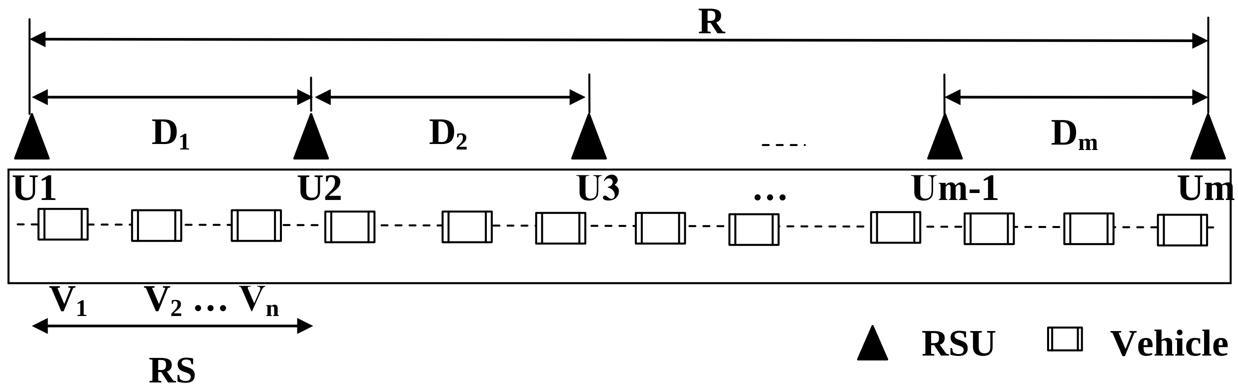

Figure 1: A road segment scenario of VANET

$$C(R) = [P(RS)]^m \quad (1)$$

Where, m = R/D

A fully connected network is formed in all subsections. Consider that there are N(RS) = n, vehicles located on the road section RS sequentially. The number of vehicles follows Poisson distribution [1], where,

$$\Pr[N(RS)=n]=\frac{e^{\lambda RS}(\lambda RS)^n}{n!} \qquad (2)$$

Where, 'λ' is the traffic density

In Figure 1, 'n' vehicles, denoted by '$V_1 \ldots V_n$' are located in a road section 'RS'. RSUs 'U1' and 'U2' are located at both ends of the road section RS. Then probability of all vehicles that are connected in the road section is Poisson distribution of 'n' vehicles located in the road section 'RS':

$$P(RS)=\Pr[N(RS)=n,\forall n]$$

$$=\frac{e^{\lambda RS}.(\lambda RS)^n}{n!}$$

By combining (1) and (2),

$$C(R)=\left[\frac{e^{\lambda RS}.(\lambda RS)^n}{n!}\right]^m \qquad (3)$$

With Eq. (3), the connectivity index 'C(R)' derived in Eq. (1) can be easily obtained in linear time. The Time Complexity of this problem is 'O(nm)'.

4. THE POWER SAVING MODEL

Based on the above analytic results (Eq.1 & Eq. 3), it is easy to compute the minimal value for 'N_{act}' subject to the network connectivity constraints C(R) ≥ p, where 'p' is determined by the Ministry of transportation [1]. Inter RSU distance RS = [N/(N_{act}*m)], can produce the required connectivity of the road section 'RS'.

In this paper, two methods for power saving have been proposed. They are

1. Probabilistic Method
2. Traffic Density Method

4.1 The Probabilistic Method

The Probabilistic Method works under a distributed manner. Each RSUs executes the following steps:

Step 1: Compute the Minimum value of 'N_{act}' Subject to the network connectivity constraints, C(R) ≥ p.

Step 2: Generate Uniform random number 'x' in the range from 0 to 1.

if x ≤ N_{act}/N

Stays in the active mode and go step 1

when traffic density 'λ' value is changed.

else

Switch to Passive mode for a time

period 'T'

end if

Step 3: After a time period 'T', when a new value traffic density 'λ' is obtained go to the step 1.

The time period 'T' is determined by the ministry of transportation.

4.2 Traffic Density Method

Traffic Density method the following algorithm is used for power saving:

Step 1 : If traffic density, λ = 0.004

all the RSUs are set in active mode

end if

Step 2 : if traffic density, λ = 0.025

alternate RSUs are set in active mode

end if

Step 3 : if traffic density, λ = 0.07

all the RSUs are set in passive node

end if

The above said algorithm works well for the power saving of RSUs without affecting the network connectivity of the VANETs. The power saving index of a road segment 'RS' is expressed using the following formula using another metric power saving index PS(R):

$$PS(R)=\frac{N-N_{act}}{N} \qquad (4)$$

If the traffic density λ = 0.004 then it is Midnight traffic. In this time all the RSUs are set in the active mode and the power save mode is disabled i.e., (N-N_{act})/N= 0. If the traffic density λ = 0.025 then it is Lunch Time Traffic. In this time alternate RSUs are set in the active mode i.e., (N-N_{act})/N = 0.5. Otherwise traffic density λ = 0.07 then it is Rush Hour Time Traffic. In this time all the RSUs are set in the passive mode and save the power fully i.e. (N-N_{act})/N = 1.

5. SIMULATION AND RESULTS

The simulation has been carried out in the Monte-Carlo Simulator. Each data point on the charts shown in the figure 2 and figure 3 is an average of 100 samples of such cases. It has been considered that the VANET topology is of 5 km(R) road section. 120 RSUs are deployed on the road section of equal distance. The transmission range of RSUs is set to 250 meter as per the FCC regulations [6].

5.1 Effects of Connectivity Index on ‘N’:

Figure 2 plots the connectivity index ‘C(R)’ against the number ‘N’ of RSUs deployed in the road section ‘R’. If all

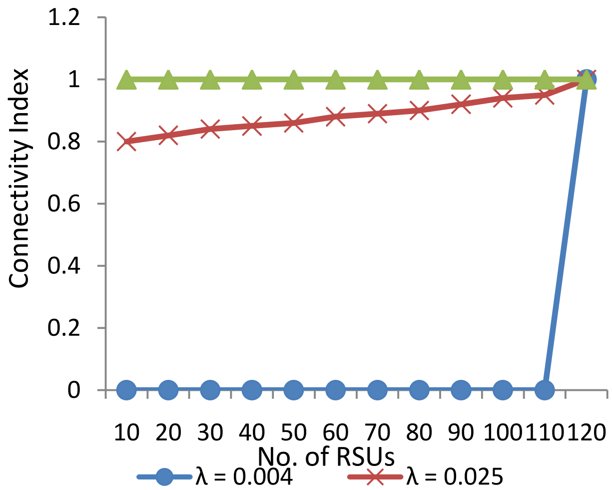

Figure 2: The connectivity index for R = 5 km in three different traffic density

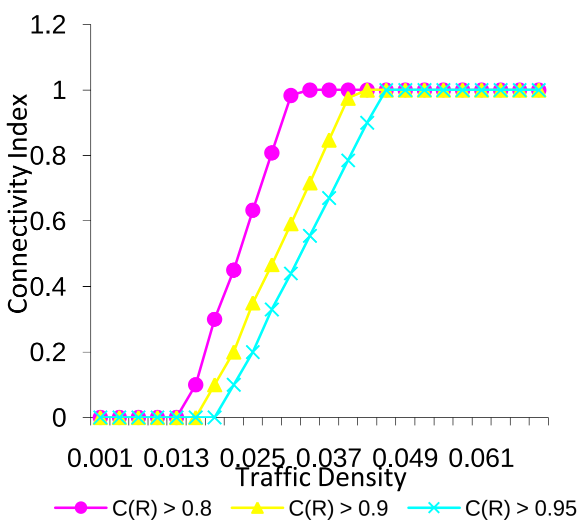

Figure 3: The power saving index for R = 5 km in different traffic density

the ‘N’ RSUs are in the active mode then power saving model is not applied. Figure 2 shows the connectivity index fir three different traffic scenario: (1) midnight traffic (λ=0.004); (2) Lunch time traffic (λ=0.025); (3) Rush Hour Traffic (λ=0.07); No RSU is in active mode during the rush hour traffic while all the RSUs are set in active mode in the midnight traffic. In Lunch time traffic, the connectivity index gradually increases from 10 to 120 RSUs. It is proved that the number of RSUs in operation should be dynamically adjusted according to the current traffic density ‘λ’.

5.2 Effects of Power Saving Index on ‘λ’:

Based on the Traffic Density Method ‘PS(R)’ described in Section IV, Figure 3 plots the power saving index PS(R) = (N – N_{act}) / N against the traffic density ‘λ’ observed on the road. Based on the empirical data measured using Eqn. (3), the traffic density ranges from 0.001 to 0.1 vehicles/meter. The experimental results show that as the traffic density increases the power saving index also increases.

Figure 4: A picture of RSU unit

In reality, an efficient power saving model should be utilized especially when the traffic is dense. However, dynamic traffic statistics is still needed so that online statistics report can be delivered to all the RSUs (Each RSU has its own memory). This can be done by traffic flow monitoring. Based on the traffic density statistics, the RSUs can be easily switched between active mode and passive mode.

6. CONCLUSION

This paper proposes two different metrics namely Connectivity index C(R) and Power Saving index PS(R) for improving the connectivity and power saving efficiency of RSUs in VANETs. Two methods for the power saving model have been proposed and the experiments were carried out using the Monte Carlo simulator. The experiments prove that, these proposed metrics provide useful insights to the estimation of power requirements of the RSUs in VANET.

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