Efficient Selection of Relay Vehicle for Accident Reporting in VANETs

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Abstract - Vehicular ad hoc networks (VANETs) offer a promising technology to promote traffic safety by providing real-time communications in the form of vehicle-to-vehicle and vehicle-to-infrastructure communications. Roadside units (RSUs) play an important role in the dissemination of warning messages that used in VANETs' safety-related applications. However, due to the expense of deploying and maintaining RSUs, they cannot be deployed in large enough quantities as to provide universal coverage. This, above all, leads to situations where communications cannot be routed from a vehicle to the nearest RSU. In this study, an efficient scheme for finding the best relay vehicle is proposed to mechanically route a safety-related message from a disabled vehicle to a RSU. To accomplish this goal, we utilize vehicle destination information obtained from GPS or navigation systems. In addition, an algorithm is proposed to efficiently perform this operation. Simulation results demonstrate that the proposed scheme outperforms alternate selection method.

I. Introduction

Traffic safety is a chief concern in today's world due the extraordinary number of accidents on the roads. The number of vehicles on the roads of the world is continually increasing and despite increased safety regulations and vehicle enhancements, the number of accidents continues to increase as well.

Today, vehicular ad hoc networks (VANETs), one of the promising applications of mobile ad hoc networks (MANETs), have drawn the attention of both industry and academia as a promising technology to address this issue which has brought serious consequences to our society. The utilization of this technology in Intelligent Transportation Systems (ITS) has been envisioned to prominently enhance the road safety, efficiency and services through real-time communications in the form of Vehicle-to-Vehicle (V2V) and/or Vehicle-to-Infrastructure (V2I) communications. This enables vehicles to send and receive hazard warnings or information on the current traffic condition. To accomplish this goal, federal communications commission (FCC) has allocated 75 MHz of spectrum in the 5.9 GHz band for dedicated short range communication (DSRC). The DSRC spectrum is structured into 7 channels each of which is 10 MHz wide. One channel is restricted to safety communications while two other channels are reserved for different purposes. All the restricted channels are service channels that might be utilized for either safety or non-safety applications.

VANETs mainly consists of two communication nodes, on-board units (OBUs) which are mounted on vehicles and provide them with V2V communication, and Roadside Units (RSUs) that are placed along the roadside and provide V2I communication. RSUs could be interconnected via wireless or wired in order to propagate messages in a timely fashion. The primary task in VANET safety applications is to obtain message of interest (e.g. traffic data) and disseminate it to all other vehicles in the network in order to shun traffic congestion, incidents, etc. Message dissemination in a timely manner is indeed a challenging task in vehicular environment due entirely to its dynamic nature and limited transmission range which increase the dissemination delay and thus, affects the quality of service (QoS) which is vital in time-critical applications. RSUs play a chief role to address this issue as their deployment in VANET provide a high-quality communication by avoiding intermittent connectivity. In addition, several works studied the advantages of deploying RSUs in terms of the re-healing time. Reis et al. [1] delineated that the deployment of RSUs remarkably reduced the re-healing time. However, deploying an ideal number of RSUs is not feasible at the initial stage of VANET vastly owing to the considerable cost of their placement and maintenance. Therefore, authorities incline to limit their number, making RSUs a precious resource in vehicular environment.

Deploying a limited number of RSUs increases the time propagation delay and affects the QoS provisioned to users which culminates in various consequences such as growth of car accidents, fuel consumption and so forth. Consequently, few works investigated the minimization of the average time taken for a vehicle to relay an event of interest to a nearby RSU by efficiently placing the RSUs within a road networks. However, there still lacks understanding of the effectiveness of VANET time-critical applications in various conditions such as where vehicles are sparsely distributed on the roads, or even when there is traffic congestions caused by accidents, rush hour, etc. Such conditions, above all, affect the movement of disseminators and make achieving satisfactory performance difficult for such applications.

Apart from the optimal placement of RSUs within the road networks, optimal selection of relay vehicles to report an incident to a nearby RSU is extremely crucial. As mentioned above, traffic condition affects the average reporting time: the time duration from occurrence of an incident till it is reported by a disseminator to an RSU. This motivates us to study an optimal selection of a disseminator through which the overall performance of the dissemination of post-crash warning will be dramatically improved. The main contributions of this study are delineated as follow.

- We identify a real-world problem regarding information dissemination in VANETs with RSU coverage gaps.
- We Present a scheme for selecting the best relay vehicle and design an algorithm to accomplish this goal.
- Using various traffic scenarios, we assess and validate the performance of our proposed scheme

The remainder of the paper is organized as follows. Section II presents related works on RSU placement and techniques for minimizing transmission times in VANETs. In section III, we will define the specific problem that this study examines. In section IV, we present our system model, the roadways and the vehicles travelling on them. Section V, introduces our technique for choosing the best relay vehicle along with an algorithm for performing the process. In sections VI and VII, we demonstrate a brief analysis of the study and provide a conclusion with ideas for further work.

II. Related Work

RSUs have been envisioned to prominently enhance real-time connectivity, routing and transmission delay. Thus, efficient usage of RSUs is a critical design consideration for a realistic VANET scenario. To this end, several approaches have been studied to decrease the deployment and maintenance costs by reducing the number of RSUs on a road network. Authors in [2] formulated the RSUs deployment problem as an integer linear program (ILP) and advised a particular configuration for every individual access point to satisfy a certain coverage requirement. The authors, indeed, made a tradeoff between cost and network coverage. In addition to this study, authors in [3], modeled this issue as a maximum coverage with time threshold problem, and utilized a genetic algorithm in order to address the problem of covering the maximum number of vehicles on the road by using the minimum number of RSUs. Apart from the studies on optimal placement of RSUs to reduce the intermittent connectivity, where there is scarcity in the number of RSUs, various approaches have been studied to improve the communication among vehicles by taking advantage of V2V communication. This way, seamless connection could be established among V2I as long as there are enough number of vehicles on roads. However, such an assumption cannot be considered as practical in a realistic VANETs environments. The rational reason behind this, is related to the traffic conditions which could not be same at all times (e.g. late midnight). Yoo et al. [4] investigated V2V relay approaches through which vehicles may maintain real-time network connectivity in order to shun unstable connections. However, V2V relay is suffered from the system performance in terms of spectra efficiency.

Among the VANET applications, time-critical ones have the highest priority. Various works studied the improvement of reliability of vehicular communications by optimally placing the RSUs within a road networks. Authors in [5] proposed an optimized RSU placement for delay-sensitive application in VANETs. Besides deployment cost constraint, authors' objective was to find the optimal positions of RSUs while respecting the application delay constraint. Furthermore, Li et al. [6] distinctly and theoretically investigated the issue of delay bounded RSUs for wired and wireless. Most of the studies we referred to are assumed that RSUs are either connected to each other or to a backbone; thus, they present little insight into the communication quality of stand-alone RSUs. However, Reis et al. [1] provided insight into communication delay, considering both connected and disconnected RSUs, by developing an analytical model. In addition, Wang et al. [7] proposed a mathematical model to delineate the relationship between average delay for delivering messages and distance between two neighbor RSUs in highway scenario. Given delay requirements for highly time-critical applications in VANETs, authors validated the feasible distance between the RSUs using simulation results. Another study by [8] also addressed the optimal placement of RSUs along highways in order to minimize the average reporting time taken for a vehicle to report an event to the nearby RSU. As far as the number of RSUs is concerned, Abdrabou et al. [9] estimated the minimum number of RSUs that need to be deployed along a straight road network in order to guarantee a probabilistic connection time, the time that traffic data needs to be delivered by moving vehicles to the infrastructure

Most of the studies we referred to aim at minimizing the message reporting time which refers to the time takes a post-crash warning message to be delivered to the nearby RSU by vehicle(s). These studies proposed various approaches to optimally place the minimum number of RSUs on roads such that the message of interest receives to the RSU within a certain time. However, this work is novel in a way that its focus is on choosing the best possible way to optimally find the desiminator that reaches the nearby RSU in the shortest time.

III. Problem Statement

In this study, we have examined a very specific problem in the field of VANET. This problem is scenario where a vehicle is disabled but is not in the transmission range of the nearest RSU to report the incident, it must then relay that incident report to a third-party vehicle so that it can be relayed to an RSU. Figure 1 depicts such a problem in a highway scenario.

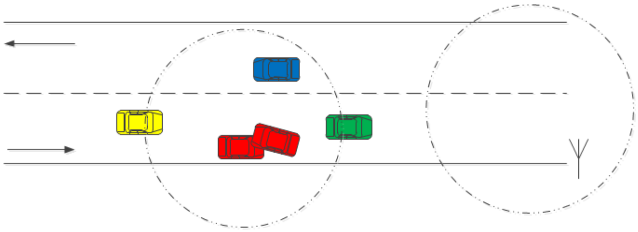

Fig. 1. Highway Scenario

This problem becomes more challenging in an urban environment where traffic patterns are not predictable. Indeed, in highways, vehicles can move in two directions and can only exit the highway at very specific points. In this situation, with the knowledge of RSU location and the velocity of the vehicles within the transmission range of the disabled vehicle, the optimal dissemination vehicle can be chosen with ease. In contrary, in an urban environment as shown in Figure 2, traffic patterns are much less predictable and RSU location is more dispersed. The naive solution would be to broadcast the accident report to all the vehicles within the transmission range of the disabled vehicles and task them all with relaying the report to the first RSU that they pass. This technique is undesirable for several reasons: it places a large burden on the network, it creates a large amount of congestion in the area of the accident and it burdens a large number of vehicles with a task that could be accomplished by less. In addition, there is no mechanism to guarantee that the message is delivered to the nearby RSU in a timely fashion.

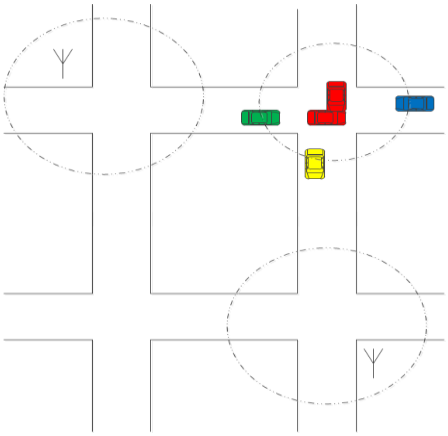

Fig. 2. Urban Scenario

Therefore, in this study, we propose an approach through which the best disseminator to relay the accident report in an urban environment is chosen. Optimally selecting the best disseminator, will lead to the minimization of the average reporting time taken for a vehicle to report an event to the nearby RSU. We assume all the vehicles are equipped with an OnBoard Unit (OBU) and GPS; thus, have knowledge of RSU location, vehicle velocity, and traffic information.

IV. System Model

We model the system in a similar fashion as other VANET related studies. A grid like network of roads and intersections, common in an urban environment, are represented as nodes and edges in a graph. Each edge has a length denoted by ΔX. The rate at which vehicles arrive at an edge is denoted as λ_{a} and the rate at which vehicles depart the edge is λ_{d}. It is assumed that all vehicles have access to this environmental information as well as current speed and a travel destination.

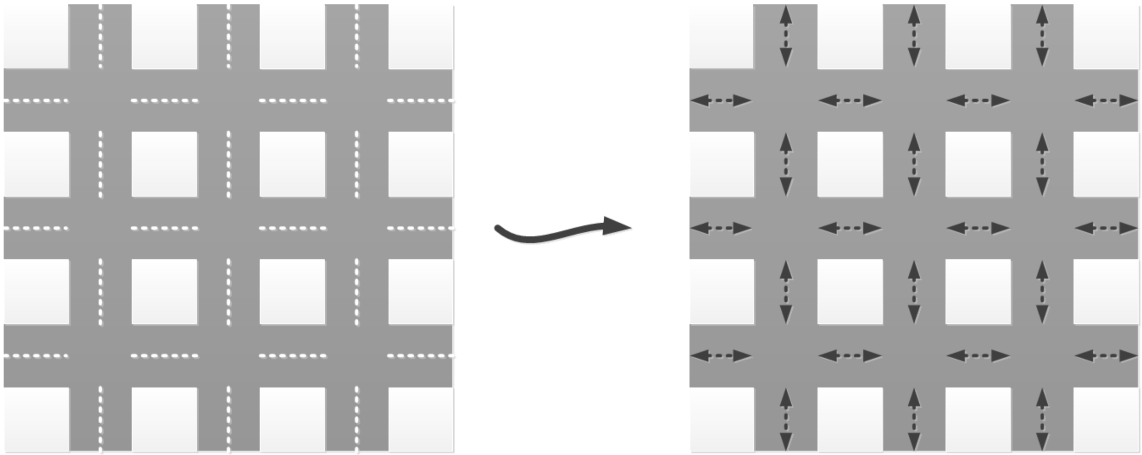

Fig. 3. Representation of Road System as Graph

Using the rates at which vehicles arrive and depart an edge, we can calculate an important metric called traffic intensity which is denoted by ρ.

$$\rho = \frac{\lambda_{\mathrm{a}}}{\lambda_{\mathrm{d}}}$$

Using an initial velocity and this traffic intensity we can calculate a vehicle's speed as it traverses a set of edges. The velocity at the departure point of an edge is equal to the velocity at the arrival point of an edge divided by the traffic intensity.

$$Vd = \frac{Va}{\rho} = Va = \frac{\lambda_{\mathrm{d}}}{\lambda_{\mathrm{a}}}$$

With the vehicle velocity at both ends of the edge and knowledge of the length of the edge we can calculate the time to traverse the edge. Table I summarizes the basic notations used in this study.

$$\Delta T = \frac{\Delta X}{Avg.V} = \frac{2\Delta X}{Va + Vd}$$

Table I. Notations

Symbol	Notation
ΔX	Length of an edge
λ_a	Average vehicle arrival rate (per unit time)
λ_d	Average vehicle departure rate (per unit time)
ρ	Traffic Intensity
V_x	Vehicle velocity at point X

V. Selection of Relay Vehicle

An efficient relay vehicle is the vehicle within the communications range of the disabled vehicle that will be within the communications range of an RSU in the shortest amount of time. We assume that all vehicles have knowledge of their destination and their intended path of travel.

We envision a scheme in which a disabled vehicle requests two pieces of information from each possible disseminator, their current velocity, and a set of edges between their current location and the first RSU on its intended path of travel.

As shown in section IV, we can obtain the time it takes to travel an edge of known length if we know the vehicle's initial velocity and the traffic intensity of the edge. Therefore, we determine the total time to deliver the warning to an RSU by repeating the calculations iteratively on each edge in the set.

The most efficient disseminator is therefore, the vehicle whose total to travel to an RSU is the shortest. Algorithm 1 demonstrates the iterative process of calculating travel time.

Algorithm 1 algorithm for calculating total travel time between current location and RSU

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Input:
        A set of edges, e[], between the current location and the closest RSU
        The vehicles current velocity, initVel
        The sets containing edge arrival and departure rates for each edge, lamdaA[] and lamdaD[]
        The set of edge lengths, deltaX[]
Output:
        The total time to traverse the set of edges
vel[0] =initVel
for i=1 to i=length(e[])
        vel[i]=vel[i-1] * lamdaD[e[n]] / lamdaA[e[n]]
end for
for j=0 to j=length(e[])
        time[j]=2*deltaX[e[n]]/(vel[n]+vel[n+1])
end for
return sum(time[])
```

VI. Performance Evaluation and Results

To assess the performance of the proposed method against other possible selection techniques a simple simulation was run. We used an area in in the west side of Houghton, MI, consisting of 38 intersections and 124 lanes. The area was represented as a series of nodes and edges as described in section IV. This part of the city was selected because its grid like pattern is very representative of urban road layouts in many cities. Each intersection was numbered and each edge (lane) was numbered and the length of the edge (ΔX) was approximated using city maps.

RSUs were located in a uniform mesh pattern, in Figure 4 the RSU locations are denoted by a differently colored node. Traffic intensities (ρ) for each edge were randomly generated using a uniform distribution between 0.95 and 1.05. An intensity of 1 means that the rate at which vehicles arrive and depart is on average equal, an intensity greater than one indicates traffic congestion while an intensity less than one indicates traffic easing.

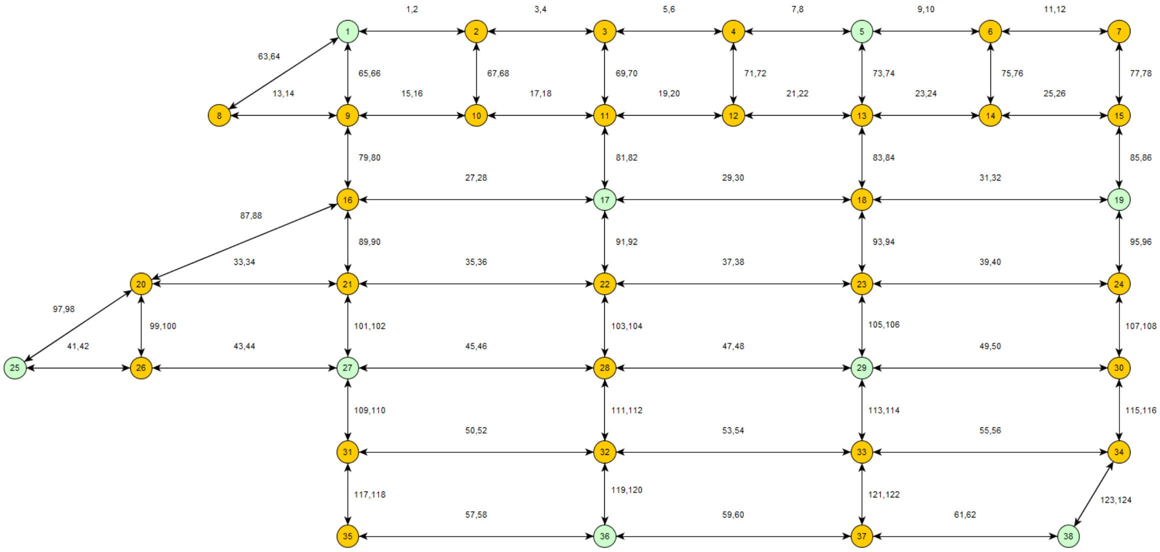

Fig. 4. Graph representing a segment of the city of Houghton used in our analysis

The simulation consisted of locating an accident within the map, and choosing the best disseminator by using three different methods. The accident was randomly located within the map at one of the 38 intersections. A random number of possible disseminators, vehicles within the transmission range of the disabled vehicles, were given random routes that started at the location of the accident and ended at an RSU. An initial velocity was given to each vehicle, randomly generated between 9 and 14 meters per second, approximately 20 to 30 miles per hour.

The three methods tested for choosing a disseminator are as follows. The first method, called the Optimal Method, is the method described within this paper. The second method, called the Velocity Method, chooses the vehicle with the greatest current velocity. The third method, called the Distance Method, chooses the disseminator by selecting the vehicle with the shortest distance to a RSU. In the second and third methods ties are broken by simply selecting the first one.

Five iterations of the simulation were run and the outcomes can be seen in Figures 5 and 6. The Optimal Method presented in this study outperformed the Velocity Method in 60 percent of the iterations and on average decreased dissemination time by 43.8 percent. The Distance Method performed much better than the Velocity Method but still the Optimal Method outperformed it in 20 percent of the simulation iterations. On average the dissemination time was decreased by 16.86 percent compared to the Distance Method.

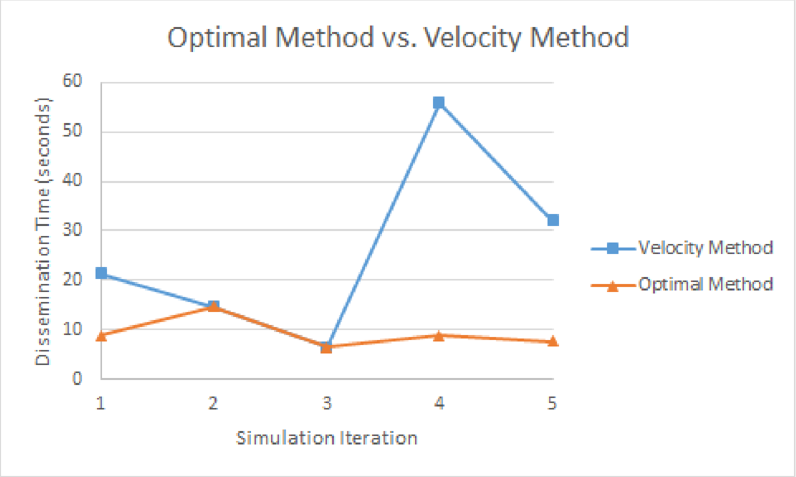

Fig. 5. Comparison of the proposed method and the Velocity Method in terms of dissemination time

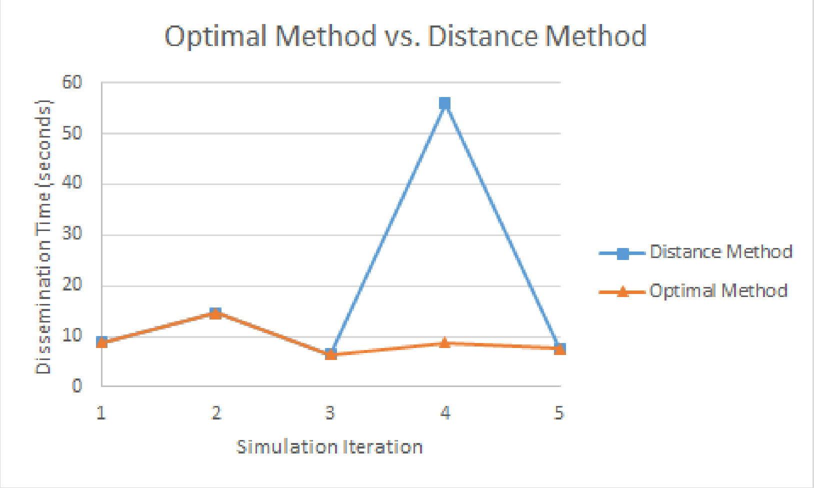

Fig.6. Comparison of the proposed method and the Distance Method in terms of dissemination time

VII. Conclusion

It has been found that RSUs play a key role in the dissemination of messages used in safety-related applications in VANETs. In addition, the performance of message dissemination could be affected by the scheme utilized for selecting the relay vehicles that, forward the message to the nearest RSU. In this work, we presented a method to efficiently determine the best relay vehicle to deliver an accident report from a disabled vehicle to a RSU. This method helps broadcasting the warning message to potentially affected vehicles in a timely manner and therefore the traffic congestion at the point of the accident could be minimized.

The performance of the proposed scheme is evaluated through the simulation studies. The results demonstrate that the proposed scheme outperforms the existing methods which select the relay vehicles based on the distance or velocity of vehicles. Some future works left open, the first one is to extend the map to various situations; the second one is to select the best relay vehicle to deliver the accident warning to an area where routing is possible.

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