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Optimal Roadside Units Placement along Highways

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***Abstract*—Roadside units (RSUs) are a critical component of Vehicular ad hoc network (VANET). Ideally, RSUs should be deployed pervasively to provide continuous coverage or connectivity. However, during the initial stages of VANET, it will not be possible to ensure such a pervasive RSU deployment due to the huge cost and/or the lack of market penetration of VANET enabled vehicles. Given a limited number of RSUs, in this paper, we address the issue of optimal placement of these RSUs along highways with the goal of minimizing the average time taken for a vehicle to report an event of interest to a nearby RSU. We present a so-called balloon optimization method ─ the optimal solution is found by using a dynamic process similar to the natural expansion of multiple balloons in a two-dimensional space where each balloon corresponds to the coverage area of one RSU. Our preliminary evaluation shows that the balloon method performs optimal or near optimal compared with the exhaustive method and it can be used for the optimal placement of RSUs along highways.**

Keywords-VANET; roadside unit; optimization; placement

I. INTRODUCTION

Vehicular ad hoc network (VANET) has numerous applications and most of these applications collect/disseminate information from/to vehicles. The collection/dissemination of this information from/to vehicles takes place via roadside units (RSUs). The effectiveness of this information flow depends on connection time/bandwidth. Connection time, between vehicles and RSUs, can easily be improved by pervasive deployment of RSUs. However, this is an expensive solution and will especially not be feasible during the initial stages of VANET when market penetration will be very low. One obvious solution is to uniformly distribute the available RSUs along the highway[1]. This solution may be effective where the need of information collection/dissemination is uniform along the whole road range of a highway, which may not always be the case. For example, if we are interested in collection of information about road conditions such as fog or ice, then some areas will always be more likely to have a fog or an ice condition than the other areas. Finding the optimal solution via exhaustively checking all possible placement strategies will become infeasible with the increase of the number of RSUs, e.g., on a 100Km highway we can have approximately 200 candidate locations for RSUs (if RSU communication range is 250m and an RSU can only deployed after every 2x250m), and if we need to place 20 RSUs among these locations then there will be 1.61 x 10^{27} different placement strategies.

In this paper our focus is on applications that collect information, such as information about road conditions, traffic conditions or traffic accident, from vehicles to nearby RSU system. We incorporate vehicle speed, vehicle density and the likelihood of occurrence of an incident/event in our optimization scheme. Our optimization goal is to minimize the average reporting time for all possible information reports in a local region; reporting time is defined as the time duration from occurrence of an event till it is reported by a vehicle to an RSU. The proposed optimization scheme can easily be extended to applications that disseminate information, here the optimization goal can be the area covered within some time bounds.

[1] In this paper our focus is on the optimal placement of RSUs along highways. For urban areas, road intersections may be more intuitive candidate locations for RSUs.

II. OPTIMIZATION SCHEMES

A. System Model

The scope of this paper is restricted to optimal placement of RSUs along one single highway. Let L be the length of a highway and R be the communication range of an RSU/vehicle. If RSUs can only be deployed after every 2xR distance then there will be $N = \lfloor L/(2R) \rfloor$ candidate locations. If M is the number of available RSUs then we aim at placing these M RSUs among N locations such that the average reporting time $T(X)$ is minimized. $X=\{x_1, x_2,.., x_M\}$ and x_i is the location of RSU_i.

The density and speed of vehicles along the highway is denoted by $d(x)$ and $s(x)$ respectively, where $0 \leq x \leq L$. For simplicity we consider a constant density D and constant speed S. If vehicles entering the highway follow Poisson distribution then there will be $\lambda = SD$ vehicles entering the highway per unit time. If y is the location of an incident/event that needs to be reported to RSU systems, a vehicle will reach the point of incident with an exponentially distributed time (mean value is $1/\lambda$). Let $f(x)$ define the distribution function of incidents/events along the highway. In order to simplify evaluation, we have considered $f(x)$ such that the locations of optimal RSUs can be derived intuitively (the two scenarios shown in Fig. 1).

B. Simple (Analytical) Optimization

If an RSU is located at position x, then for an incident/event that happened at place y, the reporting time $t(x|y)$ is the summation of the time for a vehicle to arrive at y (denoted as t_y) and the time for the vehicle to reach x from y (denoted as $t_{y\rightarrow x}$), see (1). If density and speed for vehicles in both directions are same then the average reporting time will be given by (2). The formulas for other cases such as different speed/density on opposite directions and variable speed/density have been omitted due to space limitations. For $M=1$ (single RSU placement problem), $T(x)$ for all possible locations of the single RSU is shown in Fig. 2. The optimal position of the RSU should have the minimum $T(x)$. For $M=2$, optimal positions of the two RSUs are shown in Fig. 3.

$$t(x|y) = t_y + t_{y\rightarrow x} = \frac{1}{SD} + \frac{|x-y|}{s} \qquad (1)$$

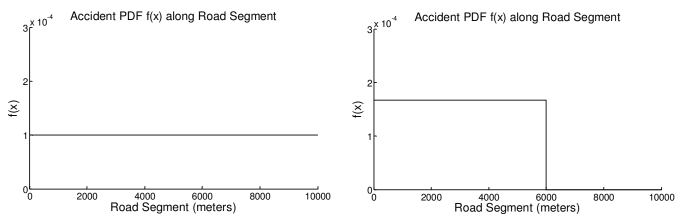
$$T(x) = \int_0^L t(x|y) f(y) dy \qquad (2)$$

C. Balloon Optimization

In this optimization method RSUs are considered as balloons, where the balloon boundaries represent the coverage area of an RSU. Let $\boldsymbol{a}$ and $\boldsymbol{b}$ be the balloon boundaries of an RSU such that $0 \leq a \leq b \leq L$. The average reporting time for each side is considered independently; $T_a(x)$ and $T_b(x)$ for side bounded by a and b respectively, and their formulas are:

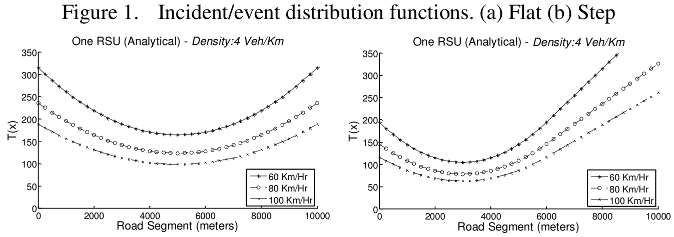
$$T_a(x) = \int_a^x \left(\frac{1}{SD} + \frac{(x-y)}{S}\right) f(y)dy,\ T_b(x) = \int_x^b \left(\frac{1}{SD} + \frac{(y-x)}{S}\right) f(y)dy \qquad (3)$$

Initially, RSUs are positioned uniformly along the highway, with $a=b=x$ and $T_a(x)=T_b(x)=0$. In each optimization iteration, the $T(x)$ on both sides of each balloon is incremented by a small value; each balloon is then expanded independently on both sides (i.e., a and b are increased) such that the computed value of $T(x)$ on both sides equals the newly incremented value. Note that the expansion of a balloon on both sides may not be uniform. For example, the side with lower values of $f(x)$ will expand more. The process is repeated till the balloon touches another RSU/balloon or the highway boundary. The expanded balloons are then repositioned such that each balloon is equidistant from other balloons or highway boundaries (in a similar way like multiple balloons bounce with each other in a constrained space). The process is then repeated all over again. The process continues till there is no more space for expansion of balloons. The positions of RSUs at this point is the optimal solution. Optimal RSU positions for $M=1$ and $M=2$ are shown in Fig. 4 and 5.



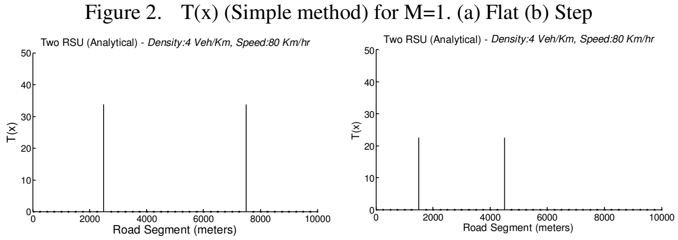
(a) (b)

Figure 1. Incident/event distribution functions. (a) Flat (b) Step



(a) (b)

Figure 2. T(x) (Simple method) for M=1. (a) Flat (b) Step

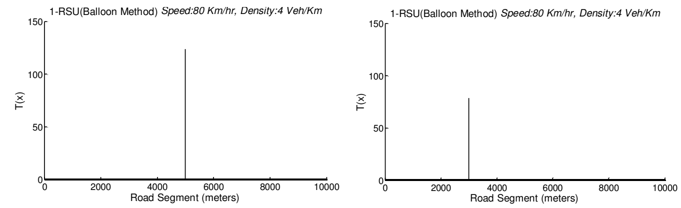


(a) (b)

Figure 3. Optimal RSU positions (Simple method) for M=2. (a) Flat (b) Step

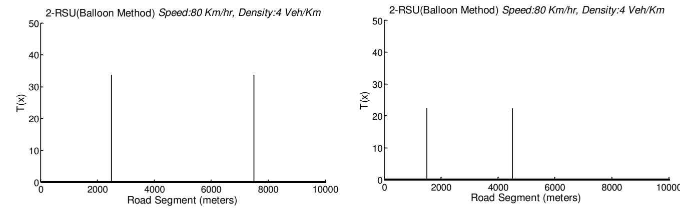
D. Discussion

As shown in Fig. 1, two different distributions of $f(x)$ were especially chosen so that the optimal positions of RSUs are intuitive. Fig. 2 and 4 show optimal positions for $M=1$ and Fig. 3 and 5 show optimal positions for $M=2$. The simple (analytical) optimization method finds optimal placement after exhaustively going through all the possible options (see Fig. 2) and will thus be uneconomical for long highways or a large number of RSUs. Balloon optimization heuristics on the other hand is much simpler and less complex. The optimal positions from both the optimization methods closely match with each other and are also intuitive.



(a) (b)

Figure 4. Optimal RSU positions (Balloon method) for M=1. (a) Flat (b) Step



(a) (b)

Figure 5. Optimal RSU positions (Balloon method) for M=2. (a) Flat (b) Step

III. Related Work

Lee et al. [1] seek optimal placement of RSUs to improve connectivity. Each intersection is considered as a potential RSU location. The optimal locations are selected based on number of vehicle-reports (per minute locations reported by taxis to telematics system) received within communication range of each RSU. The placement scheme only considers taxi location reports and does not consider speed or density of all vehicles. Li et al. [2] consider the optimal placement of gateways, which connect RSUs (access points - AP) to the Internet, while minimizing the average number of hops from APs to gateways. Here, every vehicle is connected to an AP. Vehicle speed, density or movement patterns have not been considered. Lochert et al. [3] use genetic algorithm for optimal placement of RSUs for a VANET traffic information system. The optimal placement is aimed at minimizing the travel time based on aggregated sharing of traffic information. Our optimization scheme strives to minimize the average time taken for a vehicle to report an incident/event to an RSU. It thus takes into account vehicle speed, vehicle density and likelihood of the incident/event.

IV. Conclusion and Future Work

We have presented an optimization scheme to minimize the average reporting time of an event/incident by a vehicle to a nearby RSU. Our optimization scheme is based on balloon expansion analogy, where the expansion in each direction is related to vehicle speed, vehicle density and likelihood of incidents/events. We have shown that our balloon optimization scheme performs equally well as the exhaustive optimization scheme. In future work we intend to extend our balloon optimization scheme to urban areas where roads have a two dimensional topology. We also intend to carry out simulation with realistic vehicle traces to further ascertain the effectiveness of our optimization scheme.

References

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