A Winning-Probability-based Incentive Scheme in Vehicular Networks

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***Abstract*—Vehicular ad hoc networks (VANETs) are envisioned to provide promising applications and services. One critical deployment issue in VANETs is to motivate vehicles and their drivers to cooperate and contribute to packet forwarding in vehicle-to-vehicle or vehicle-to-roadside communication. In this paper, we examine this problem, analyze the drawbacks of two straightforward schemes, and present a secure incentive scheme to stimulate cooperation and contribution in VANETs. We first define the measurement of contribution according to the unique characteristics of VANET communication. Our scheme uses the weighted rewarding component to ensure fairness.**

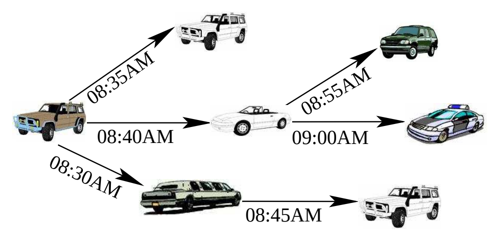


Fig. 1. An example vehicular ad hoc network (VANET).

I. Introduction

To bring the vehicular networks to their full potential, an incentive scheme needs to be developed and employed according to the vehicular ad hoc netowrks' (VANETs) unique features and potential applications to stimulate cooperation. Unlike other MANETs where the topologies are assumed to be relatively stable and packets are forwarded along fixed links, links in VANETs are intermittent and unpredictable due to the high mobility of vehicles. Consequently, vehicles use a store-and-forward model in routing to cope with intermittent links. Moreover, the continuously changing topology also makes it easier for selfish or malicious users in the vehicles to exaggerate their contribution to get more rewards.

Fig. 1 shows a typical packet forwarding process in VANETs. Vehicles encounter one another at different times, and packets are opportunistically forwarded. If an intermediate vehicle stores a packet for a long time or actively sprays the packet to other vehicles, the packet will be more likely to reach the intended destination. Therefore, by combining the storage time and number of sprays, we define our measurement of contribution for the intermediate vehicles. To stimulate intermediate vehicles to contribute more, the source vehicle should follow the incentive scheme and reward the intermediate vehicles according to their measured contributions.

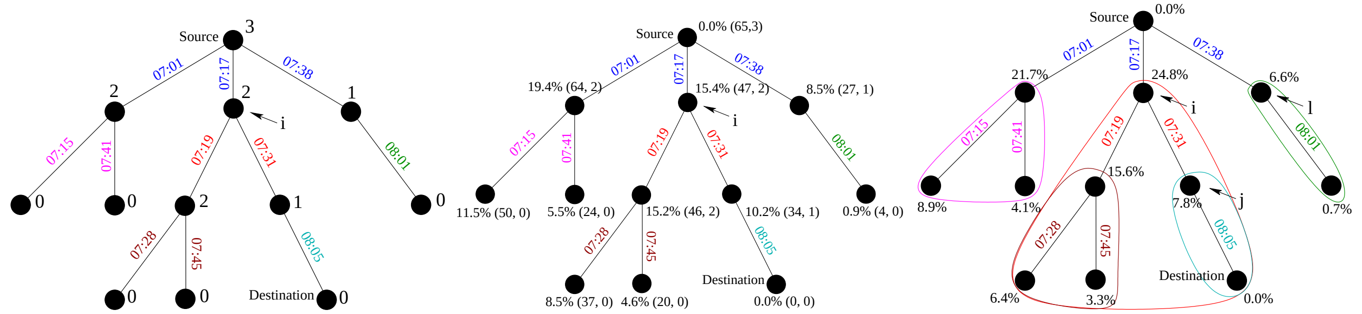
To stimulate cooperation among selfish nodes in ad hoc networks, several incentive schemes have been proposed [1], [2], [3], [4], [5], [6]. Buttyán and Hubaux brought the virtual credit into incentive schemes to stimulate packet forwarding in [7]. Nodes are willing to help in forwarding others' packets to earn the virtual credit, which can be used when they need to send their own packets. In [8], Zhong et al. presented an incentive scheme that utilizes the VCG mechanism to select the best available single path. Lee et al. discussed some unique characteristics of the incentive schemes for VANETs in [1] and proposed a receipt counting reward scheme, which focuses on the incentive for spraying. However, the characteristics of VANETs are not considered in most of the schemes, and the receipt counting scheme in [1] has a serious overspending problem. Based on the characteristics of VANETs, we propose a more comprehensive weighted rewarding method in this paper and compare it with the receipt counting scheme.

The design of the reward calculation is the core of the incentive scheme. It should guide users to follow the protocols in the VANET and encourage vehicles' desirable behavior. We propose an incentive scheme to assign different winning probabilities to vehicles according to their contribution in packet forwarding, in an effort to achieve fairness and provide motivative stimulation for participation. Our scheme utilizes a weighted rewarding component to decide the winning probability. Each vehicle has a designed probability to be the winner. The design of the winning probability keeps the packet forwarding attractive to the potential intermediate vehicles.

II. Main scheme

The core of the winning-probability-based scheme is presented in this section. We use a forwarding tree to represent the propagation process of a packet M. The root represents the source vehicle. Each intermediate vehicle corresponds to one node in the tree. The parent node corresponds to the vehicle that first sprays M to the current node. Vehicles will ignore a packet if they have received it before. Therefore, each node will appear only once in the tree. Each link in the tree corresponds to an encounter in the vehicle network, which is associated with a time stamp.

Contribution measurement: In the VANETs, if all vehicles store a packet longer and propagate the packet to more vehicles, the probability that the destination will get the packet



(a) Receipt counting (b) Proportional (c) Weighted

Fig. 2. Tree representation for three incentive schemes.

increases. Therefore, an intermediate vehicle's contribution of relaying a packet contains the following aspects: the time period that it stores the packet, ΔT_i, and the number of direct sprays that it makes, K_i. The measurement of contribution, C, for an intermediate vehicle i can be calculated as:

$$C_i = \alpha \cdot \Delta T_i + (1 - \alpha) \cdot K_i, \quad (1)$$

where α is the balancing factor. K_i and ΔT_i are calculated based on the secured evidences.

Intuitive schemes such as receipt counting and proportional rewarding have drawbacks. Receipt counting causes an over-spending problem, and the proportional rewarding makes current forwarders reluctant to send packets to potential forwarders. We propose a weighted rewarding component to address these issues.

Weighted rewarding component[1]:

The source should commit a fixed amount of reward V_r for the weighted rewarding. The vehicles that participate in the forwarding will receive a share of the total reward. However, the share is divided according to the calculated weight instead of direct contribution value in this method. In the tree representation, each node sprays the packet to its child nodes. To encourage spraying, we need to link the children's contribution when calculating a node's weight. Based on the contribution measurement, the weighted rewarding component utilizes a convex function to calculate each vehicle's weight and allocate rewards according to the calculated weights. Fig. 2 shows an example that compare the three rewarding schemes and illustrate the basic idea of the weighted rewarding scheme.

In Fig. 2, the time denotes the time that two vehicles meet each other, the probability beside each node is its probability to win, and the number in the parentheses in Fig.2(b) represent the storage duration and number of sprays. Fig. 2(a) illustrates an example using receipt counting. Node i collects 2 receipts. If each receipt's value equals 1, node i will get 2 virtual credits as the reward. An example for proportional rewarding is shown in Fig. 2(b). Suppose the source promises 10 as the total reward. Node i contributes: $\frac{0.09 \cdot 47 + 0.91 \cdot 2}{43.3} = 15.4\%$ of the total contribution. Therefore, node i gets 1.54 as the reward.

[1]Further information can be found in http://student.cse.fau.edu/∼fli4

In Fig.2(c), node i's contribution is 6.7. Since the weighted rewarding scheme is adopted, nodes in $sub(i)$ also contribute to i's weight. So i will get 24.8% of the total V_r. Let us examine another case where j is not a child of i but rather the child of l. In this case, Q_i is reduced to 19.5%.

Securing the evidences: We assume that each vehicle in the VANET keeps one original identification certificate. This certificate contains the vehicle's identity (e.g. plate number), the vehicle's public key and authority's signature. With the help of security entities in the VANET, we propose a set of security evidence generation, collection and verification schemes to support the incentive scheme.

III. Conclusion

We proposed a secure incentive scheme to motivate vehicles and their drivers to cooperate and contribute to the packet forwarding process in VANETs. We first defined the measurement of contribution according to the unique characteristics of VANET communication. We then proposed the weighted rewarding component that ensures fairness. We also presented the security measures as the basis for the incentive scheme. In the future, we plan to investigate incentive scheme that utilizes reputation instead of virtual credit in the VANETs.

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