Simulation Study of Trust Management Schemes in Vehicular Ad Hoc Networks (VANETs)

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Abstract

Existing trust management schemes for Vehicular Ad Hoc Networks (VANETs) can be classified into four main categories: role based, experience based, priority based, and majority opinion. To our knowledge, there is no study that compares the reliability of each of the four trust models to accurately report an accident. In this paper, we perform a comparative simulation study to measure the accuracy of each trust model to report an accident in a road. We simulate road accidents with varying vehicle densities using Manhattan mobility model. We report on how to measure the relative accuracy of four existing trust management schemes for VANETs. Our simulation results show that experience based trust outperforms other trust models in accurately reporting accidents in a road. We also demonstrate that for Majority Based Trust, setting the threshold at 20% enables more vehicles to reliably learn about an accident than when a 50% threshold is used.

Introduction

Vehicular Ad Hoc Networks (VANETs) provide intelligent systems for vehicles to communicate with each other on roads. The role of VANET trust management schemes is to ensure that messages shared among vehicles in a road network are reliable, accurate, and secure. So, what is message trust? It is the ability of vehicles to verify that real-time warning messages they receive from other vehicles are confidential, accurate and reliable¹. Trust management schemes for VANETs can be classified into four main categories: 1) Role Based Trust (RBT) assigns roles to vehicles and gives an associated trust value. Messages from vehicles with lower roles are given higher priority. 2) Experience Based Trust (EBT) cumulatively calculates trust of vehicles based on direct and indirect experience. 3) Priority Based Trust (PBT) considers both vehicle priority and experience based trust values. PBT gives a higher priority to vehicles with lower roles and higher experience trust values. 4) Majority Based Trust (MBT) sets a threshold when sending requests for reports about road conditions. Reports from vehicles that meet the threshold are accepted as reliable².
If messages sent in a VANET environment are misleading, vehicle collisions and road congestion can occur. By the year 2007, Americans spent 4.2 billion extra hours on roads, and bought 2.9 billion extra gallons of fuel. This led to a total monetary cost of $78 billion. Traffic congestion results in $40 billion loss of productivity annually in the United States. Every year, Americans spend a total of 2 billion hours in traffic jams. Vehicle crashes due to collisions cost the US economy a financial loss of $150 billion, and 40,000 deaths every year. Around the world, road traffic accidents kill 1.2 million people and leave 50 million injured every year.

To address the problem of vehicle collisions and false messages in road networks, several approaches exist for managing trust in VANET environments. What is hard, however, is to come up with a single model that globally evaluates the accuracy of all the four categories of trust management schemes to report an accident. We would like to have a benchmark that individual vehicles can use to choose which VANET trust scheme to adapt based on prevailing road conditions. If such a benchmark becomes available for traffic flows and road safety, we could save lives, drive time, fuel consumption, and greenhouse gas emissions.

It is difficult to model a scheme that measures the accuracy of all existing VANET trust approaches. Real world systems are not available for testing, so simulation is required. Even if simulations are used, a wide array of simulation software and mobility models abound. Furthermore, developing test beds and doing experiments on actual roads is time consuming and expensive. On top of that, test beds only represent particular locations that they are run on. Therefore, results from test beds are hard to control and repeat.

In light of this, a global benchmark for measuring the accuracy of existing VANET trust management schemes is necessary. From our review of existing literature, such a benchmark does not exist. Our solution to this problem is to perform a comparative simulation study of four major trust systems using random road accident warning scenarios. In our simulations, we observe how each of the four trust schemes accurately reports an accident. We vary vehicle density and time in each simulation run. We use Manhattan mobility model for our simulation. In designing our mobility model, we studied the realistic vehicle traces from Multi-agent Microscopic Traffic Simulator (MMTS) from three areas in Switzerland. We would like our simulation scenarios to be as comparable as possible to other road topologies and network simulators.

The contributions of our work are: (1) we test the performance of existing VANET trust management schemes using Manhattan mobility model; and (2) we provide simulation results which can be used as a benchmark for evaluating trust management schemes under different mobility conditions.

The remainder of this paper is organized as follows. In Section II we present related work. In Section III, we elaborate on existing trust management schemes. In Section IV we define terms used in our work. In Section V, we discuss our performance metrics. In Section VI we explain our simulation setup. In Section VII we analyze our simulation results. Finally in Section VIII we conclude our paper.
Related Work

Two main objectives for VANET safety applications are: 1) to prevent false alert messages from being sent in the environment, and 2) to verify that events reported about traffic are accurate. Variations in capabilities of sensors by manufacturers, and changing road topologies present a challenge for enhancing traffic safety applications. In this section, we discuss some existing schemes for VANET reputation management.

One of the traditional approaches to trust management in VANETs is the use of cryptographic schemes for message authentication. In their approach, Boneh and Franklin use both symmetric and asymmetric key cryptography to ensure message integrity. Boneh and Franklin use elliptic curve cryptography to secure VANET environments. While cryptographic techniques provide some level of security in VANETs, they acquire overhead when performing key management. Furthermore, cryptographic systems cannot cope up with dynamic nature of road conditions for key management. Consequently, techniques have been proposed to prevent false messages from being sent in VANET environments without relying entirely on cryptography. Raya et al. use approaches that identify and isolate misbehaving vehicles from the network.

Recent literature on VANET security is moving towards reputation frameworks for both messages and vehicles. Broadly speaking, VANET reputation schemes can be categorized into: Role Based Trust Management Schemes, Reputation Trust Management Schemes, Priority Based Trust Management Schemes, and Majority Based Trust Management Schemes.

Our work differs from the related work in that we simulate the four existing trust models and compare how accurately they report an accident in a road. Additionally, our work is novel because none of the existing literature can determine which trust scheme is suitable for various road conditions and vehicle densities. Moreover, our simulation framework of vehicles with a density of up to 7000 in a 3000 square meters grid can be used as a reference model to benchmark future trust evaluation schemes.

Role Based Trust Management Schemes

The concept of Role Based Trust has been proposed by Minhas, Zhang, Tran, and Cohen. In Role Based Trust management scheme (RBT), agents within the road are assigned pre-defined roles. Each role has a role trust value associated with it. A central licensing authority is responsible for assigning roles. Minhas, Zhang, Tran, and Cohen assign roles in decreasing order as follows: (1) Authority, (2) Experts, (3) Seniority, and (4) Ordinary road users.

The roles are further designated as follows: 1) Authority: law enforcement entities and traffic patrols, 2) Experts: agents who are specialists in road conditions, 3) Seniority: agents who have traveled the road for a long time and have good driving records, and 4) Ordinary: agents who do not belong to any of the categories above. When an agent receives multiple messages from other agents, the receiving agent checks the role of the sending agents. Priority is given to messages from agents with the lowest role.
The drawback with this scheme is that the number of agents with lower roles may be limited in a large road network.

**Experience Based Trust Management Schemes**

In experience based trust, agents are assigned cumulative trust values based on direct and indirect interactions. Tracking and updating experience trust values can be space costly, given the dynamic nature of roads. Therefore, a tradeoff is necessary to give older interactions less weight.

Experience Based trust management scheme (EBT) updates trust values recursively based on an agent’s direct and indirect interactions with other agents. The interval for trust is given in the range of (-1, 1), where -1 represents absolute distrust, and 1 represents absolute trust. Suppose agent A receives reports about a road condition from agent B. Suppose agent C has previously traveled the same route a short while before. Suppose A has previously interacted with C, and established that C is trustworthy. A verifies with C if the message given by B is correct. If the message is correct, the trust value of B is increased. If the message is wrong, the trust value of B is lowered. The equation to increase an Agent’s trust value $T$ is given by

$$T \leftarrow \begin{cases} T + \alpha (1 - T) & \text{if } T \geq 0 \\ T + \alpha (1 + T) & \text{if } T < 0 \end{cases}$$

where $0 < \alpha < 1$

To lower an Agent’s trust value, we use the equation by

$$T \leftarrow \begin{cases} T + \beta (1 - T) & \text{if } T \geq 0 \\ T + \beta (1 + T) & \text{if } T < 0 \end{cases}$$

where $-1 < \beta < 0$. The absolute values for $\beta$ and $\alpha$ are based on the sparsity of data. So for sparse data, both $\beta$ and $\alpha$ should be larger.

**Priority Based Trust Management Scheme**

Priority based trust gives a higher priority to vehicles with low role numbers and higher experience based trust values. In the approach by, safety related messages such as accidents are given priority over other messages. Similarly, in their work give a higher priority to traffic messages that are safety related. For example, if there is a message about a road accident, and a message about construction work going on, the vehicle will first process the accident message.

Within the list of priorities, agents are also ordered based on their Experience Based Trust values. If an agent receives multiple messages from agents with the same role, priority is given to agents with the highest Experience Based Trust values.
Majority Opinion Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>Ci</td>
<td>Time closeness</td>
</tr>
<tr>
<td>Te</td>
<td>Experience based trust</td>
</tr>
<tr>
<td>Tr</td>
<td>Role based trust</td>
</tr>
<tr>
<td>Rj</td>
<td>Reports from vehicles</td>
</tr>
<tr>
<td>Bj</td>
<td>Vehicles in a network</td>
</tr>
<tr>
<td>Cj</td>
<td>Location closeness</td>
</tr>
</tbody>
</table>

Table 1. Majority Opinion Terms

Majority Opinion Trust Management Scheme

In majority opinion based trust, an agent receiving multiple reports sets a threshold value that must be met for the report to be accepted. A forgetting factor is included to take into account older interactions. Location closeness between the agent and reported event is also considered.

Majority opinion takes into account both Experience Based Trust (EBT) and Role Based Trust (RBT). Majority opinion also considers both time closeness and location closeness between the reporting agent as well as the events reported. It also considers the location closeness between the reporting agent and the receiving agent. Definitions for the terms of majority opinion are given in Table 1. Minhas, Zhang, Tran and Cohen calculate majority opinion using the equation

\[ E(R_j) = \sum_{B_i \in B_j} \frac{T_e(B_i)T_r(B_j)}{C_i(R_j)C_j(B_j)} \]

where \(1 \leq i \leq n\) and \(m \leq n\)

Definitions

We determine the truth value of two things: reports from the vehicle's system model, and the direct experience of other vehicles. We evaluate the performance of our simulation based on four truth table logics described below.

True True (TT)

If the system model reports an accident has occurred, we consider the system's report to be true. We call this state SYSTEM = TRUE for that particular vehicle. If the vehicle travels close to the scene of the accident, and observes that the accident indeed occurred, we call this a true value too. So we say EXPERIENCE = TRUE.
True False (TF)

Suppose the system model reports an accident has occurred, and a vehicle is not in the range where the accident occurred. Then the vehicle did not directly experience the accident. So we say EXPERIENCE = FALSE. We call this True False (TF).

Performance Metrics

We evaluate the performance of our simulation based on three metrics: time, vehicle density and average percentage reporting true.

Time

We record the time in minutes that it takes for each of the four trust schemes to report an accident. Time begins from 0 to 5 minutes. As time increases, we measure the average percentage it takes for each of the models to learn about an accident.

Vehicle Density

Vehicle density is defined as the number of vehicles in 3000 meters by 3000 meters road grid. We begin with vehicle density of 1000 and increment by 1000 until the density reaches 7000. The idea here is to observe whether or not vehicle density has any effect on knowledge of an accident.

Average Percentage Reporting True

We record the number of vehicles that have learned about an accident and correctly reported the accident to other vehicles within their communication range.

Simulation Set Up

In this paper, we run our simulation on Manhattan mobility model. We vary vehicle densities from 1000 to 7000. In each simulation run, we create a random accident in a road grid. We observe how the four performance metrics (TT, TF, FT, and FF) accurately report the accident to vehicles within their communication range.

We make the following assumptions in our simulation. First, vehicles with the role of authority have a longer communication range of 1000 meters. Other vehicles have a communication range of 300 meters. Secondly, Manhattan mobility model represent the way vehicles actually flow in real life scenarios. Third, all vehicles are registered through a trusted central authority. This authority issues and revokes licenses, as well as assigns roles to vehicles.

For Majority opinion, we set two threshold values, one at 20%, and another at 50%. In the first case, if 20 per cent of respondents agree with the question asked about a road condition, we accept their opinion. We call this MBT 20%. In the second case, we raise the threshold to 50%, and call it MBT 50%.
Table 3. Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Processor</td>
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<tr>
<td>Topography</td>
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<tr>
<td>Simulation Time</td>
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<td>Mobility Model</td>
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<td>Vehicle Density</td>
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<td>Vehicle Speed</td>
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<td>Communication Range (Other Vehicles)</td>
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<td>Simulation Software</td>
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Simulation Results

Our simulation results show that Experience Based Trust and Majority Based Trust report the highest percentage of cars that did not witness the accident, but received true reports from the system about road conditions.

As vehicle density increases, the number of vehicles that received reports about accidents also increases. Experience Based Trust reports the highest percentage of vehicles that learned about an accident and sent message alerts.

Figure 2 shows the average percentage of additional knowledge of the accident by elapsed time and vehicle density. We measure how all the four trust models report knowledge of the accident after 1, 2, 3, 4 and 5 minutes. When we use a majority opinion with a threshold of 20 percent, we observe an increase in the number of vehicles reporting an accident compared to when we use a threshold of 50%. As time increases, more vehicles become aware of the accident. For all the four trust models, the average percentage increases with time. For EBT with 20% threshold, MBT and RBT, the percentage of knowledge begins to stabilize at time 4 minutes.

When we consider vehicle density, experience based trust with 20% threshold shows the highest average additional knowledge at 63%. As more vehicles get into the system, experience based trust is able to provide more accurate and reliable information about an accident. This is because experience based trust relies on actually receiving first-hand message alerts about an accident.

In our simulation, an accident occurred at time $t = 0$. Priority based trust has an increase in additional knowledge of accident from 1000 to 4000 vehicles, and then the knowledge begins to stabilize or drop. It is possible that after a density of 4000 vehicles, enough vehicles have learned about the accident such that it has no effect on additional knowledge when PBT is used. Role Based Trust and Majority based Trust schemes remain fairly constant regardless of the change in vehicle density.
Figure 2. Average percentage of additional knowledge of all trust schemes.
Figure 3. Average percentage of additional knowledge of EBT by elapsed time
Figure 3 shows the average percentage of additional knowledge of Experience Based Trust model by elapsed time after the accident. The percentage of vehicles that witnessed the accident after time t increase as vehicle density increases.

Figure 4 shows the average percentage of additional knowledge of Majority Based Trust and Priority based Trust models by elapsed time after accident. As more time elapses, more vehicles become aware of the accident that occurred. As time increases and more vehicles learn about the accident, PBT reports an increase in knowledge of accident. PBT is derived from reports from vehicles with higher roles and higher EBT values. In our simulation, authority vehicles relay messages to other authorities even if they are not in communication range of the accident scene. The authorities broadcast this message to vehicles within their communication range. This explains why Priority Based Trust has a better performance than Majority Based Trust in reporting an accident.

Conclusion and Future Work

In this paper, we have presented a simulation evaluation of four existing categories of VANET trust management schemes (Role Based, Experience Based, Priority based, and Majority Opinion). We have compared the accuracy of the four schemes to reliably report an accident in a road network. Through our simulation, we have shown that Experience Based Trust provides
more accurate results than all other trust models. We have also illustrated that in Experience Based Trust model, as vehicle density increases, more vehicles which had no prior knowledge about an accident receive accurate alert messages.

For Priority Based Trust, our simulation results show that as time increases, more vehicles become aware of an accident. When we compared majority opinion of 20% with 50%, we found out that a majority opinion of 20% records a much higher percentage of vehicles with additional knowledge of the accident than a majority opinion of 50%. Therefore, it may be a good idea to set a threshold of majority opinion at around 20%.

We have simulated a scenario where all authority vehicles relay messages about accidents to other authority vehicles even if they are not close to the accident. Our work can be used as a benchmark to figure out which trust scheme to use in a road network under different vehicle densities. Our study can be extended to include more mobility models such as Random Waypoint, rural, and urban. We leave this for future work.

Bibliography


