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Design and evaluation of an alert message dissemination algorithm using fuzzy logic for VANETs

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Abstract

Several multi-hop applications developed for vehicular ad hoc networks use broadcast as a means to either discover nearby neighbors or propagate useful traffic information to other vehicles located within a certain geographical area. However, the conventional broadcast mechanism may lead to the so-called broadcast storm problem, a scenario in which there is a high level of contention and collisions at the link layer due to an excessive number of broadcast packets. We present a fuzzy alert message dissemination algorithm to improve performance for road safety alert application in Vehicular Ad-hoc Network (VANET). In the proposed algorithm, when a vehicle receives an alert message for the first time, the vehicle rebroadcasts the alert message according to the fuzzy control rules for rebroadcast degree, where the rebroadcast degree depends on the current traffic density of the road and the distance between source vehicle and destination vehicle. Also, the proposed algorithm is the hybrid algorithm that uses broadcast protocol together with token protocol according to traffic density. The performance of the proposed algorithm is evaluated through simulation and compared with that of other alert message dissemination algorithms.

Keywords: Alert message dissemination, defuzzification, fuzzy logic, rebroadcast, VANET.

1. Introduction

VANET or Vehicular Ad-hoc Networks are emerging as the preferred network configuration for intelligent transportation systems. VANET is based on short-range wireless communication (e.g., IEEE 802.11) between vehicles. The Federal Communications Commission (FCC) has recently allocated 75 MHz in the 5.9 GHz band (ASTM E2213, 2010) for licensed dedicated short-range communication (DSRC) aimed at enhancing bandwidth and reducing latency for vehicle-to vehicle (V2V) communication. Unlike other forms of MANETs (Tonguz and Ferrari, 2006), applications developed for VANET have a very specific and clear goal of providing intelligent and safe transportation system.

The specific characteristics of VANETs allow the development of the following two most relevant category applications (Tseng *et al.*, 2002):

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- Comfort applications: This category tries to improve the comfort and traffic efficiency and/or optimize the route from a source to its destination. Traffic, weather, gas station or restaurant location and price information system, and interactive communication such as the Internet access or music download are some examples of this kind of applications.
- Safety application: The purpose of this category is to increase the safety of the drivers and passengers by exchanging safety relevant information. Examples of applications in this category are emergency warning system, lane-changing assistant, intersection coordination, traffic sign/signal violation warning, and road-condition warning.

Although much effort is needed for make these applications to become reality, methods to disseminate various messages seem to be the most important challenge. Moreover, the huge social and economic cost related to road accidents makes research of proactive safety services a task of primary importance in the intelligent transportation system (ITS). A fundamental application for providing this safety service is the fast and reliable propagation of alarm message or warning message to upcoming vehicles in case of hazardous driving situations such as accident and dangerous road surface conditions. The dissemination of safety message could prevent secondary accidents and play an important role in rescue operation. The main problem of VANET communication is the broadcast storm problem.

In this paper, we present a fuzzy alert message dissemination algorithm to improve performance for road safety alert application in VANET. In the proposed algorithm, when a vehicle receives an alert message for the first time, the vehicle rebroadcasts the alert message according to the fuzzy control rules for rebroadcast degree, where the rebroadcast degree depends on the current traffic density of the road and the distance between source vehicle and destination vehicle. Also, the proposed algorithm is a hybrid algorithm that uses broadcast protocol together with token protocol according to traffic density.

The remainder of this paper is organized as follows. Section 2 reviews the related works. Section 3 describes the proposed fuzzy alert message dissemination algorithm. Section 4 presents the performance evaluation of the proposed fuzzy alert message dissemination algorithm through simulation. Section 5 concludes the paper and discusses future works.

2. Related works

2.1. Regional alert system

Very much different from other forms of MANETs reported in the literature (Tonguz and Ferrari, 2006), a VANET consists of mostly mobile vehicles that can intelligently communicate with one another over the 5.9 GHz frequency band via a DSRC (ASTM E2213, 2010) based device.

A wide spectrum of services in VANETs include, but are not limited to, public safety, traffic management, freight/cargo transport, transit, and traveler information. It is anticipated that vehicles in the future will be equipped with DSRC devices capable of communicating with nearby vehicles in one-hop or multi-hop fashion in order to extend the drivers' range of awareness beyond what they can directly see. Emergency information such as collision or emergency braking can be propagated along the road to notify drivers ahead of time so that necessary action can be taken to avoid accidents. In addition to an emergency warning, drivers can also plan a trip in accordance with traffic conditions received from other vehicles or roadside units in order to save time on the road. The scope of applications can also be expanded to cover other services, which are of private business or automotive industry interests, such as on-road entertainment streaming/downloading and Internet access.

Informally, the regional alert problem can be stated as follows: given an alert with a location, a time duration, and the safety and operating radius, if feasible, all cars traveling through the alert region during the time of the alert should be notified before breaching the safety radius. Regional alert system (RAS) is useful for disseminating information like road conditions, accidents, congestion, road repairs, detours, etc.. The key characteristics of a RAS are (Sun and Garcia-Molina, 2004):

- No association between senders and an alert. An alert is associated with a location rather than a particular sender or car. There does not exist an ”owner” of an alert. There is, however, an originator of an alert who first detects and propagates the alert condition.
- No stationary “repeater” at the origin of the alert. In other words, the originator of an alert does not remain at the site of the alert to continuously relay the alert. Unlike accidents where a disabled car may function as a repeater, road condition alerts originate from passing cars, thus it is unreasonable to assume a repeater at the origin of the alert message.
- No pre-determined set of receivers. Receiving cars are determined by their location with respect to an alert. In other words, the set of receivers is highly dynamic.
- A time duration for the alert. When an alert occurs, instantaneous delivery to cars in the affected region is not sufficient. One must continuously inform other cars coming into the region.
- Many cars are expected to enter and leave the alert region during the alert duration.

These characteristics require a solution that is more than just the traditional flooding or store-and-forward scheme in ad-hoc and mobile networking. Any RAS solution must address both the geographical constraint and the time duration constraint of an alert. Instead of the traditional problem of routing a message instantly via an ad-hoc network to a specific client or group of clients, RAS must route an alert to all clients in a region for a duration, even if the underlying ad-hoc network changes as cars enter and leave the region.

Simple broadcast (Tonguz *et al.*, 2007; Suriyapaibonwattana *et al.*, 2008) is the simplest protocol used in V2V Safety alert applications for VANET. When there is an accident, safety alert application will send alert messages to all vehicles approaching towards accident site. When a vehicle receives a broadcast message for the first time, it retransmits the message. The vehicle then ignores all subsequent broadcast messages (with same ID) it receives, from other vehicles rebroadcasting the same message. There are two main problems in this simple broadcast method. First, there are many redundant rebroadcast messages because of flooding. Thus, when a n hosts for the first time, n replications will there is a high probability that a message will be received by many hosts located in a close proximity. Each host will severely contend with one another for access to medium. As show in Figure 2.1, when accident is occur B, C, D, E and F, which are in transmission receive alert message and rebroadcast it. It will then give rise to broadcast storm, and collision will occur, which lead to retransmission and further collision.

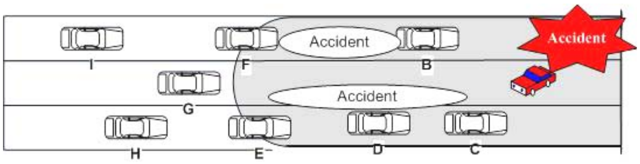

Figure 2.1 Situation of an accident and nearby vehicles on the road.

p-Persistence (Tonguz *et al.*, 2007; Suriyapaibonwattana *et al.*, 2009) tries to reduce the broadcast storm problem by using a stochastic selection method to decide the vehicles that will rebroadcast the alert message. When a vehicle receives a broadcast message for the first time, the vehicle will rebroadcast the alert message with a random probability p. This method will help to reduce number of re-broadcasting vehicles and thereby broadcast storm problem. However failures to extend the alert message decide not to, which will cause the loss of alert message. For example, if all vehicles B, C, D, E and F decide not to rebroadcast the message, no car behind them will receive the alarm message. This approach is sometimes referred to as Gossip-based flooding (Haas *et al.*, 2006).

2.2. Fuzzy inference system

A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if-then rules, aggregation of output sets, and defuzzification. An FIS with multiple outputs can be considered as a collection of independent multi-input, single-output systems. A general model of a FIS is shown in Figure 2.2. The FIS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions. The inference engine defines mapping from input fuzzy sets into output fuzzy sets. The defuzzifier maps output fuzzy sets into a crisp number. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number (Lee, 1990; Bae, 2009; Bae and Kim, 2007).

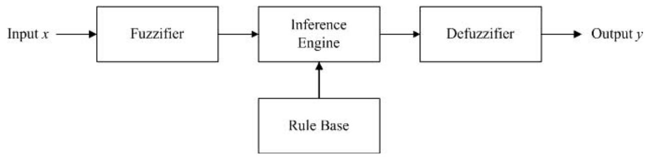

Figure 2.2 Block diagram of a fuzzy inference system.

3. Fuzzy alert message dissemination algorithm

In this paper, we present a Fuzzy Alert MEssage Dissemination Algorithm (FAMEDA) to improve performance of road safety alert application in VANET. Upon receiving a packet from vehicle i, vehicle j rebroadcasts it with some probability if it receives the packet for the first time; otherwise, it discards the packet. The probability is depended on the current traffic density of the road that a car accident occurs and the distance between source vehicle and received vehicle.

In the design of FAMEDA, we assume the following:

- Here, before transmitting alert message, GPS is used to calculate the distance between source vehicle i and destination vehicle j.
- All vehicles can know the current traffic density degree from traffic sensors into or onto roads or broadcasting "HELLO" message periodically and the time when the significant change in vehicle's velocity is occurred.
- All vehicles are equipped with a directional antenna that is an antenna which radiates greater power in one or more directions allowing for increased performance on transmit and receive and reduced interference from unwanted sources.

In FAMEDA, when a vehicle receives an alert message for the first time, the vehicle rebroadcasts the alert message according to the fuzzy control rules for rebroadcast degree, where the rebroadcast degree depends on the current traffic density of the road and the distance between source vehicle and destination vehicle. Also, the proposed algorithm is a hybrid algorithm that uses broadcast protocol together with token protocol according to traffic density.

We map the distance between source vehicle i and destination vehicle j ($Dis_{i,j}$) to the five basic fuzzy sets: VS (very short), S (short), M (moderate), L (long) and VL (very long) using the fuzzy function as shown in Figure 3.1. The membership function is a function in [0, 1] that represents the degree of belonging. The membership function fully defines the fuzzy set. Membership functions on Dis represent fuzzy subsets of Dis. The membership function which represents a fuzzy set DI (DIstance) is usually denoted by μ_{DI} ($Dis_{i,j}$), where R represents the average transmission range.

Also, we map the current traffic density (TD_c) to the five basic fuzzy sets: VH (very heavy), H (heavy), M (moderate), L (light) and VL (very light) using the fuzzy function as shown in Figure 3.2. Membership functions on TD represent fuzzy subsets of TD. The membership function which represents a fuzzy set TD is usually denoted by μ_{TD} (TD_c), where TD_{max} represents the maximum traffic density.

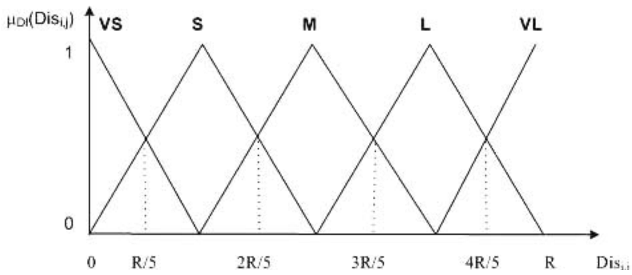

Figure 3.1 Membership function for the distance between source vehicle i and destination vehicle j.

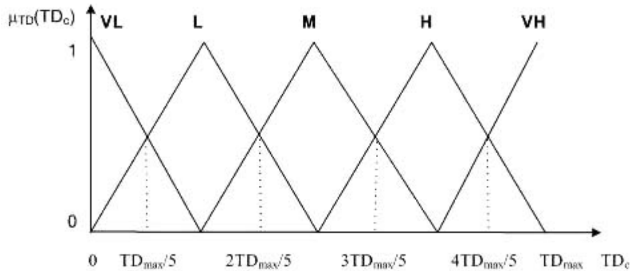

Figure 3.2 Membership function for the current traffic density.

Figure 3.3 shows a few examples of proposed FAMEDA, where R_L, R_M and R_S represent the regions of long, moderate and short distances from a vehicle accident point, respectively. First, consider the scenario depicted in Figure 3.3(a) where the current traffic density of the road that a car accident occurs is very heavy. If two nodes F and G that are far away from source node A received an alert packet for the first time, the vehicles F and G rebroadcast with low probability. If two nodes D and E that are a moderate distance away from source node A received an alert packet for the first time, the nodes D and E rebroadcast with low probability. And, if two nodes B and C that are near the source node A received an alert packet for the first time, the nodes B and C rebroadcast with very low probability.

Second, consider the scenario depicted in Figure 3.3 (b) where the current traffic density is moderate. If node D that is far away from source node A received an alert packet for the first time, the node D rebroadcasts with high probability. If node C that is moderate distance away from source node A received an alert packet for the first time, the node C rebroadcasts with medium probability. And, if node B that is near the source node A received an alert packet for the first time, the node B rebroadcasts with low probability.

Third, consider the scenario depicted in Figure 3.3 (c) where the current traffic density is very light. Source node uses broadcast protocol together with token protocol to reduce the loss of alert message. Accordingly, node A broadcasts an alert packet and passes an alert token to the farthest vehicle traveling in opposite direction. If node B that is far away from source node A received the alert packet for the first time, the vehicle B rebroadcasts with very high probability. Also, node C passes the token to node B, and node B discards the token. If node B is beyond transmission range, node B be receiving the token from node C, and will rebroadcast with some probability.

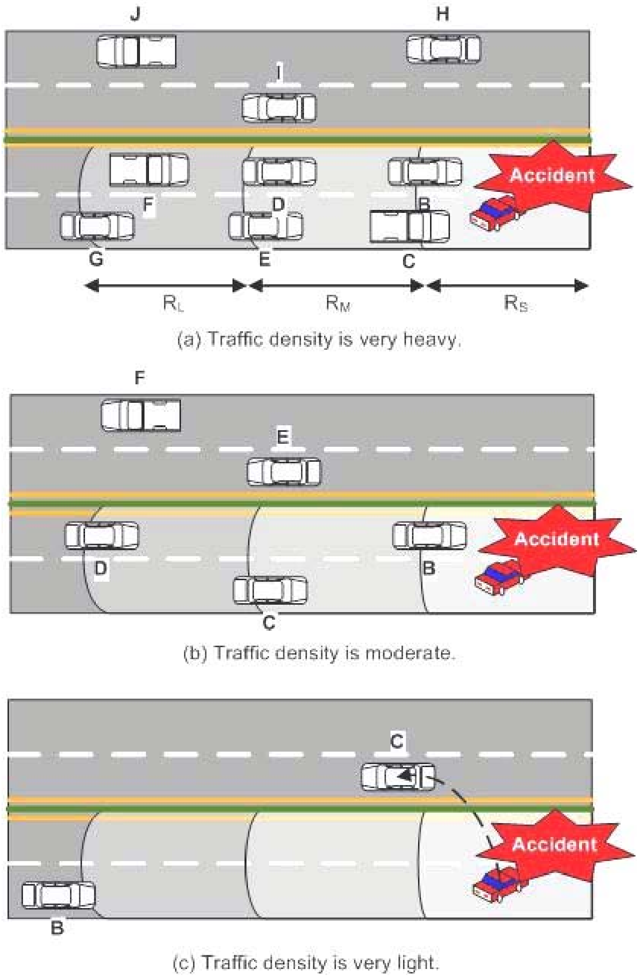

Figure 3.3 Example of FAMEDA.

The control rules for rebroadcast degree which consider the current traffic density of road and the distance between source vehicle and received vehicle are shown in Table 3.1.

A fuzzy inference system maps an input vector to a crisp output value. In order to obtain a crisp output, we need a defuzzification process. The input to the defuzzification process is a fuzzy set, and the output of the defuzzification process is a single number.

Table 3.1 The control rules for rebroadcast degree.

		DI				
		VL	L	M	S	VS
TD	VH	M	L	L	VL	VL
	H	M	M	L	L	VL
	M	H	M	M	L	L
	L	VH	H	M	M	L
	VL	VH	VH	H	M	M

(input variables) TD: VH (very heavy), H (heavy), M (moderate), L (light), VL (very light)
DI: VL (very long), L (long), M (moderate), S (short), VS (very short)
(output variables) Degree for rebroadcast: VH (very high), H (high), M (medium), L (low), VL (very low)

Upon receiving a packet from vehicle i, node j checks the packet ID and rebroadcasts with probability P_{ij} if it receives the packet for the first time; otherwise, it discards the packet. To determine pij, defuzzifier maps from a linguistic degree for rebroadcast to a probability value for rebroadcast as in Eq.(3.1).

$$P_{ij} = defuzzifier(a\ linguistic\ degree\ for\ rebroadcast) \tag{3.1}$$

$$defuzzifier\left(\left\{\begin{array}{l} VH \\ H \\ M \\ L \\ VL \end{array}\right\}\right) = \left\{\begin{array}{l} 0.8 \\ 0.65 \\ 0.5 \\ 0.35 \\ 0.2 \end{array}\right\}$$

4. Performance evaluation

The primary objective of our algorithm is to the improve success rate of safety alert messages which means the percentage of vehicles that receive the alert message. We also aimed to reduce the broadcast storm problem that occurs in most of the VANET's safety alert protocols. We use three metrics to evaluate different protocols.

- Collision: The number of alert message collisions that occur during the period of simulation.
- Success rate: Percentage of vehicles that received alert message.
- Time: Time delay from accident occurred till last vehicle received alert message.

The parameters and values of the performance evaluation for FAMEDA are shown in Table 4.1.

We have evaluated the performance of FAMEDA in the MATLAB 7.0 (Graham, 2005; Kay, 2009). Figure 4.1 shows the number of alert message collisions that occurred according to the distance of alert region. We can see that FAMEDA has lowest number of collision because FAMEDA uses the fuzzy control rules for rebroadcast degree that considers the current traffic density and the distance between sender and receiver.

Table 4.1 Simulation environment.

Parameter	Value
Distance of alert region	2 ~ 10 Km
Transmission range	250 meters
Traffic density	4 ~ 200 vehicles/Km
Vehicle speed of opposite lane	100 Km/h
Lane	2
The rebroadcast probability in p-Persistence	0.5
Transmission delay	100 ms/hop

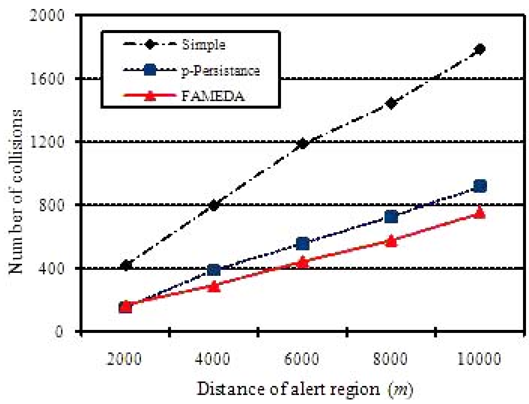

Figure 4.1 Number of collision with alert region distance.

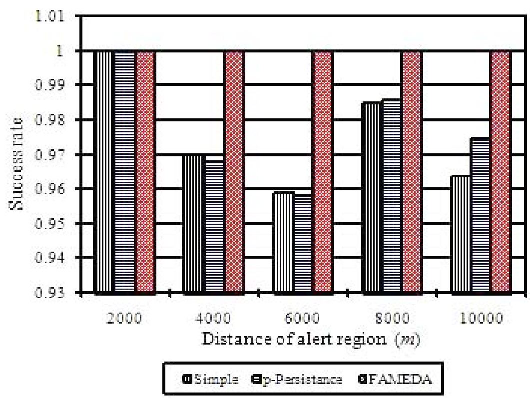

Figure 4.2 Success rate with alert region distance.

The most important result, the success rate for different algorithms, is shown in Figure 4.2. Loss of alert message causes low success rate. The success rate of FAMEDA is higher than that of existing algorithms. FAMEDA achieves perfect success rate because the sender uses broadcast protocol together with token protocol to reduce the loss of alert message in case that the current traffic density is very light.

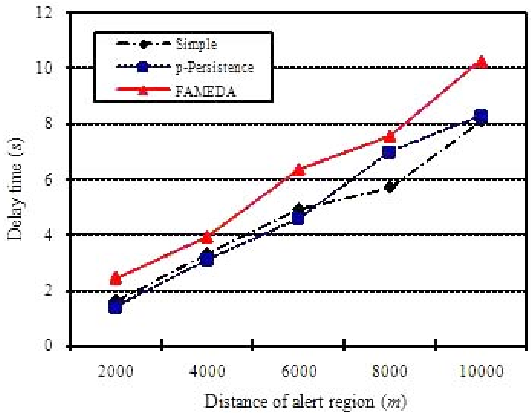

Figure 4.3 Delay time with alert region distance.

Message dissemination delay is shown in Figure 4.3. In FAMEDA, the sender node passes an alert token to the farthest vehicle traveling in opposite direction in case that a vehicle does not exist in backward transmission range. The vehicle which receives the token keeps it until it encounters a vehicle in opposite direction, then passes the token to the vehicle. Because the traveling time of the vehicle with the token is added in total delay, The delay of FAMEDA is little longer than that of other algorithms

Table 4.2 Analysis result of FAMEDA performance.

	Fuzzy sets for rebroadcast					Rebroadcast probability
	VL	L	M	H	VH	
# of occurrences	63	86	119	167	194	629/1328 ≒ 0.47

Table 4.2 shows the number of occurrences of the fuzzy sets for rebroadcast in FAMEDA performance in case that the distance of alert region is 10 Km. The rebroadcast probability is computed by the number of rebroadcast nodes over total number of nodes. Therefore, the rebroadcast probability of FAMEDA is 629/1328≒0.47. We know that the rebroadcast probability of FAMEDA is smaller than that of p-Persistence, so the number of alert message collisions of FAMEDA is lower than that of p-Persistence.

5. Conclusions

Since most applications in VANETs favor broadcast transmission as opposed to point-to-point routing, routing protocols should be designed to address the broadcast storm problem to avoid unnecessary loss of important safety related packets during message propagation.

In this paper, we presented a fuzzy alert message dissemination algorithm to improve performance for road safety alert application in VANET. In the proposed algorithm, when a vehicle receives an alert message for the first time, the vehicle rebroadcasts the alert message according to the fuzzy control rules for rebroadcast degree, where the rebroadcast degree depends on the current traffic density of road and the distance between source vehicle and received vehicle. Also, the proposed algorithm is the hybrid algorithm that uses broadcast protocol together with token protocol according to traffic density. The performance of the proposed algorithm is evaluated through simulation and compared with that of other alert message dissemination algorithms. From the performance evaluation, we know that FAMEDA is superior to other algorithms in collision and success rate, but the FAMEDA is little longer than other algorithms in time.

Our future work includes a performance evaluation of FAMEDA through changing simulation environment and the different distributions of vehicle traffic, and studying on an adaptive alert message dissemination algorithm which considers the conditions of road shapes and the number of lanes.

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