A Fuzzy logic based Next-hop Selection Scheme for Emergency Message Propagation in VANETs

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Abstract: Vehicle Ad hoc Networks (VANETs) with a large number of roadside and vehicle on board devices can provide various services for users. To improve the road safety services, the emergency message generated by safety-related devices which are closest to the dangerous spot should be propagated to the other nearby vehicles immediately when road traffic accidents or dangers are detected. As road safety is a time-criticality problem, so choosing a suitable next-hop is very important for in time message propagation under unicast situations. To address this, this paper presents a next-hop selection scheme in VANETs for propagating and relaying emergency message. A fuzzy logic time-distance headway based next-hop selection scheme is proposed, which has considered the influences of the following three factors: distance headway factor, time headway factor and signal strength factor. Compared with the conventional next-hop selection schemes, the number of informed vehicles and the probability to inform a vehicle both have much better performances than the conventional schemes. Therefore, the proposed next-hop selection scheme for propagating emergency message from the safety-related devices can be used to keep road safety by avoiding unnecessary road collisions.

Key–Words: Fuzzy logic time-distance headway, next-hop, emergency message, road safety

1 Introduction

Recently, with increasing number of vehicles, road traffic accidents are increased dramatically, which have brought many serious safety related issues. Therefore, it is necessary to solve the road safety problems for saving people's lives. Vehicle Ad hoc Networks (VANETs) with a large number of roadside and vehicle on board devices have received wide attention, which can provide various kinds of services for the people on vehicles. Road safety in the transportation system is one of typical services(e.g., collision avoidance, dangerous alter, driving assistance) based on VANETs, which is applied for protecting people from road traffic accidents and dangers.

The VANET is a special case of Mobile Ad hoc Networks (MANETs) [1]. the VANETs have several features which are different with the MANETs. In fact, the VANETs have several typical features which are different with the MANETs, such as the vehicles are served as mobile nodes, the topologies are changed rapidly while predictable, no energy limitations, and information of road conditions can be obtained by outside equipments (road side equipments) or inside equipments (vehicle on board equipments) by vehicle to road side units (V2R) communications and vehicle to vehicle (V2V) communications [1]. Hence, the VANETs environment can be used to provide lots of road safety-related services for users based on these special features.

When a road traffic accident or danger is detected, the emergency message will be generated by the vehicles which located around the dangerous spots, and then propagated to nearby vehicles immediately. The threatened vehicles are the nearby vehicles which approaching to the dangerous spots. Hence, the proceeding vehicles can take measurements in advance for avoiding unnecessary crashes after they have received the emergency message. To achieve this aim, it asks for the vehicles in the dangerous spot to alter an emergency message and then propagate this message to the nearby vehicles by multi-hop immediately. Therefore, timely emergency message propagation is highly related to the road safety and even the people's lives. Actually, choosing suitable next-hop is the key process for timely message propagation in the multi-hop networks.

To meet the requirements of the emergency situations, this paper proposes a new next-hop selection scheme, which is suitable to ensure the safety of the most threatened vehicles, and as well as all the nearby approaching vehicles. The proposed scheme can be shortly described as follows: if vehicles are located in the dangerous area, a proposed fuzzy logic time-distance headway based next-hop selection scheme is applied, and if the vehicles are located in the safety area, a distance-headway based next-hop selection scheme is applied.

The rest of this paper is organized as follows. In section II, related works are presented and analyzed. In Section III, the proposed scheme is described in detail. The performances are evaluated in the Section IV. Finally, the conclusion and future work are discussed in Section V.

2 Related Works

In self-organized MANETs, the multi-hop message dissemination is the main way for propagation message from source nodes to destination nodes if there is no direct-connected path. Thus, in the multi-hop solution, the next-hop selection is the key process for successful message propagation.

For example, Authors in [2] indicated that a suitable hop-based priority technique would lead to less data packets contention when multimedia streaming service was provided for certain home applications in wireless ad hoc networks. Besides, the research [3] showed that a multi-hop reservation method based on changing period for path nodes would guarantee low end-to-end latency and high power efficiency in wireless sensor networks when data delivered from sensors to a home based station. Besides, authors in [4] chose the tall vehicles as the next-hop relay nodes, as they found out that the height of receiver antenna installed on vehicles had significant influences on effective communication in the VANETs, due to the tall vehicle nodes had better channel than low vehicles. From the above three cases, it is easy to get the conclusion that the next-hop selection is very important for data propagation in every kind of ad hoc networks.

Back to the VANETs environment, most researchers focus the researches on choosing the next-hop based on the distance headway (headway is a measurement of the distance or time interval between vehicles in a transit system [5]). Such as, the authors in [6][7] and [8], both of them set the routing path based on the distance headway. According to [6][7][8], the most nearest vehicle to the sender vehicle was treated as the most threatened one.

Take the scenario presented in Fig.1 as an example, in this figure, all the vehicles have the same moving directions in these three lanes. *d1* to *d7* stand the distances to the dangerous spot for the vehicles from *C1* to *C7*, and $d1 < d2 < d3 < d4 < d5 < d6 < d7$. The red arrow curve stands for the propagation path. Based on the distance headway schemes, the vehicle *C1* was the most threatened vehicle in the Fig.1. So the nearest vehicle *C1* was selected as the first next-hop for propagation and relay. Actually, in some cases, this distance headway based next-hop selection scheme was feasible.

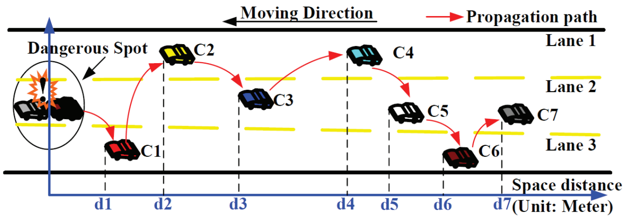

Figure 1: Conventional distance-headway based next-hop selection scheme.

However, the safety-related emergency message propagation is a time-criticality problem, so in the severe emergency situations, the most threatened vehicles are the ones which will arrive at the accident spot at the earliest time, instead of the distance-nearest ones.

Take the scenario presented in Fig.2 as an example, in this figure, all the vehicles have the same moving directions in these three lanes. *t1* to *t7* stand the needed time to arrive at the dangerous spot for the vehicles from *C1* to *C7*, and $t3 < t1 < t2 < t5 < t4 < t7 < t6$. The red arrow curve stands for the propagation path.

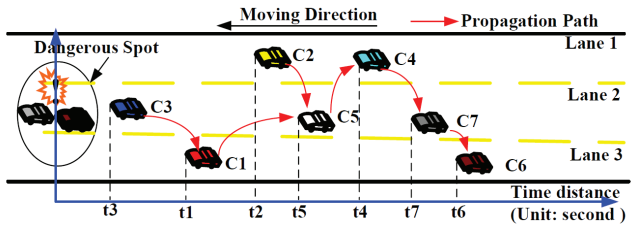

Figure 2: Time-headway based next-hop selection scheme.

Clearly, the vehicle *C3* will arrive at the dangerous spot first, so *C3* must be the most threatened vehicles. Even though *C1* is the nearest to the dangerous spot, the *C1* is not the possible first one to crash with the dangerous spot. This indicates that, choosing the next-hop based on the distance headway sometimes cannot ensure the safety of the most threatened vehicle. It is easy to understand this point, e.g., when vehicles driving in different lanes at different speeds, the time intervals for arriving at the dangerous spot will be surely different even under the same distance to the dangerous spot, just as shown in the Fig.1 and the Fig.2.

From the above analysis, it is easily to get the conclusion that the distance-headway based next-hop selection is not always feasible. So authors in [9] turned to the time-headway based multi-hop path selection for improving channel utilization in VANETs. But if just based on the time-headway to choose the next-hop, the packets contention would be high. Thus, [10] proposed a time and location-critical framework for emergency message propagation, which considered the time headway and the distance headway both. Even the combined time and distance headway schemes have better performances than the single time headway or the distance headway based schemes, there still have space to be improved when considered the power of the sender message. If the signal power or signal strength of sender is not enough for arriving at the destination, the selected path would be unfeasible no matter based on time headway or distance headway. Therefore, the signal strength is a key factor that should be considered for a better message propagation.

Considering the features of the distance-headway based scheme and time-headway based scheme, and also the features about the signal strength factor of the message packets, a fuzzy logic time-distance headway based next-hop selecting scheme is proposed in this paper. The proposed scheme has wider road safety related scenarios for emergency message and also other kinds of data propagation among vehicles than the two conventional schemes.

3 Proposed Scheme

A time-distance headway based next-hop selection scheme was designed according to the vehicles' location areas in our previous scheme presented in [11]. However, this previous proposed scheme still has space to be improved, as the signal strength factor was not considered. To enhance this and to make it more suitable for the emergency message propagation in realistic, a fuzzy logic time-distance headway based next-hop selection scheme is proposed in this paper.

3.1 Introduction of the Fuzzy Logic Time-Distance based Next-hop Selection Scheme

Fuzzy logic is an engineering technique used in uncertain systems [12]. In the fuzzy logic system, a fuzzy variable is assumed to have multi-valued linguistic value, which is opposed to crisp logic or two-valued logic [12]. As the next-hop selection is restricted by several factors, the mathematical method of selecting suitable next-hop is quite complex if includes all factors. However, the fuzzy logic method can include all the possible factors, because all these factors can be set as the inputs of the fuzzy logic system. Therefore, by using the fuzzy logic method, it is easily to change the complex problem into simple.

In this paper, we suppose the message is propagated to the nearby vehicles by unicast, only the suitable next-hop vehicle would be received the message, and the others couldn't receive this message.

The proposed fuzzy logic time-distance headway based system has considered the following three inputs when the vehicles located in the dangerous area: the Distance Headway Factor (*DHF*), the Time Headway Factor (*THF*) and the Signal Strength Factor (*SSF*) of the message packet. The output of this system is the Probability of being Chosen as the Next-hop (*PCN*). Based on the fuzzy logic theory [12][13], this proposed system can be presented as Fig.3.

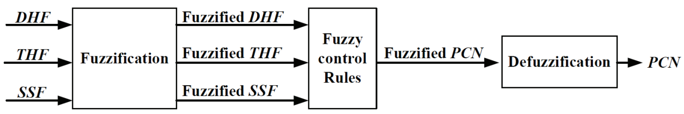

Figure 3: Fuzzy logic system for next-hop selection in dangerous area.

In the following, the detail of the inputs and output will be introduced.

- **A. Distance Headway Factor (*DHF*)**

Suppose each vehicle has the same transmission range noted as R. Similar to the calculation method proposed by [14], the sender vehicle will calculate a *DHF* that related to the back proceeding vehicle i as

$$DHF(i) = \begin{cases} 1 - \frac{d(i)}{R} & d(i) \leq R \\ 0 & d(i) > R \end{cases} \tag{1}$$

Here, *d(i)* is the distance headway between the vehicle i and the sender vehicle.

This input helps to find the probability of the vehicle i to be selected as the next-hop from the distance headway views.

Here, the *DHF(i)* has three linguistic values: *DHF(i)* = {Low, Medium, High}. From the formula (1), the range of *DHF(i)* is obtained as [0, 1]. Therefore, the membership functions of the *DHF(i)* can be depicted in Fig.4(a).

For easily to understand the proposed fuzzy logic based scheme, a definition for membership function is present here. The membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as

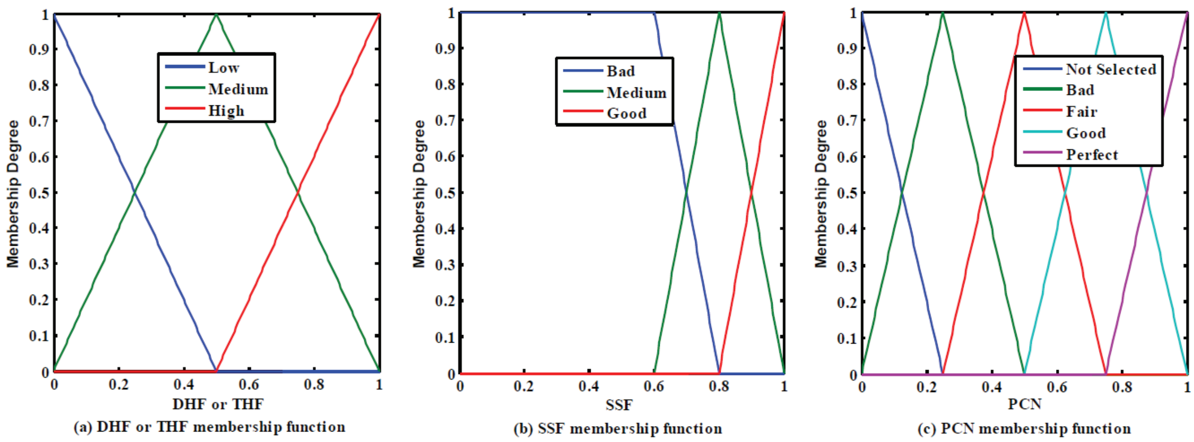

Figure 4: Membership Functions of the *DHF*, *THF*, *SSF* and *PCN*.

an extension of valuation, and fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition [16]. Thus , the Fig.4 show the degree of truth of the *DHF*, *THF*, *SSF* and *PCN*.

- **B. Time Headway Factor (*THF*)**

Suppose the current speed of vehicle i is v, the current distance to the dangerous spot is $d_{spot}(i)$, and the maximum allowed speed for each vehicle is S_{max}, so the minimum needed time interval from current location to arrive at the dangerous spot can be calculated as

$$T_{min}(i) = \frac{d_{spot}(i)}{S_{max}} \tag{2}$$

Besides, the minimum available safe time to avoid possible collisions can be set as

$$T_{safe} = \frac{R}{S_{max}} \tag{3}$$

Then, the sender vehicle will calculate a *THF* related to the back proceeding vehicle i as

$$THF(i) = \begin{cases} 1 & t(i) < T_{safe} \\ \frac{t(i)}{T_{min}(i)} & t(i) \geq T_{safe} \end{cases} \tag{4}$$

Where $t(i)$ is the time headway between the sender vehicle and the back proceeding vehicle i.

This input helps to find the probability of the vehicle i to be selected as the next-hop from the time headway views.

Here, the *THF(i)* has three linguistic values as: *THF(i)* ={Low, Medium, High}. From the formula (4), the range of *THF(i)* is calculated as [0, 1]. Since the linguistic values of *DHF* are the same as the *THF*, so the *DHF* and *THF* have the same membership functions. Therefore, the graphs of their membership functions can be merged into one figure, as shown in the Fig.4(a).

- **C. Signal Strength Factor(*SSF*)**

Suppose the strength of the propagated signal in the sender vehicle is SS_{sender}, and in the possible next-received proceeding vehicle i is $SS_{receiver}$, then the *SSF(i)* can be calculated as

$$SSF(i) = \begin{cases} \frac{SS_{receiver}}{SS_{sender}} & d(i) \leq R \\ 0 & d(i) > R \end{cases} \tag{5}$$

This input helps to find the probability of the vehicle i to be selected as the next-hop when the signal strength is enough for transmitting the message to the vehicle i. From formula (5), if the vehicle i is not located in the available communication range of the current sender vehicle, the vehicle i has no probability to be selected as the next-hop. And if the vehicle i is within the transmission range of the sender, the probability to be selected as next-hop is depended on the signal strength in the sender and the possible receiver.

Here, the *SSF(i)* has three linguistic values as: *SSF(i)* ={Bad, Medium, Good}. From the formula (5), the range of *SSF(i)* is [0, 1]. The membership functions of the *SSF(i)* can be depicted in Fig.4 (b).

- **D. Probability of being Chosen as Next-hop(*PCN*)**

The probability of being chosen as the next-hop *PCN* is the output of the fuzzy system. According to fuzzy control rules, different linguistic values of the three inputs will bring out different output values.

Here, the linguistic values of *PCN* are set as *PCN*={Not Selected, Bad, Fair, Good, Perfect}, and the range of *PCN* is [0, 1]. The membership functions of *PCN* are shown in Fig.4(c).

According to the fuzzy logic theory [12], if the system has F fuzzy inputs with L linguistic values each, there would be F^L rules. In fact, the number of rules can be reduced if the system has special requirements. Based on the features of *DHF*, *THF*, and *SSF*, the sender vehicle uses the **IF/THEN** rules to calculate the probability of the back proceeding neighbor vehicles to be selected as the next-hop. One of the rules can be written as: **IF** *DHF* is Low, *THF* is Bad and *SSF* is Bad, **THEN** *PCN* is Bad. To save the space, this paper just lists six rules to give examples, as listed in TABLE 1.

Table 1: Fuzzy logic control rules.

Rules	*DHF*	*THF*	*SSF*	*PCN*
Rule1	High	High	Good	Perfect
Rule2	Medium	High	Good	Good
Rule3	High	Low	Good	Fair
Rule4	Medium	Medium	Medium	Fair
Rule5	Low	Medium	Bad	Bad
Rule6	Low	Low	Bad	Not Selected

Here, Center of Gravity (COG) method [12] is used to defuzzify the fuzzified *PCN* results. After defuzzification, the sender vehicle will select the highest *PCN* vehicle as the next-hop, and then transmit the message to the vehicle with highest *PCN*.

In all, this proposed scheme is shown in Fig.5, where *ti* and *di* stand for the time headway and distance headway between the vehicle i and dangerous spot, respectively. R is transmission range of each vehicle. D is the extension area of the dangerous area. All the vehicles have the same moving directions in the two lanes in the Fig.5 .

Thus, the proposed scheme can be summarized as following: if vehicles are located in the dangerous area, the fuzzy logic time-distance headway based scheme will be employed, and the next-hop vehicle is the one with the highest *PCN* to the sender vehicle; while if vehicles are located in the safety area, the distance-headway based scheme (shown in the Fig.1) will be used, and the next-hop is the one which is the nearest to the sender vehicle.

As the emergency message is greatly related to the road safety issues, the more surround nearby vehicles can be informed by the emergency message, the more vehicles can be rescued and more road accidents can be avoided. Besides, the higher probability to receive the message, the more road accidents can be avoided as well. Thus, the number of informed vehicles and the probability to inform vehicles can be used to evaluate the performances of the next-hop selection scheme.

In the following, a numerical analysis of the proposed scheme will be held from two aspects: the number of informed vehicles and the probability to inform vehicles.

3.2 Numerical Analysis of the Proposed Scheme

Suppose the average number of vehicles in a given area with unitary extension is equal to N(a constant in a given road area), so the area with x extension should have Nx vehicles. As vehicles' distribution on the road is followed to Poisson distribution with parameter Nx [7], then the probability that k vehicles in the area of extension x can be described as

$$P(k,x) = \frac{(Nx)^k e^{-(Nx)}}{k!} \tag{6}$$

This paper will employ the warning delivery model proposed by [7]. The speed of vehicles is obeyed zero mean Gaussian distribution [15]. So the time headway of vehicle i can be calculated by the relative speed v_{relat} to the sender vehicle and distance *d(i)* to the around sender vehicle. Then, the time headway $T_{headway}$of the vehicle i will be as

$$T_{headway} = \frac{d(i)}{v_{relat}} \tag{7}$$

The formula of *S(n)* is used to calculate the probability that n vehicles are informed within the extension *d(i)*, which can be depicted as

$$S(n) = P[n, d(i)]\alpha^n = \frac{[Nd(i)]^n e^{-Nd(i)}}{n!}(1-e^{-Nd(i)})^n \tag{8}$$

Where, α is the probability that two consecutive vehicles are direct-connected, and *P[n,d(i)]* is the probability that n vehicles in the area of *d(i)*.

Clearly, in the dangerous area, the *S(n)* is given by two contributions. One is the joint probability that n vehicles are direct-connected in the area of T and another is that more than n vehicles in the area of T, but only the first n of them are direct-connected[7]. Suppose the distance headway between two consecutive vehicles is followed to exponentially distribution with parameter γ. Thus, the *S(n)* can be written as

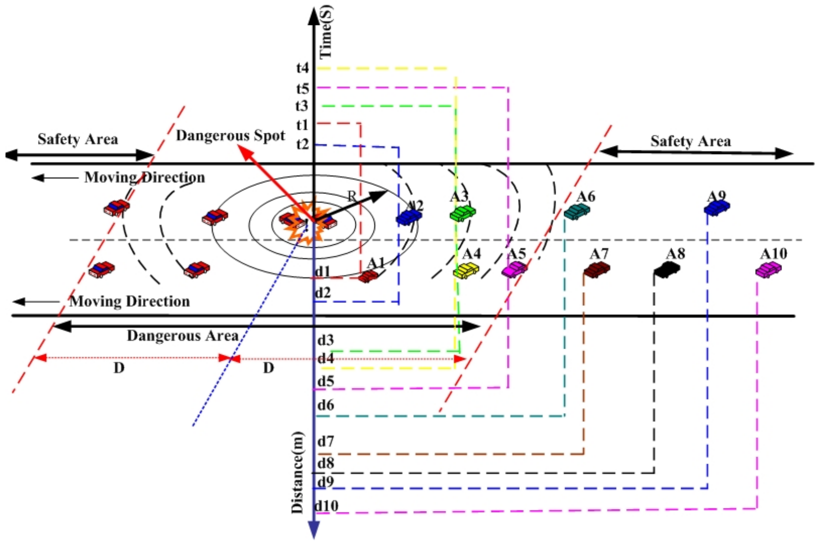

Figure 5: The proposed fuzzy logic time-distance headway based next-hop selection scheme.

$$\begin{aligned} S(n) &= P[n,T]\alpha^n + \sum_{m=n+1}^{\infty} P[m,T]\alpha^n(1-\alpha) \\ &= \frac{(\gamma T)^n e^{-\gamma T}}{(n)!}(1-e^{-\gamma T})^n + \\ &\sum_{m=n+1}^{\infty} \frac{(\gamma T)^m e^{-\gamma T}}{m!}(1-e^{-\gamma R})^n e^{-\gamma R} \end{aligned} \quad (9)$$

Then, the number of informed vehicles in the extension area of T can be obtained as

$$\widetilde{S} = S(n)TN \quad (10)$$

Set Q as the probability to inform a vehicle, then the average probability $\widetilde{Q}$ to inform a vehicle in the extension T can be described as

$$\widetilde{Q} = \frac{\widetilde{S}}{\gamma T} \quad (11)$$

Set $d_{spot}(i)$ as the distance between vehicle i and the dangerous spot, and set the area of extension D is the dangerous area. Then if $d_{spot}(i) < D$, the vehicles are located in the dangerous area, and the next-hop is chosen based on the fuzzy logic time-distance headway. If $d_{spot}(i) > D$, the vehicles are located in the safety area, and the next-hop is chosen based on the distance-headway.

Thus, the process of the proposed scheme can be described in Fig.6.

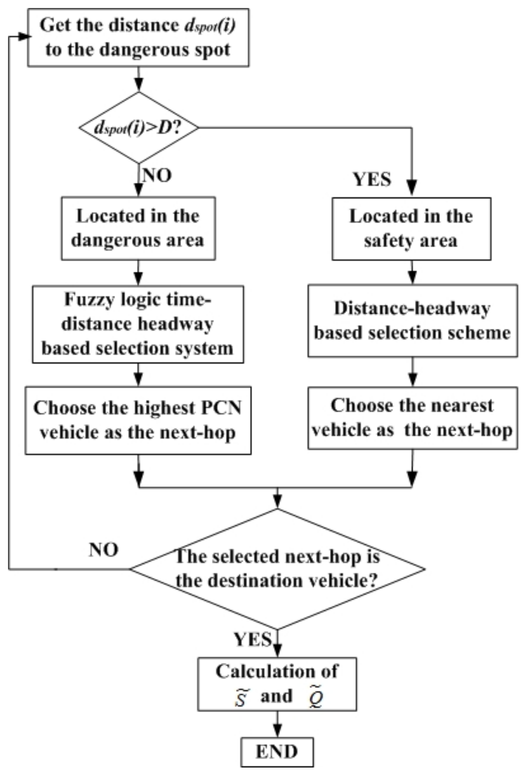

Figure 6: Process of the enhanced proposed scheme.

4 Performance Evaluation

4.1 Simulation Scenario

To evaluate the proposed scheme, simulation is done in a 3000 meters 2-way 4-lane road scenario. The related simulation parameters are listed in Table 2.

Table 2: Simulation Parameters.

Name	Value
Simulation road type	2-way 4-lane road
simulation road range	3000(meters)
Vehicles' maximum speed S_{max}	70(Km/Hour)
Transmission Range R	100(meters)
Range of dangerous area D	300(meters)
The unitary extension range	1000(meters)
Simulation time	200(seconds)
Parameter γ	0.2(vehicle/second)
Probability α	0.1, 0.5, 0.9

4.2 Simulation Results

To compare the performances, four different schemes are simulated: the distance-headway based scheme, the time-headway based scheme, the time-distance headway based scheme, and the proposed fuzzy logic time-distance headway scheme. Here, three values of α are simulated as $\alpha = 0.1$, $\alpha = 0.5$ and $\alpha = 0.9$ to compare the $\widetilde{S}$ and $\widetilde{Q}$ under the four different schemes.

(1) The case of $\alpha = 0.1$

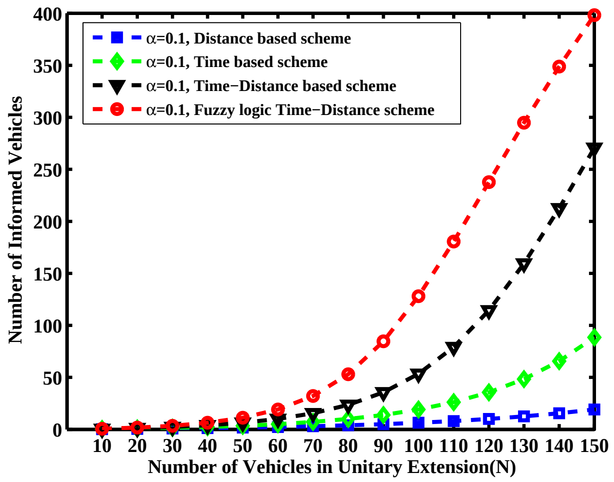

Figure 7: Average number of informed vehicles under four schemes when $\alpha = 0.1$.

As shown in Fig.7 and Fig.8, when the probability of two consecutive vehicles direct-connected α is fixed at $\alpha = 0.1$, the $\widetilde{S}$ and $\widetilde{Q}$ both are increased with the increase of the number of vehicles N in the unitary extension.

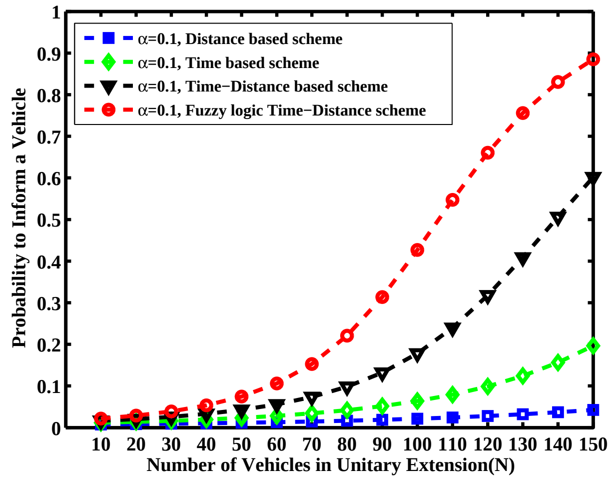

Figure 8: Probability to inform a vehicle under four schemes when $\alpha = 0.1$.

From the Fig.7 and the Fig.8, when the N is less than about 50($N < 50$), the four schemes have almost the same performances of the $\widetilde{S}$ and $\widetilde{Q}$. This phenomenon can be explained from the following two aspects:

The first aspect, in the simulation scenario, the unitary extension is set to 1000 meters (as listed in Table 2). If the $N < 50$, the available connected links among each vehicle is very few as there are only less than 50 vehicles in the range of 1000 meters, so when the sender vehicles select the next-hop via four different schemes, there are few available communication links, which will result in the phenomenon that few message will be received and propagated.

The second aspect, when the $\alpha = 0.1$, the probability of the two consecutive vehicles direct-connected α is just 0.1, this is a very low value, which means the two consecutive vehicles only has a 0.1 probability to direct-connected with each other (or within each other's available communication range). Thus, when the number of vehicles is few ($N < 50$), the possible receiver vehicles may not in the communication range of the sender vehicles, and the available communication may not be successful built. Therefore, no matter what kinds of schemes are selected, the probability of available communication is very low. Thus, the small values of the N and the α both have great impacts on the performances of the $\widetilde{S}$ and $\widetilde{Q}$. So these four schemes present almost the same performances when the $N < 50$.

However, when the $N > 50$, the proposed fuzzy logic time-distance scheme has the best performances compared with the other three schemes. This because, the fuzzy logic based scheme chooses the possible next-hop from the highest *PCN* vehicles which has considered the impacts of the three factors (*DHF*,*THF*, and *SSF*). Especially, the *SSF* is the key factor for the successful propagation. However, the two conventional schemes only have considered one factor such as the distance headway or the time headway, and the time-distance based scheme has only considered the combined *DHF* and *THF* factors. As we mentioned above, if the next-hop is selected just based on the *DHF* or *THF* or the combined two factors, the message may not be propagated successfully due to the selected next-hop may not in the communication range of the sender vehicles. By contrast, the fuzzy logic based scheme is chosen the next-hop from all the available connected vehicles which within the transmission range to ensure successful propagation. Therefore, the $\widetilde{S}$ and $\widetilde{Q}$ both are increased a lot under the fuzzy logic based scheme when the $N > 50$, compared with the other three schemes.

(2) The case of $\alpha = 0.5$

As shown in Fig.9 and Fig.10, when the probability of two consecutive vehicles direct-connected is fixed at $\alpha = 0.5$, the $\widetilde{S}$ and $\widetilde{Q}$ both are increased with the increase of the N.

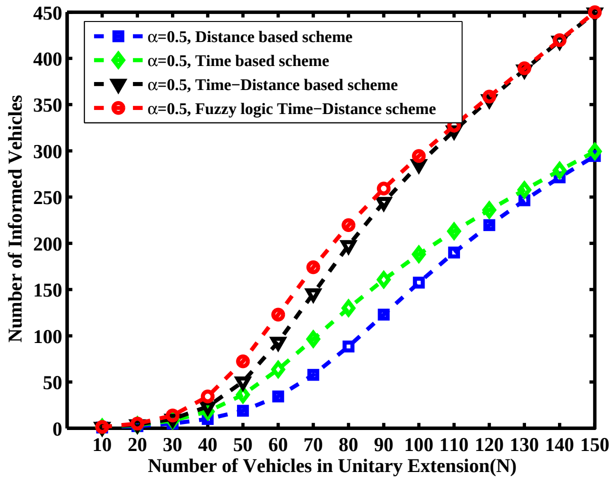

Figure 9: Average number of informed vehicles under four schemes when $\alpha = 0.5$.

Similar with the Fig.7 and the Fig.8, when the $N < 50$, these four schemes present almost the same performances. The reasons are the same as we mentioned for explaining the Fig.7 and the Fig.8, due to the small value of the N and the α. For save space, this paper will not repeat this reasons again.

Besides, in the Fig.9 and the Fig.10, when the $N > 100$, another phenomenon also needs to be pointed out: the fuzzy logic based scheme has better performances than the distance based scheme and time based scheme, but the performances are almost the same as the time-distance based scheme. The reasons for this can be explained as: if there are more than 100 vehicles($N > 100$) in the unitary extension, then the average distance between two adjacent vehicles is about 10 meters, which means the two adjacent vehicles are located in each other's available communication range(R=100 meters). In this situation, the *SSF*factor is always strong and each possible link can be used for the message propagation, so the *SSF* factor is not the key factor in this situation. Thus, the *DHF* and the *THF* factors have greater effects than the *SSF* for the performances. Therefore, the proposed scheme has almost the same performance as the time-distance headway based scheme. In addition, when the $N > 100$, the fuzzy logic based scheme and time-distance based scheme both have considered the *DHF* and *THF* two factors, and the combined two factors surely have better performances than the single factor *DHF* or *THF*. Hence, these two schemes have better performances than the two conventional distance-headway based scheme and the time-headway based scheme.

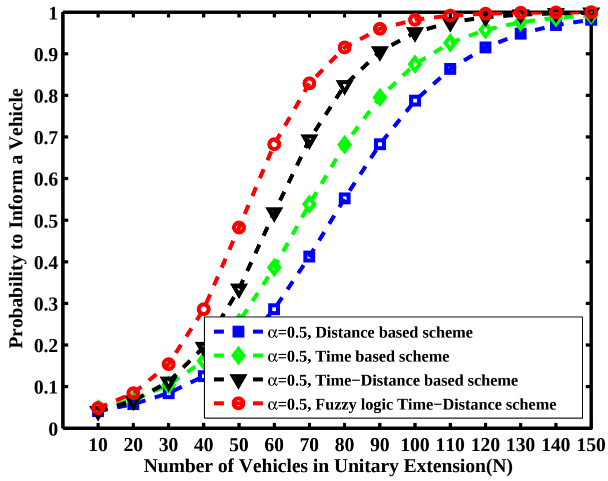

Figure 10: Probability to inform a vehicle under four schemes when $\alpha = 0.5$.

(3) The case of $\alpha = 0.9$

When the probability of two consecutive vehicles direct-connected α is fixed at $\alpha = 0.9$, the simulation results of the $\widetilde{S}$ and $\widetilde{Q}$ are shown in the following Fig.11 and Fig.12.

Two typical features are revealed from the above two figures. The first feature is that the proposed fuzzy logic based scheme has almost the same performances

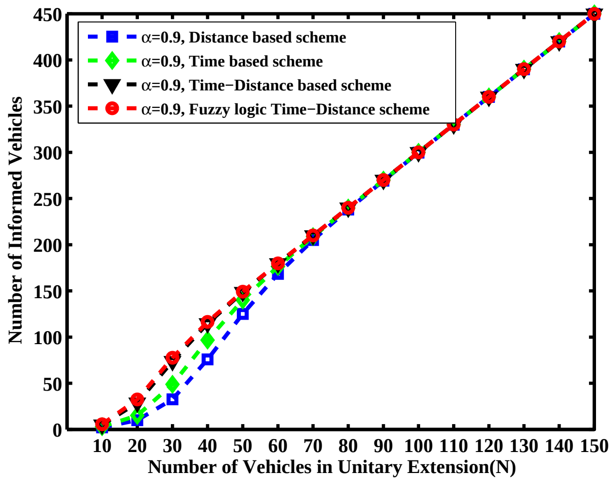

Figure 11: Average number of informed vehicles under four schemes when $\alpha = 0.9$.

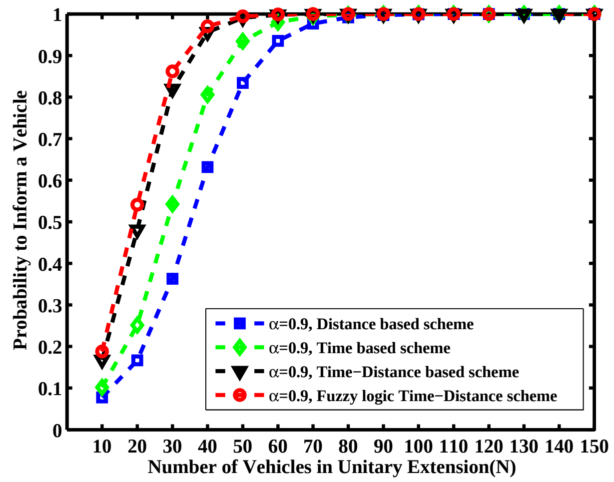

Figure 12: Probability to inform a vehicle under four schemes when $\alpha = 0.9$.

as the time-distance scheme proposed in[11]. The second feature is that when $N < 50$, the proposed fuzzy logic based scheme and the time-distance scheme have slightly better performances than the distance-headway based scheme and the time-headway based scheme, but these four schemes have almost the same performances when $N > 50$.

The reasons for the first feature can be explained as follows: the fuzzy logic based scheme has considered three factors as *DHF*, *THF*, and *SSF*, and the time-distance headway based scheme has only considered two factors as *DHF* and *THF*. As mentioned before, the difference between this two schemes is included or not included the *SSF* factor. However, in the $\alpha = 0.9$ case, the α is much higher than the above two cases ($\alpha = 0.1$, and $\alpha = 0.5$). In this case, if the vehicles are within the transmission range of each other, the successful transmission is possible all the time, no matter by the time-distance headway or fuzzy logic time-distance headway. Thus, the *SSF* factor shows very slight impacts on the message propagation, but the other two factors(*DHF*, *THF*) play more important roles for the successful transmission. Therefore, when $\alpha = 0.9$, the performances of fuzzy logic based scheme and the time-distance based scheme are almost the same.

The reasons for the second feature can be explained as follows: even though the two consecutive vehicles have much higher probability ($\alpha = 0.9$) that within the transmission range of each other, the density of vehicles in the unitary extension is low (as the $N < 50$), thus the *DHF* and *THF* two factors both have un-ignored impacts on the propagation. If ignores one of these two factors, the results would be worse, just as the results shown by the distance-headway based scheme or the time-headway based scheme. So when the $N < 50$, the fuzzy logic based scheme and time-distance based scheme both have slightly better performances than the distance-headway and the time-headway based schemes. By contrast, when the $N > 50$ and the $\alpha = 0.9$, the four schemes have almost the same performances, due to the high density of vehicles in the unitary extension and high probability of two consecutive vehicles.

In addition, the revealed two features are quite different with the results shown in the Fig.7 to the Fig.12. This because the values of α are different, higher value of the α surely shows better performances than the lower value of the α.

In all, it is easily to get the conclusion that, higher value of the α surely shows better performances than the lower value. The number of informed vehicles and the probability to inform a vehicle both improved a lot by the proposed fuzzy logic time-distance headway based next-hop selection scheme when compared with the other three schemes. The simulation results indicated that ignored any one of the three factors (*DHF*, *THF* and *SSF*), the results would be worse, especially in the case of small values of the α and the N. Thus, with higher probability to inform vehicles, more vehicles will be informed, more messages will be successfully propagated and more road accidents will be avoided.

5 Conclusion and Future Work

This paper discusses a fuzzy logic time-distance headway based next-hop selection scheme for emergency message propagation in VANETs for road safety. The proposed scheme has considered the signal strength factor to select the next-hop for the vehicles located in the dangerous area, and to ensure the most threatened vehicles to receive the message in advance to avoid unnecessary collisions. The the numerical analysis evaluation results indicate that this proposed scheme has better performances than the other conventional schemes. Thus, by using the proposed fuzzy logic time-distance headway based scheme, the emergency message can be received by more vehicles in advance, and each vehicle also has a higher probability to propagate the received message to the surround vehicles. For the future works, the authors will design numerical analysis of the propagation time of the selected next-hop propagation path.

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Acknowledgements: This work was supported by the National Natural Science Foundation of China (Grant No.61401387, 61472343 and 61301111), the Universities Natural Science Research Project of Jiangsu Province(NO.14KJB510035), and the Natural Science Foundation of Yangzhou City(Grant No.YZ2014054).