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V2V Routing with Fuzzy Inference Mechanism in Vehicular Networks

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ABSTRACT

The 5th generation (5G) mobile communication technology is an important technology for high throughput, low latency and high reliability. Vehicular Ad-hoc Networks (VANET) provides information switching through Vehicle-to-Vehicle (V2V) wireless network communication technology, where the performance requirements for low latency and high transmission capacity is the most challenging. The multi-hop routing-linking strategies investigated in previous works, First Nearest Vehicle (FNV), Second Nearest Vehicle (SNV) and Third Nearest Vehicle (TNV) can provide different requirements for the transmission delay time and transmission capacity. However, the three routing methods are suffered by the variation situation on the vehicle densities and the transmission range in vehicular network (VN). Therefore, this study explored the application of Fuzzy inference system (FIS) for the V2V routing issues. The proposed fuzzy inference routing (FIR) mechanism was designed to compromise the advantage of the multi-hop routing methods and to reach the requirements of transmission delay time and high reliability. Simulation results show that the proposed fuzzy inference routing-premium (FIR-P) can outperform the multi-hop routing methods and satisfy the 90% transmission delay less than 1ms for VN.

Key words : 5G Mobile Communication, Fuzzy Inference System (FIS), Low Latency, Vehicle-to-Vehicle (V2V) Wireless Communication.

1. INTRODUCTION

In 2020, the number of mobile devices and Internet of Things (IOT) devices will reach more than 5 billion. IoT devices such as cars, smart phones, tablets and personal computers will gradually pursue audio and video HD 4K quality and other needs more action bandwidth requirements [1]. For the developing fifth generation communication technology (5G), the major automakers around the world are constantly researching the technology of driverless vehicles, which is making vehicular networks (VNs) a hot topic through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), Infrastructure-to-infrastructure (I2I) communication technology. The vehicle-to-everything (V2X) technology provides information exchange between the cars and the cars. The VN is composed of various communication technologies, including Dedicated short-range communication (DSRC) [2], 5G, fourth-generation communication technology (4G), and Wi-Fi, etc. [3]. In the VN environments, there are many situations for V2V communications, such as unbalanced traffic configuration of the multi-path topology and low network resource usage [4]. How to simplify network management and join V2V and V2I communication technology services to build a flexible and programmable architecture will be one of the key requirements of the VN.

The multi-hop routing-linking strategies have been investigated in previous works [5]. The First Nearest Vehicle (FNV), Second Nearest Vehicle (SNV) and Third Nearest Vehicle (TNV) can provide different requirements for the delay time and transmission capacity. However, the three routing methods are suffered by the variation situation on the vehicle densities and the transmission range in the VN [5].

The fuzzy theory was proposed by Professor L. A. Zadeh in 1965 [6]. The fuzzy theory is an approximation reasoning mechanism. Therefore, this study will explore the application of Fuzzy inference system (FIS) for the V2V routing issues. The pro-posed fuzzy inference routing (FIR) mechanism was designed to compromise the advantage of the multi-hop routing methods and reach the requirements of transmission delay time and high reliability. Therefore, in this study an FIS based routing mechanism are proposed to reach the requirements of 90% transmission delay time (90%Td) less than 1 ms for VN.

2. SYSTEM MODELS

The channel model includes path loss and shadow fading. According to the characteristics of millimeter wave, the channel model of any pair of V2V links is,

$$PL_{dB}(r_j) = \alpha + \beta \times 10\log_{10}(r_j) + \xi \quad (1)$$

where r_j is the distance between any pair of V2V links (in kilometers); α and β represent the initial offset and path attenuation index, respectively; ξ is the shadow fading effect can be expressed using logarithms normal (Log-Normal) distribution of random variables by $N(m, \sigma^2)$, where m is the mean value and σ^2 is the variance.

In the V2V communications, there are two channel models with the LOS (Line of sight) and the NLOS (Non-line of sight), which can be expressed by,

$$L_{LOS}(r_j)[dB] = 69.6 + 20.9 \times \log_{10}(r_j) + \xi_{LOS} \quad (2)$$

and

$$L_{NLOS}(r_j)[dB] = 69.6 + 33 \times 10\log_{10}(r_j) + \xi_{NLOS} \quad (3)$$

respectively, where ξ_{LOS} and ξ_{NLOS} are the shadowing fading effect of LOS and NLOS environments.

The simulation environment is shown in Figure 1; in which it is assumed that the roadside unit (RSU) is located in the fog cells. All the vehicles use the millimeter wave (mmWave) to communicate with each other V2V covered by the fog cell communication range. It is assumed that the vehicle V_α is going to transmit message to the RSU by V2V, where L_α is the transmission length of the vehicle V_α to RSU.

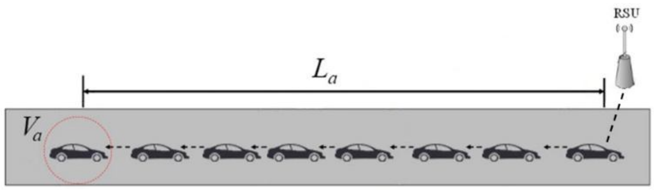

Figure 1: Multi-hop vehicle routing models. [5]

Due to the limited transmission range of the vehicles, it is assumed that there are k relay hops between the vehicle V_α and the RSU. The vehicle V_α selects other vehicles as relays to the RSU, and the total transmission delay time (T_d) of the vehicle V_α is expressed by [7],

$$T_d = (k-1)T_{pro} + \sum_{j=1}^{k}\left(T_{hop_j} + T_{retran_j}\right) \quad (4)$$

where T_{pro} is the data transfer processing time of the vehicle relay node; T_{hop_j} is the message transmission delay time between the j-th vehicle relay nodes; T_{retran_j} is the V2V retransmission time between the j-th vehicle relay nodes. When the communication transmission distance is too far, the transmission would be probably failed. Then the delay time of waiting and retransmission is required. In this study, it is assumed that it need 10 times of the slot time to retransmitted the message successfully, that is $T_{retran_j} = 10t_{slot}$.

From the channel model on (2) and (3), if the V2V wireless transmission distance is r_j, the channel gains $h(r_j)$ of LOS and NLOS are equaling to $10^{-L_{LOS}(r_j)}$ and $10^{-L_{NLOS}(r_j)}$, respectively. Then the SNR of the j-th vehicle for the V2V wireless transmission can be expressed by [7],

$$SNR_j = \frac{P_{tx}h_j}{N_0 W_{mmWave}} \quad (5)$$

where P_{tx} is the transmission power plus the antenna gain of the vehicle nodes; h_j is the channel gain between the vehicle relay nodes C_{j-1} and C_j; N_0 is the power spectral density of added white Gaussian noise (AWGN)); W_{mmWave} is millimeter wave band-width (4 GHz). Then the average transmission capacity of each V2V multi-hop link can be obtained by Shannon theory as,

$$C_j = W_{mmWave} \times \log_2(1 + SNR_j) \quad (6)$$

In this study we investigated three V2V transmission modes. In the FNV, the closest vehicle is selected as the relay point for transmission. In the SNV, the second approaching vehicle is selected as the relay point for transmission. In the TNV, it selects the third approaching vehicle as the relay point for transmission [7].

At first, we investigated the transmission delay performance of the three transmission modes FNV, SNV, and TNV for different vehicle density with $\rho = 0.01\sim0.5$ vehicle/meter. Then we obtained two examples of cumulative distribution function (CDF) of transmission delay in Figure 2 at the transmission distance $L_\alpha = 300$ meters. When the vehicle density is 0.3, as shown in Figure 2(a), it can be seen that FNV can reach more than 90% of the transmission delay time less than 1ms threshold. However, from Figure 2(b), it can be seen that FNV cannot meet the threshold of 90% or more transmission delay time below 1ms when $\rho = 0.31$. Therefore, the SNV transmission mode needs to be used instead.

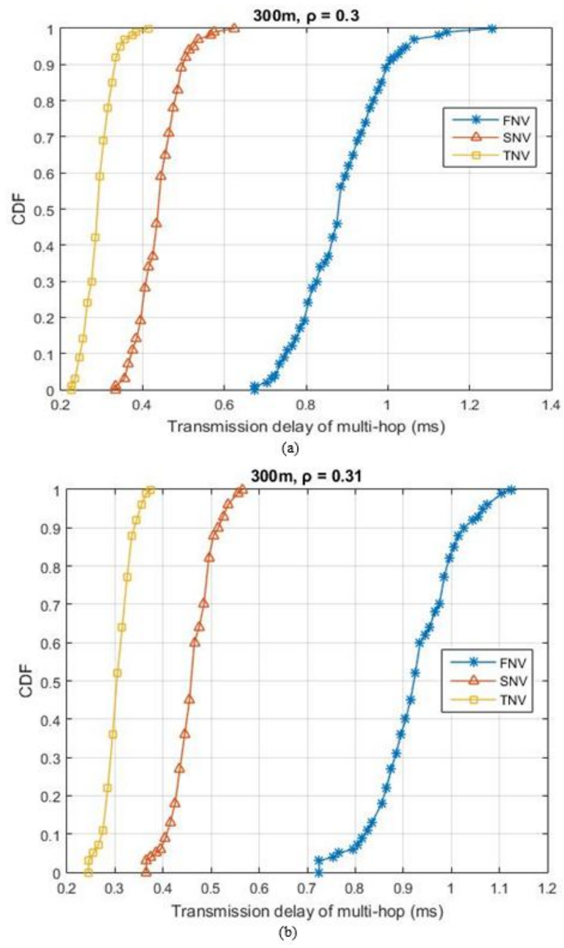

Figure 2: The CDF of transmission delay for three routing methods in VN with $L_\alpha = 300$ meter and (a) $\rho = 0.3$, (b) $\rho = 0.31$ vehicle/meter.

3. FUZZY INFERENCE ROUTING MECHANISM

Fuzzy Inference System (FIS) mainly uses the IF-THEN inferring method as the control rule. The fuzzy inference system can be constituted by four parts. One is the fuzzification on fuzzy input. The value is converted to the membership degree of triggering to the fuzzy linguistic terms. The fuzzy inference engine, according to the fuzzy rule base we designed, calculates the system input trigger to the weight value of each fuzzy rule. At last part, the defuzzification turns the results of fuzzy inference into output values [8].

First of all, we need to establish fuzzy rule bases and membership functions (MBFs) for the input and output variables. We set the membership functions of vehicle density according to the analog transmission distance L_α=300, 400, and 500 meters, respectively. Thus, we choose three Triangular MBFs to cover the entire universe of discourse of two inputs, density ρ and distance L_α and one output routing modes P, respectively. The three linguistic terms, Rare (R), Normal (N), and Crowd (C) are chosen to cover its universe of discourse of vehicle density ρ, as shown in Figure 3(a). The three linguistic terms, short (S), medium (M), and long (L), are chosen to cover its universe of discourse of the transmission distance L_α as shown in Figure 3(b). The three linguistic terms, First Nearest Vehicle (FNV), Second Nearest Vehicle (SNV), and Third Nearest Vehicle (TNV) are chosen to cover its universe of discourse of routing modes P as shown in Figure 3(c).

The Triangular MBF of the fuzzy set F_i^l in each interval $[C_i^-, C_i^+]$ of the universe of discourse U can be expressed by,

$$\mu_{F_i^l}(x_i) = \begin{cases} 1 - \frac{2\left|x_i - \bar{x}_i^l\right|}{w_i}, & \bar{x}_i^l - \frac{w_i}{2} \le x_i \le \bar{x}_i^l + \frac{w_i}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (7)$$

where $l = 1,2,3$, $i = 1,2,3$, $x_i \in [C_i^-, C_i^+]$, and $\bar{x}_i^l$ and w_i are the mean and width of the Triangular MBF, respectively.

The fuzzy control rule is represented by two inputs and one outputs by [8],

$$R_j: IF\ density(\rho)\ is\ F_1^{l_1}\ \text{AND}\ L_a\ \text{is}\ F_2^{l_2} \quad THEN\ P = F_3^{l_3} \qquad (8)$$

where $F_1^{l_1}, F_2^{l_2}$ and $F_3^{l_3}$ are the Linguistic Terms, which represent the inputs of vehicle density, transmission distance, and the output of routing methods, respectively, and $l_1, l_2, l_3 = 1,2,3$, and the index of rule $j = 1,2,\dots,9$. Then, the FIS for the VN routing can be performed as shown in Figure 4. The proposed FIS is called as Fuzzy Inference Routing-Preliminary (FIR-P). The fuzzy rules shown in Table 1, including 9 fuzzy IF-THEN rules for FIR-P, can be established heuristically by the experimental results, which infer the relations between the adequate routing methods of vehicle density and distance.

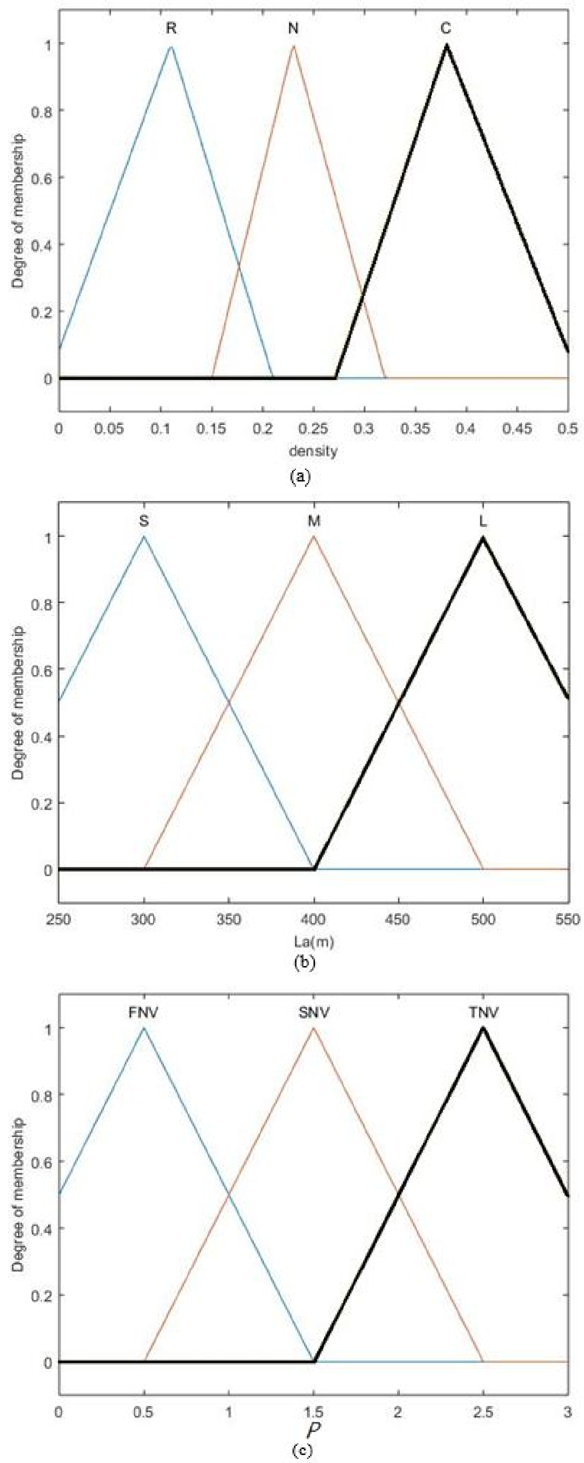

Figure 3: The membership functions of the input variables (a) density ρ and (b) distance L_α, and output variable (c) routing modes P for the proposed FIR-P scheme.

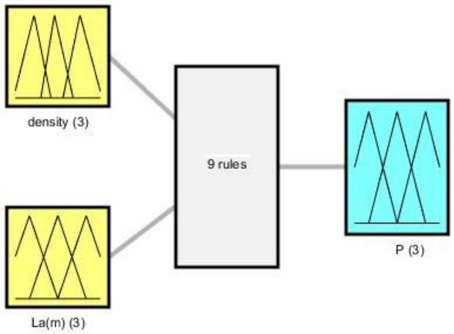

Figure 4: The fuzzy logic system for multi-hoping routings of VNs with 2 inputs, 1 output and 9 rules.

Table 1: The rule base for the proposed FIR-P.

Density (ρ) \ L_a	S	M	L
R	FNV	FNV	FNV
N	FNV	SNV	SNV
C	SNV	SNV	TNV

There are many defuzzification methods available. However, the following centroid calculation, which returns the center of area under the aggregated MBFs curve, is being employed here [8]:

$$P = \frac{\sum_{i=1}^{n} z_i \times \mu_{F_3^l}(z_i)}{\sum_{i=1}^{n} \mu_{F_3^l}(z_i)} \quad (9)$$

where n is the number of quantization levels of the output area under the aggregated MBFs, z_i is the amount of the inference output at the quantization level i and $\mu_{F_3^l}(z_i)$ is its membership value in the output fuzzy set $F_3^{l_3}$. Then, the inference 3-D results for the routings methods P in VNs can be obtained as shown in Figure 5. From Figure 5, the three-dimensional relationship between the FIR-P of the output variable obtained by the fuzzy rules and the vehicle density and L_α.

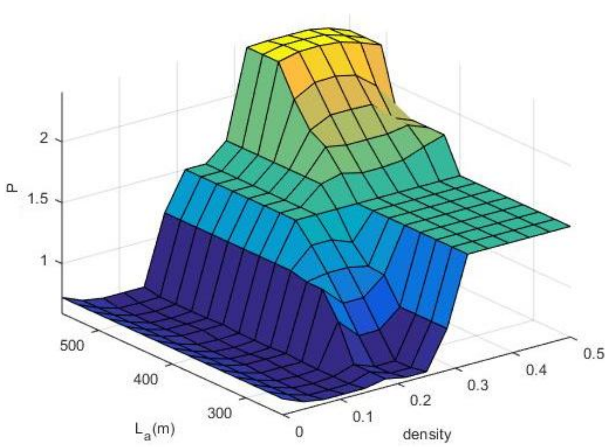

Figure 5: The 3-D inferring diagram for FIR-P scheme in VN.

4. SIMULATION RESULTS

In the simulation environments, the transmission distance L_α is set from 250 meters to 550 meters. The simulation parameters are shown in Table 2. To compromise the different transmission delay of the routing methods, we compare the performance of four methods of FNV, SNV, TNV and FIR-P. In the VN, it requires a transmission delay of less than 1 ms. In the simulation results of Figure 6 at a transmission distance of 300 meters, it can be observed that the 90% transmission delay time of the FNV exceeds 1 ms to 1.4 ms and with only 60%(T_d) less than 1ms. Moreover, the SNV and TNV can obtain 89%(T_d) and 86%(T_d) less than 1 ms, respectively. Therefore, the three methods of and the average delay time of FNV, SNV and TNV are all do not meet the requirement of low latency and reliability. However, from Figure 6, it can be seen the proposed FIR-P not only reaches the requirements of 90%(T_d) less than 1 ms but also perform the low latency with 90%(T_d) less than 0.75 ms and high reliability with 96%(T_d) less than 1 ms.

Table 2: Simulation parameters.

Total Distance (L_α, m)	250-550
Density of Vehicles (ρ, vehicles/meter)	0.01-0.5
Transmission Power of Vehicles (P_{tx}, dBm)	30
Transmission Range of Vehicles (R, m)	70
Power Spectral Density of AWGN (N_0, dBm)	-174
Bandwidth of mm Waves (W_{mmWave}, GHz)	4
SNR Minimum Threshold (θ, dB)	10
Standard Deviation of Shadowing Fading (σ, dB)	LOS: 5, NLOS: 7.6
Processing Time (T_{pro}, μs)	5
Duration of Time Slot (T_{slot}, μs)	5

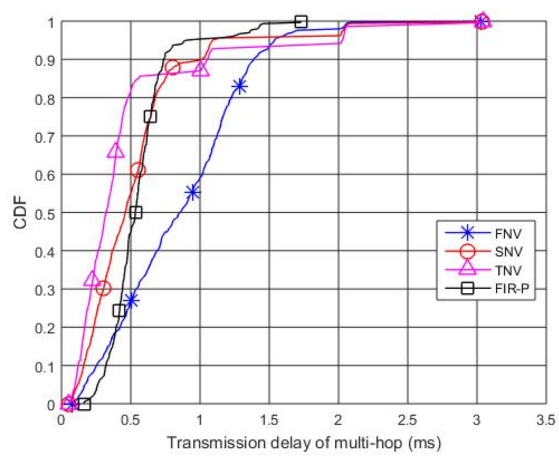

Figure 6: Comparison of CDF of transmission delay for proposed routing schemes with L_α = 300 m.

In addition, we investigate the performance of the strict requirements of 90%(T_d) below 1 ms as shown in Figure 7 for different transmission distance. From Figure 7, it can be seen that the 90%(T_d) of FNV exceeds 1 ms for all distance. the 90%(T_d) of SNV and TNV are almost little higher than 1 ms for all distance. However, the 90%(T_d) of the proposed FIR-P performed all less than 1 ms.

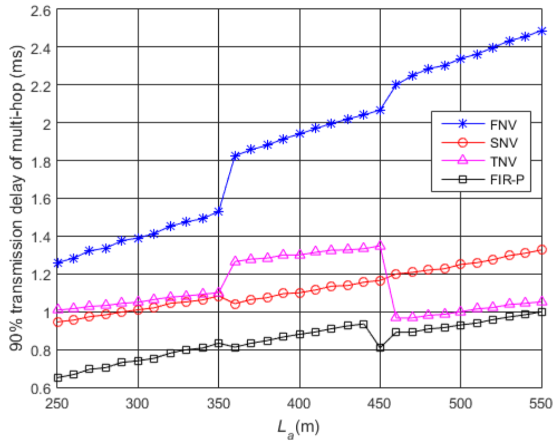

Figure 7: Comparison of 90%(T_d) for proposed routing schemes.

Furthermore, the performance of system capacity is compared in Figure 8 for different transmission distances of 250 m to 550 m with the vehicle density of ρ = 0.01~0.5 vehicles/meter. From Figure 8, it is observed that due to the FNV performing the nearest distance hops, the capacity of FNV is highest among the schemes. However, the pro-posed FIR-P outperforms the other two schemes of SNV and TNV.

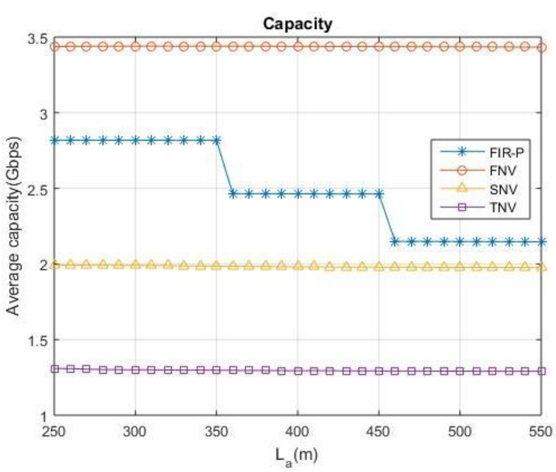

Figure 6: Comparisons of transmission capacity of the proposed routing schemes in VN.

5. CONCLUSION

In this study, we applied the FIS to propose a fuzzy inference routing mechanism under different traffic vehicle densities and transmission distances between the roadside unit (RSU). Simulation results show that the proposed FIR-P can outperform the multi-hop routing methods and satisfy the 90% transmission delay less than 1ms for VN under different vehicle densities. Moreover, the proposed FIR-P not only reaches the requirements of 90%(T_d) less than 1ms but also perform the low latency with 90%(T_d) less than 0.75 ms and high reliability with 96%(T_d) less than 1 ms at transmission distance L_α = 300 meter.

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