Constructing Alternative Routes for VANET Using Machine Learning Techniques

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Abstract

With the growth up of internet in mobile commerce, researchers have been reproducing various mobile applications that vary from entertainment and commercial services to diagnostic and safety tools. Meanwhile, mobility management has widely been recognized as one of the most challenging problems in seamless access to wireless network resource. In this paper, a novel link enhancement mechanism is proposed to deal with mobility management problem in vehicular ad hoc networks. Two machine learning technique, named particle swarm optimization and fuzzy logic systems are incorporated into the proposed schemes to enhance the accuracy of prediction of link break and congestion occurrence. The experiment results illustrate the effectiveness and feasibility of the proposed schemes.

Keywords: vehicular ad hoc network (VANET), mobility pattern, particle swarm optimization (PSO), fuzzy logic, routing enhancement, congestion avoidance

1. Introduction

With the growth up of internet in mobile commerce (m-commerce), service subscribers, providers, content developers and researchers have reproduced various mobile applications including context-aware services, mobile financial services, massively multiplayer online games and mobile auctions [1]. Most of theses applications can be accessed via personal digital assistant or mobile phones. However, handhelds have limited abilities and thus are impractical or dangerous when they are used during car driving.

Fortunately, enabling new m-commerce applications for drivers or passengers in motor vehicles becomes possible with the explosive growth in wireless local area network (WLAN) devices and wireless networking technology. These applications are varied from entertainment and commercial services to diagnostic and safety tools. However, there are several challenges need to be tackled before vehicular m-commerce are realized.

Wireless mobile ad hoc networks (MANET) technology promise delivery of network access area without the need of infrastructure, which is required by other technologies. There have been several researches [2][3] on the construction of ad hoc network among vehicles in the early stage of development of MANETs. Recently, the usage of MANETs as a base technology in inter-vehicle communication (IVS) has gained popularity due to its potential applications, such as providing support for intelligent transportation systems (ITS) and expediting Internet access in high ways.

It is well known that the major challenge for designing routing protocols in MANETs is to find a path from the source to the destination without any preconfigured information or regularly varying link situations. The position based routing becomes a suitable candidate for vehicular ad hoc networks (VANET) because this kind of routing protocol depends only on geographic position information and the information can be easily obtained by navigation systems, such as GPS [4].

Mobility management [5] has been widely recognized as one of the most challenging problems in seamless access to wireless network resource [7]. Most researches involved discussions of some node mobility models that exhibit the dominating effect of mobility on MANET performance [8][9][10]. It is necessary to generate synthetic movement patterns in these analytical models since real-life traces are difficult to obtain. Many literatures show that the performance of a MANET heavily depends on

the appropriate choice of a mobility model. There are two main aspects that need to be considered in mobility management; one is location management and the other is connection management. In this work, we mainly focus on connection management.

Most studies on mobility of MANET protocols [11][12] focus on node mobility in various environments where mobile nodes change their speed and direction more or less randomly. Moreover, vehicle movements are often expressed by extending these models and are typically relative to road traffic and are restricted to one dimension. Thus, Several traffic models [13][14][15] have been proposed to represent vehicles as particles moving randomly do not fit for realistic traffic pattern. In this work, we proposed an alternative link construction mechanism based on the prediction of possible link break and congestion. A fuzzy congestion detector and a fuzzy link break predictor are proposed to determine whether alternate route construction process should be activated. Particle swarm optimization (PSO) technique is used to adjust the parameters of the membership functions employed in the fuzzy logic systems in order to deal with the volatile characteristics of the VANET. The experimental results showed that the proposed work achieves better performance than other representative schemes in the literatures in terms of several performance metrics such as packet delivery ratio, end-to-end delay, and control overhead.

The remainder of this paper is organized as follows. Section 2 gives a brief overview of the mobility models in the literature. Section 3 presents the proposed link enhancement mechanisms. The simulation results are given in Section 4. Conclusion is made in section 5.

2. Related works

Saha and Johnson [16] proposed a realistic model of node motion based on vehicular traffic, suitable for evaluating VANETs. With most widely used Random Waypoint mobility model, using Dynamic Source Routing (DSR) protocol, they showed that in many cases the random waypoint mobility (RWP) model is a good approximation of their new model. Lu, Lin, Gu, and Helmy [17] classified various mobility models, in addition to proposing the contraction, expansion, circling, hybrid contraction and hybrid Manhattan and random waypoint mobility models. These models covered scenarios in which nodes merge, scatter or switch to different mobility patterns over time. Mobility metrics like, node degree, link duration, relative speed, temporal dependence, and spatial dependence are studied to differentiate the characteristics of proposed and existing mobility models. They showed that average node degree and link duration are very useful in capturing mobility dynamics.

Camp, Boleng, and Davies [18] investigated characteristics of different random mobility models including random walk, random waypoint, random direction, and reference point group mobility model. They compared these mobility models using mobility metrics like data packet delivery ratio, average end to end delay, average hop count, control packet transmissions per data packet delivered and control byte transmissions per data packet delivered against average node speed. However, the problem with these models is that the nodes are assumed to move in the same direction with the same speed so the mobility of nodes is unavailable as they seem static with respect to each other.

Two approaches have been used in the literature to tackle the problem of designing realistic and reproducible mobility and communication model. In the first approach, mobility models are created by means of most closely representing the real world, after conceiving actual use of the systems. However, this approach can potentially lead to overly complex models that are hard to analyze. In the second approach, models are created much like the creation of benchmark programs for computer systems. Tan, Zhou, Ho, Mehta, and Tanabe [20] used a combination of these two approaches and presented a general purpose method that may be used to reliably generate realistic mobility patterns with different characteristics. They introduced perception sub-model, behavioral sub-model and movement sub-model. The mobility metric shown is proportional to the amount of movement of nodes relative to surrounding nodes, which might break and change links. In the random mobility model, the metric exhibits a strong linear relation to number of link changes.

Unlike the above mentioned related works, this work proposed an alternative route construction mechanism based on mobility pattern to prevent disconnected routes from link break and congestion and the topology connectivity and network performance is thus enhanced.

3. PSO-tuned fuzzy link

connectivity enhancement mechanism

In the VANETs, the robust connectivity can be established by offering alternative routing paths whenever the broken link event or the congestion event occurs on the routing path. In this work, a link failure avoidance module and a congestion detection module, which are mainly composed of fuzzy logic systems, are used to predict possible link event and congestion occurring at each node.

Meanwhile, we adopt particle swarm optimization technique to adjust the parameters of the membership functions in the proposed fuzzy logic systems.

3.1. Constructing alternate route based on link break indicator

In order to prevent link break caused by mobility, we use mobility pattern, such as the distance between two consecutive vehicles, driver's age, and the current speed of the vehicle as the inputs to the fuzzy speed prediction module to estimate the vehicle's speed in next time period. Once the predicted speeds of the vehicle and its neighbors are obtained, we can easily determine whether the vehicle is within the communication range of its neighbors by computing the distances of the vehicle and its neighbors in next time period. In case the vehicle's position is determined to be out of the communication of its neighbors in next time period, the vehicle can initiate backup route construction process to prevent link failure caused by mobility of vehicles by piggybacking link break warning message to its neighbors.

3.1.1. Fuzzy speed prediction module

The fuzzy logic techniques have been used to solve several resource assignment problems efficiently in ATM and wireless networks in the literature [21]. We thus employ fuzzy logic systems to determine the vehicle's speed in next time period.

The basic function of the components in the fuzzy speed prediction module are described as follows:

- **Fuzzifier**: The fuzzifier performs the fuzzification function that converts three inputs into suitable linguistic values which are needed in the inference engine.
- **Fuzzy rule base**: The fuzzy rule base is composed of a set of linguistic control rules and the attendant control goals.
- **Inference Engine**: The inference engine simulates human decision-making based on the fuzzy control rules and the related input linguistic parameters.
- **Defuzzifier**: The defuzzifier acquires the aggregated linguistic values from the inferred fuzzy control action and generates a non-fuzzy control output, which represents the predicted speed.

Notably, the input to the fuzzifier d represents the distance between the vehicle and the one in front of it; the input A_d denotes the driver's age, and S stands for the current speed of the vehicle. The fuzzy linguistic variables "close", "intermediate" and "far" give different distance measure in the membership function for d. Three linguistic term sets, "young", "middle" and "old" are used for A_d, and "slow", "medium" and "fast" are used for S. The output parameter of the inference engine, V, is defined as the estimated speed factor of the vehicle in next time period. The fuzzy linguistic variables for the output of the inference engine, V, are "slow", "medium" and "fast".

The non-fuzzy output of the defuzzifier can then be expressed as the weighted average of each rule's output after the Tsukamoto defuzzification method is applied:

$$V = \frac{\sum_{i=1}^{27} V_i \cdot w_i}{\sum_{i=1}^{27} w_i}, \quad (1)$$

where V_i denotes the output of each rule induced by the firing strength w_i. Notably, w_i represents the degree to which the antecedent part of each fuzzy rule constructed by the connective "**AND**" as shown in the above example is satisfied.

The estimated speed of the vehicle in next time period can be derived as follows:

$$\Lambda = \nu \cdot S, \quad (2)$$

where V stands for the non-fuzzy output, and S is the current speed of the vehicle.

3.2. Congestion avoidance mechanism

In case congestion occurs in a node along the routing path, we allow the congested node to piggyback congestion information in the data packets to its neighbors for notifying the occurrence of the congestion. Once the message is received by its downstream neighbor, the downstream node will re-initiate route discovery process to construct a new route to the destination.

3.2.1. Fuzzy congestion detection module

We utilize fuzzy logic systems to determine whether congestion might occur at a node. The queue length, the expected counts of the packets travel through the vehicles and its neighbors, and

expected number of the vehicles in next time period are used as the parameters for the fuzzy congestion detection module to avoid occurrence of possible node congestion.

The architecture of the fuzzy congestion detection module is quite similar to that of the fuzzy speed prediction module as presented in section 3.1.1. The output of the inference engine is congestion indicator that represents the seriousness of the congestion occurring at the vehicle and its neighbors.

3.2.2. Alternate route construction process

Figures 3 shows the construction of alternate path to prevent the congestion or link break. Consider a path S-A-B-C-D constructed as illustrated in Fig. 3. When there is a possible congestion or link break detected at node B, it sends a congestion/link break warning message to all its neighbors. As node A receives the message, it re-initiates route discovery process with congestion/link break indicator piggybacked in data packets to find an alternate path to destination D. Thus, new arrived data packets can then be delivered via a new path S-A-E-C-D.

3.3. Particle swarm optimization

Particle swarm optimization (PSO) is a computational intelligence approach to optimization that is based in the behavior of swarming or flocking animals, such as birds or fish. In the PSO, every individual moves from a given point to a new one which is a weighted combination of the individual's best position ever found, and of the group's best position. The PSO algorithm itself is simple and involves adjusting a few parameters. With little modification, it can be applied to a wide range of applications. Because of this, PSO has received growing interest from researchers in various fields.

In this work, we allow each vehicle to execute its individual PSO algorithm. The PSO is used to adjust the two parameters, mean and variance, in the membership functions of the inputs for the fuzzy speed prediction module and fuzzy congestion detection module.

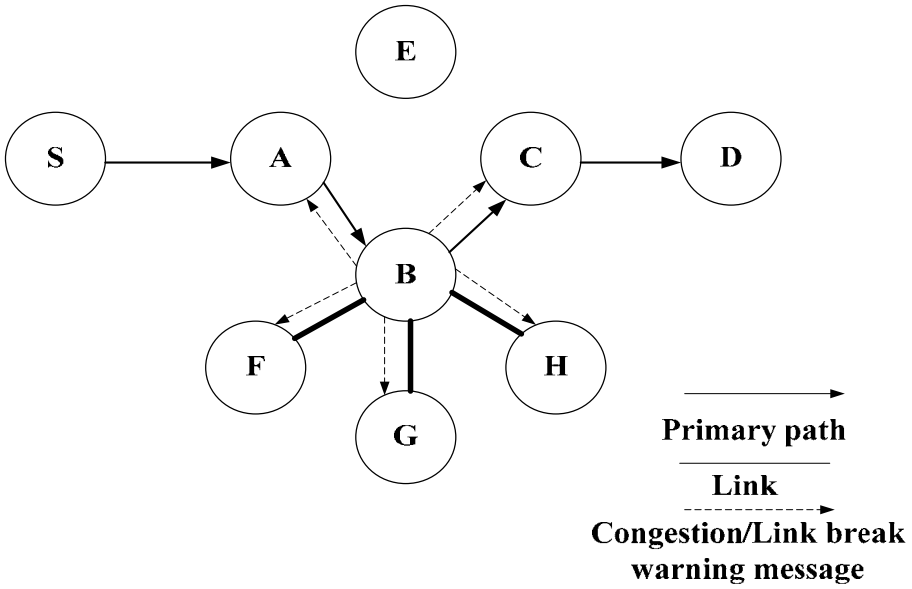

Fig. 1. Congestion/Link break warning message.

4. Simulation

We ran a series of simulation to evaluate the performance of the proposed work by using a network simulator written by C++. We chose AODV [23] as the based routing protocol since the AODV is capable for both unicast and multicast routing, and the route discovery is simply on-demand. The compared schemes includes the proposed alternate route construction mechanisms embedded with PSO-tuned fuzzy inference system (MAODV-PFCG), the alternate route construction mechanisms embedded with traditional fuzzy inference system (MAODV-FCG), the alternate route construction mechanism based on link break indicator alone (MAODV), pure AODV, and DSR [24]

4.1 Simulation scenario

The simulation environment is a 1000×100 square meter, and 50 vehicles are randomly distributed within the network. In order to simulate the road traffic, the traffic flow is simulated with microscopic model [25]. The detail simulation parameters are listed in Table 1.

Notably, CBR/UDP traffic is generated between randomly selected pairs of vehicles and the bandwidth for each channel is 2Mbps. The CBR data packet size is 512 byte and packet rate is 4 packets per second. Each vehicle moves along the direction of the pathway, and the speed is randomly changed within a preset range that is related to the dirver's age and the distance between the vehicle and the one in front of it. Once it reaches that position, it will change the speed and repeats the process.

4.2 Simulation results and analysis

We investigate the impact of vehicle speed on the packet delivery ratio, end-to-end delay and control overhead. The vehicle speed is varied from 0 m/s to 30 m/s, the traffic flow is fixed at 0.1 vel/sec. Notably, packet delivery ratio is the total amount of received data divided by the total amount of data transmitted during the simulation. The comparison of packet delivery ratio is separated into two figures since DSR and AODV exhibit significant lag when compared with the other three schemes. Note that DSR and AODV simply drop data packets when the route is disconnected, packet delivery ratio for these two schemes is thus worse than the proposed MAODV-PFCG, MAODV-FCG and MAODV schemes as shown in Fig. 2. The proposed MAODV-PFCG, MAODV-FCG and MAODV have better packet delivery ratio since they construct alternate path in case they predict a link break. Fig. 3 compares the packet delivery ratio of the three proposed schemes. The one embedded PSO-tuned fuzzy logic systems achieve better accuracy on the prediction of congestion and link break indicators than the other two do.

Table 1. Simulation parameters

Parameter type	Parameter value
Simulation time	500 sec
Simulation terrain	1000 m x 1000 m
Number of vehicles	50
Traffic flow	0.1 vel/sec
Traffic model	microscopic model
Mobility	0~30 m/s
Channel bandwidth	2M bps
Mac protocol	802.11
Transmission range	33.75m
CBR data sessions	25

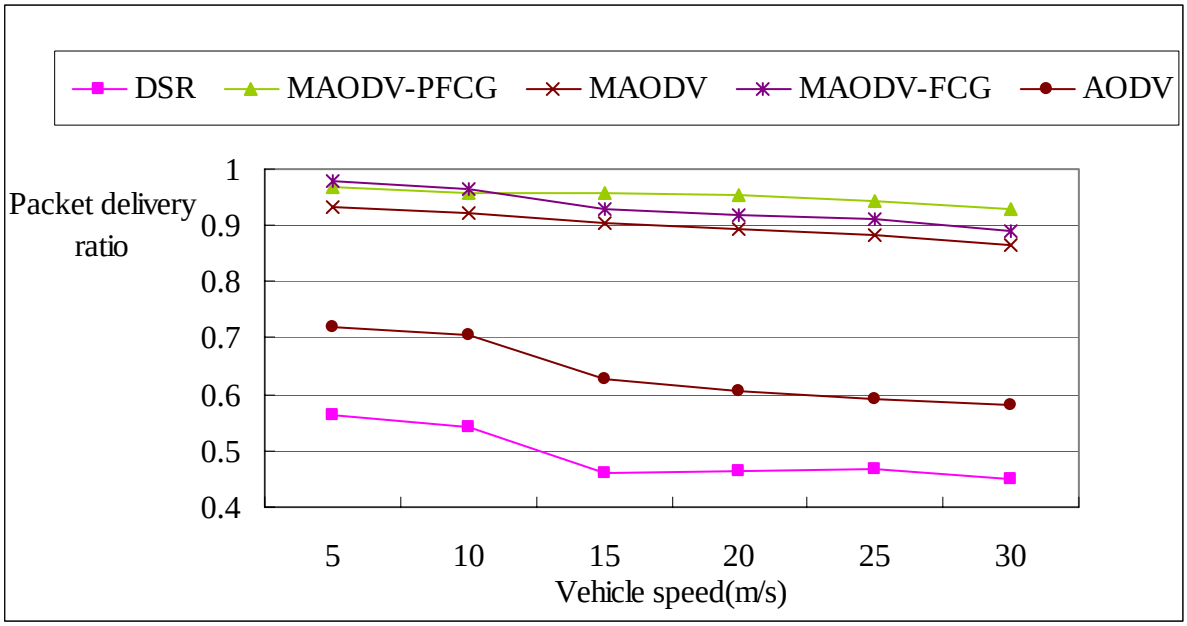

Fig. 2. Packet delivery ratios for DSR, AODV, MAODV, MAODV-FCG and MAODV-PFCG under different moving speeds.

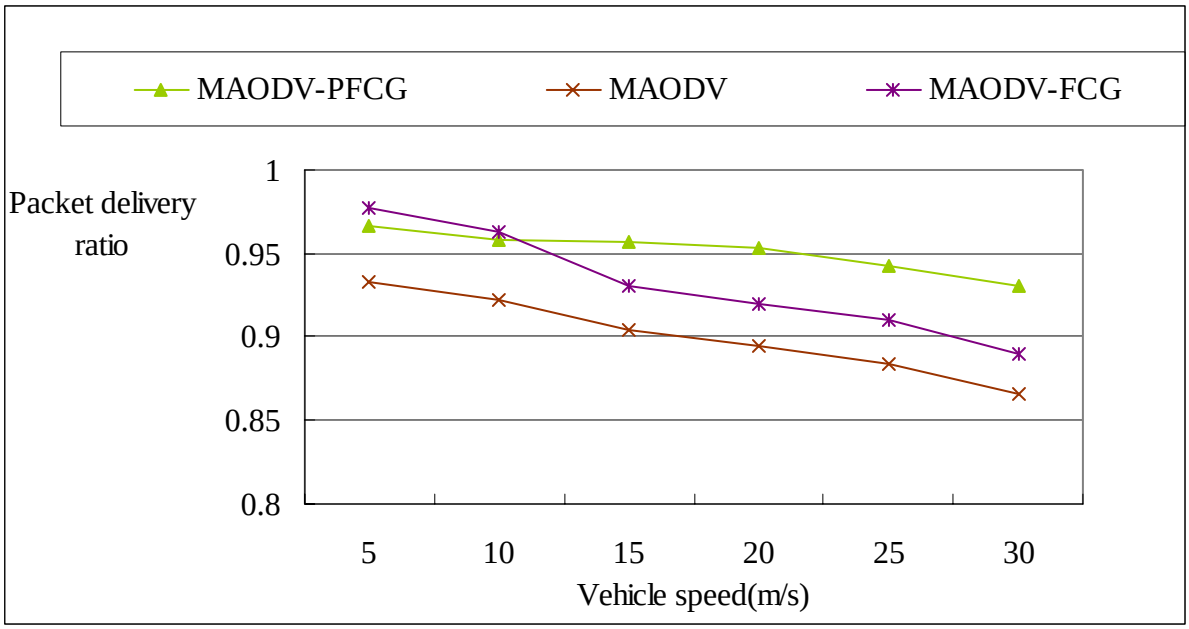

Fig. 3. Packet delivery ratio for MAODV, MAODV-FCG and MAODV-PFCG under different moving speed.

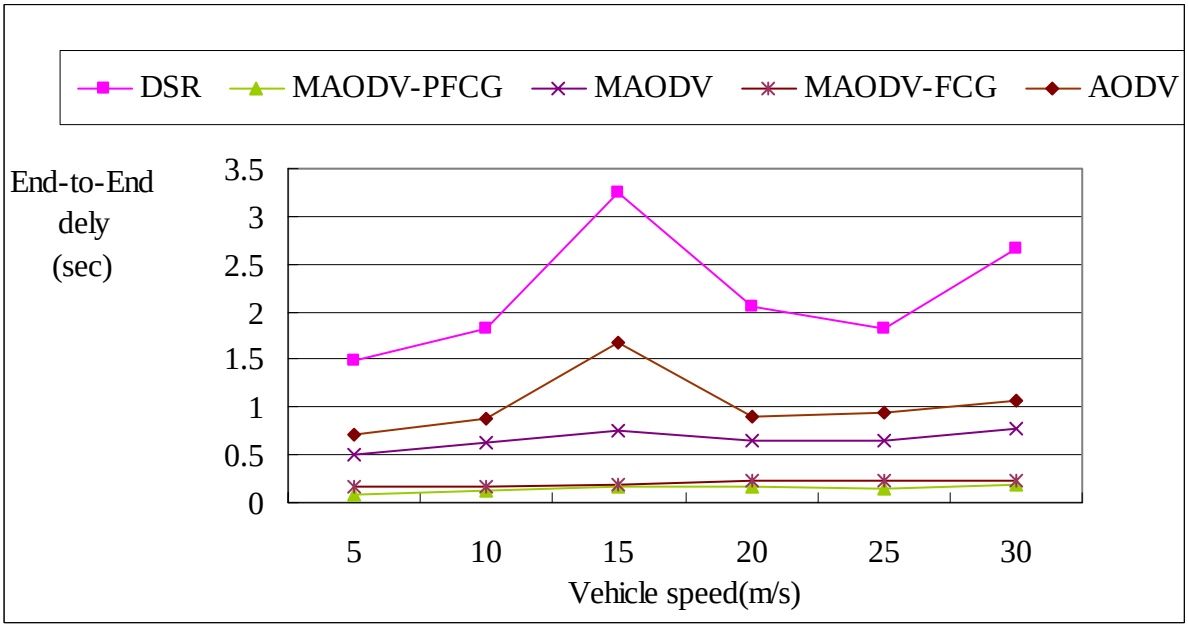

Fig. 4. End-to-end delay for DSR, AODV, MAODV, MAODV-FCG and MAODV-PFCG under different moving speed.

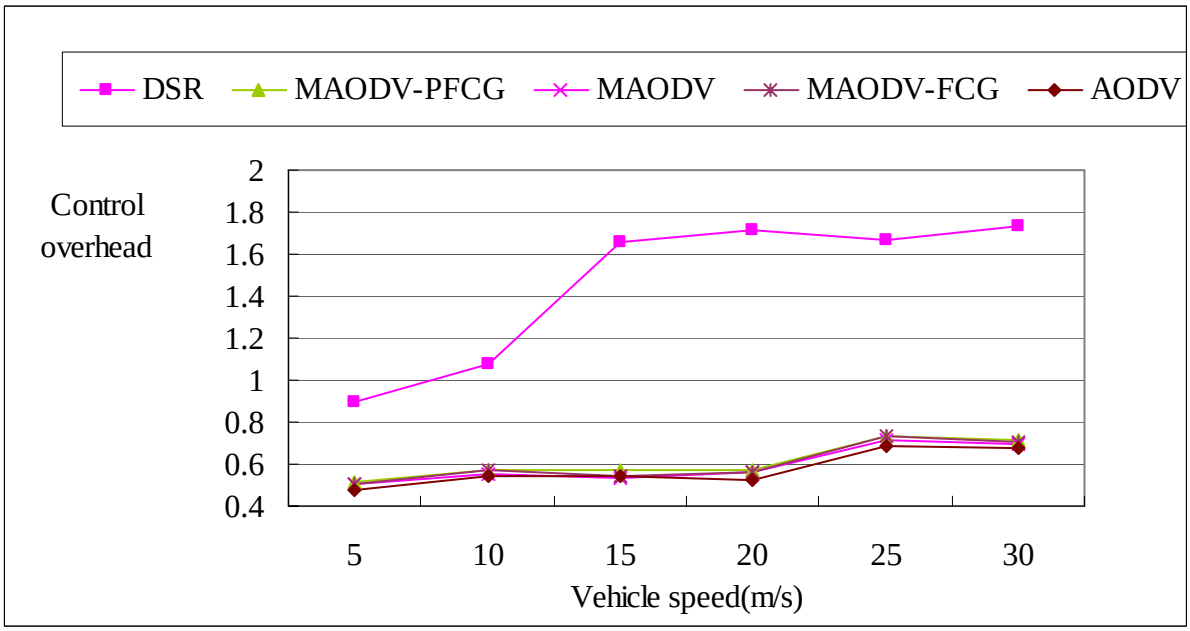

Fig. 5. Control overhead for DSR, AODV, MAODV, MAODV-FCG and MAODV-PFCG under different moving speed.

Fig. 4 shows the end-to-end delay for the five schemes under different moving speeds. Notably, the end-to-end delay in this work stands for the routing delay plus other processing delays such as the calculation of the PSO calculation time and fuzzy inference time. The delay is measured for those data packets from the mobile source vehicle to the mobile destination vehicle. The proposed MAODV-PFCG, MAODV-FCG and MAODV schemes have comparable performance since they are able to find a shorter path by re-initiating route discovery process through backup route mechanism. They not only transmit data packets through shorter path but also prevent losing data packet caused by link break. On the contrary, DSR has the poorest packet delivery ratio and transmits data packets through more hops than other schemes as well.

Fig. 5 shows the control overhead for the five schemes under different moving speeds. The control overhead is the required number of control packets that completes a data transmission. Apparently, DSR has the higher control overhead than all proposed schemes. As for the pure AODV, it has less control overhead than proposed schemes since it does not repair the route when a link failure occurs.

The last but not the least, it can be inferred from Fig. 2 to Fig. 5 that PSO process can effectively adapts the parameters of the membership functions for the fuzzy logic systems to the volatile change of network topology in the VANET.

5 Conclusion

In this paper, a link enhancement mechanism for VANETs is proposed. Alternate route construction mechanism and congestion avoidance mechanism based on mobility pattern are presented to prevent the link failure caused by vehicle movement and the congestion occurrence. Fuzzy logic systems are used as the core modules in the link enhancement mechanism to generate the link break and congestion indicators that can be piggybacked in the data packets to inform the neighbor vehicles. Meanwhile, particle swarm optimization technique is adopted to dynamically tune the parameters in the membership function of the fuzzy systems due to the volatile characteristics of VANETs. The simulation results show that the proposed alternate route construction mechanism based on mobility pattern can effectively prevent the link break caused by varied vehicle movement and traffic flow and improve the performance metrics including packet delivery ratio, control overhead, and end-to-end delay. The effectiveness and the feasibility of the proposed link enhancement mechanism is thus verified.

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