Delay-Aware Routing based on Game Theory in Vehicular Wireless Networks

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***Abstract*—This paper aims to solve the route selection and selfish behavior problem in Vehicular wireless networks (VANET). We propose Delay-aware Routing based on Game-Theory (DARGT) to find out an applicable path for packet delivery and to reduce the transmission delay. The selfish behavior in wireless environment can result in serious performance degradation due to the lack of cooperation. In order to solve selfish node problem, we present a forwarding game. By giving nodes a trust value as node's utility, we expected that utility exchange can encourage the node to cooperation. We also propose the Delay-aware Utility Allocation method to determine how many packet utility should pay for the forwarder. Finally, we used NS2 network simulator to perform the experiment. Simulation results indicated that DARGT can efficiently arrest the selfish behavior of nodes. Furthermore, DARGT can also reduce the packet transmission delay in vehicular wireless networks.**

***Keywords*— Routing,Game-Theory,DARGT**

1. INTRODUCTION

In wireless networks, the existing wireless technology likes IEEE 802.11 a, b and g are mature and being widely used. But in vehicular networks, the existed protocols might not be suitable because node moves at high speed and the network topology changes frequently, which may easily cause wireless connection intermittent. Thus, the IEEE team modify IEEE 802.11 a, b and g to establish the IEEE 802.11p and the IEEE 1609 family of standards for Wireless Access in the Vehicular Environment (WAVE).

Vehicular network applications can be classified as safety applications and non-safety applications. The safety applications use alert message to notify drivers of urgent event on highway, and to allow drivers avoid the accident. The non-safety applications focus on the comfort applications improvement, which allows driver and passengers to access wireless network for entertainment. No matter what kind of applications, the transmission delay in wireless network must take into consideration.

So far, the major method of packet transmission in VANET is via broadcasts. However, the study shows that broadcast commonly caused packet centered on particular nodes, which may result in heavy congestion and delay. To solve this problem, a suitable routing method is necessary. The term routing refers to selecting paths along which node sends data. Unlike the traditional wired network, routing in wireless environment became much more complicated. Such like less reliable communication links, and the highly mobility of vehicular nodes must be considered. In addition, packet transmission in wireless networks may suffer the interference from outside, like broadcast storm, which leads to the heavy transmission delay. Despite that, there are still some emergency applications in wireless networks. For example, the emergency messages broadcast when car accident occurred. The emergency packets could not reach the destination in time without a suitable routing path. So the aim of this research is to find out a reliable and suitable delay-aware routing method.

To achieve the goal, we design a forwarding game. Forwarding game can analyze the behaviors and strategies of the network nodes. And then we can find a way to encourage nodes to cooperation. Further, to reduce the transmission delay and packet loss caused by selfish behavior. We also use path weighting to calculate the cost of each routing path, and find out which path has lowest total cost.

In Non-safety environment, not only about how nodes can transmit packet faster, but also have to make sure that forwarders are willing to help forward the packet, because every node is considered selfish by nature: Nodes would not help to forward packets unless there are enough benefit/utility for them. It became a complicated problem when delay-aware concept and utility allocation came together. Within this section, we modify a trust value as a utility for nodes. We expect forwarding game can encourage cooperation between nodes via trust value exchange.

This paper is organized as follows. Section 2 briefly describes existing game theory research and routing protocols. In Section 3, we proposed a Delay-aware Routing based on Game-Theory in vehicular networks. Section 4 shows the simply graphic schematic diagram and simulation results. Finally, we conclude this paper in Section 5.

2. Related Work

Game theoretic applications have been widely applied in recent years. Game theory is a branch of applied mathematics, which deals with multi-person decision making and can be used to analyze the interaction between game participants (Players).In the following, we introduce some game theoretic applications in wireless networks.

2.1. Game theory based load-balancing routing [1]

GBLBR investigates the wireless routing problem. Traditional routing protocols often using a shortest-path to establish the route may easily cause a large amount of data packet center in particular nodes, which result in serious performance degradation. DARGT focus on the concept of load-balancing routing. And apply game theory to deal with the selfish node problem.

For load-balancing, GBLBR first calculates the delay utility function of each path, and then allocate the throughput depending on the link capacity. Another key-point of GBLBR is Cooperation Stimulation (CS). CS defined a parameter γ which can be called to selfish value. Let γ=N-delivery/N-request. γ represents the proportion of forwarded packets to total forwarding request. An enthusiastic node has a high γ value, such that other nodes know this node is not selfish and trustable.

By combination with the γ value, GBLBR allocates throughput based on the utility function, in addition there is also a punishment mechanism for selfish node. While forwarder node received packets from sender, at the same time forwarder node also get the γ value from sender. The probability of forwarding packets depends on the γ value. As a result, packets from selfish nodes become difficult to be sent, selfish nodes suffer by heavy packet delay may change its selfish attitude.

This paper applied Game Theory to calculate the delay utility function of each path. The experimental results show that load-balance concept actually improved the end-to-end delay, packet loss rate, and overall performance.

2.2. Cooperative Game-Theory Model for Bandwidth Allocation in Multi-hop Wireless Networks [2]

Multi-hop may result in uneven bandwidth allocation in wireless network. The traffic flow concentrated in certain nodes could easily cause the congestion. This paper proposed a cooperation game, which can allocate the traffic flow to the suitable path evenly, and then use the KS-Raiffa solution to implement the cooperation.

In order to restrain selfish nodes, this paper claims to replace the well-intentioned encourage attitude by threats selfish nodes as interference (Denial of service attack). If the selfish node reject to forward packets, the other nodes will interfere with its transfer.

Table 1 Strategy.

	B Silent	B Active
A Cooperative	(10,0)	(0,5)
A Non-cooperative	(10,0)	(5,0)

Table 1 shows that nodes A and B can be formed as a two-node game. Assume that B must rely on A to transmit, at this point, the choice between two nodes may have two conditions: cooperation or interference. Different combinations have different probabilities p1~p4. Assume that p1+p2+p3+p4=1. The utility of each path can be calculated and we can obtain the ideal bandwidth allocation.

3. DARGT

Delay-aware Routing based on Game-Theory (DARGT) applies game theoretic approach on routing protocols for reducing the selfish behavior and packet transmission delay. As soon as a route establishes, sender nodes begin to send data follows the design of forwarding game.

DARGT can be classified as two phase: Phase 1 is the delay-aware routing path selection and Phase 2 is a forwarding game. In Phase 1, sender starts the route discovery to find out a suitable path with the least transmission delay. In Phase 2, sender sending data packets triggered the forwarding game: sender asks the other node along the path to forward the packets by giving the trust value (benefit/utility) as incentive. According to the forwarding game, different amount of utility may change the strategy of forwarding. And based on the reaction of each forwarder, the utility amount might be adjusted.

The traditional AODV simply selects the shortest hop path as the routing path. The AODV easily transmits data packets in some particular paths and results long delay. To avoid the transmission delay, DARGT calculates the path cost by considering the system load, hop-count, trust and the delay of each path. The term system load refers to the queue capacity of each node. If there are many packets waiting in queue, it means this node has high system load. Finally, senders can select a suitable route with the least path cost from candidate paths.

The selfish node in wireless networks brings down the overall performance. To solve this problem, DARGT used a parameter called trust in forwarding game. Trust is a numeric value expressed as a percentage. Trust can be applied to determine whether a node is trustable. We will describe trust in detail in Section3.4.

3.1. Weights calculation and route selection

Traditional AODV updates its routing table based on the shortest-path.

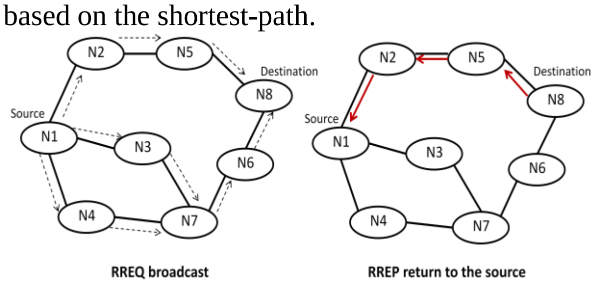


Figure 1. AODV route discovery

Figure 1 shows AODV simply select the shortest path (N8-N5-N2-N1). But in DARGT, DARGT applies several parameters such like delay (D), system load (SL), hop-count (H) and trust (T) to calculate the cost of a path.

While route discovery, the sender first broadcasts an RREQ message to search a route. When RREP is sent back from the destination, other nodes along the routing path attached their personal information (D, SL, and H) to RREP. Based on those parameters, nodes can maintain a suitable routing table. Senders might receive several RREP from different nodes while route discovery, but senders only need to select the best next-hop node to establish the route.

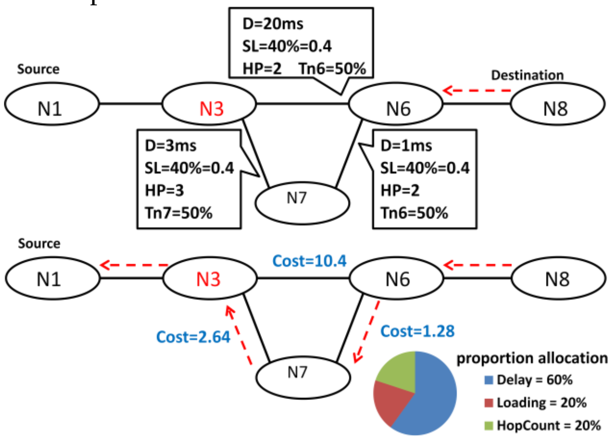


Figure 2. Path cost calculation

In Figure 2, the node which rebroadcasts the RREP message will attach its own information. Assume that p optional paths can represent as p_{all}. Let p_i represents the i-th path. We can define the formula of path cost:

$$\begin{cases} U_1 + U_2 + U_3 = 1 & (1) \\ \min U_{pi}(C_{pi}) = \min\left(\frac{(Delay_i \cdot U_1)\cdot(SL_i \cdot U_2) + H_i \cdot U_3}{(U_1 + U_2 + U_3)}\right)\cdot\frac{1}{T_i}, p_i \in p_{all} \end{cases}$$

This formula considers the factors that may cause delay and congestion. A path with the minimum cost is the ideal path for routing. The $\min U_{pi}(C_{pi})$ function means to select a node with the minimum cost in candidates, and senders can establish a route with it. $U_1, U_2,$ and U_3 stand for three adjustable weighting parameters. DARGT can revise the relative weighting of three parameters whenever experiments need. In this paper we focus on the delay reduction, so let U_1 (delay) holds the largest proportion, while U_2 (SL) and U_3(hop-count) have the same smaller proportions.

For example, in Figure 2 we assume that all trusts in whole nodes are the same (T = 50%). When node N3 received an RREP, this RREP message may be broadcasted by N6 or N7. In traditional AODV, N3 will simply select N6 to establish the routing path. But In DARGT, we select the routing path based on the path cost. N3 can calculate the path cost N3-N6 = 10.4, and N3-N7 = 2.64. But node N7 must reach the destination via N6, therefore the path cost N7-N6 must be taken into account. Finally, N3 can obtain the total path cost (N3-N7-N6) 2.64 +1.28 = 3.92, which is less than N3-N6. In N3's case, N7 is better to establishing routing path than N6.

Along the routing path, every node will select the appropriate next-hop node to establish route. When RREP finally returned to the sender, a sender obtains many established routes in the routing table

3.2. Delay-aware routing

In order to reduce packets transmission delay, DARGT proposed delay-aware routing. Once a node received a RREP packet, the node first checks whether it has a routing table to the destination node. If the routing table exists, the node will calculate a new transmission cost between the destination node and itself base on formula (1). The new path cost will compare to the old routing path cost. A path with less cost represents the lower transmission delay, and the sender will select the path with less cost as a new routing path.

3.3. Forwarding game design

A forwarding game in DARGT can express as:

1) Players: N = { $S, F_1, F_2 \dots F_{n-2}, D$ }: Assume the players set N represents all the nodes in the forwarding game. There are total n nodes. S is the sender node and D is the destination node. F stands for the forwarder nodes along the routing paths.

2) Strategy: S = $\{p_1, p_2 \dots p_x\}$

F = { $Forward,\ Drop$ }:

Each strategy must be considered separately because of different roles in the forwarding game. If the node is sender, it has to select a path from x candidate paths. The transmission path set can be express as { $p_1, p_2 \dots p_x$ }. If the node is a forwarder, it only needs to decide whether to help the transmission. The strategy set is simply { $Forward,\ Drop$ }. Node to do any decisions premises that it will get enough benefit back.

3) (Utility): $Packet\ Utility = Trust = \alpha \times T_f$

The utility in forwarding game is trust. For example, if the forwarder node helps transmission, the utility (trust) which sender pays for it will increase. Once the roles sender and forwarder changed, the original sender might be more willing to transmit packets for each others. We will describe trust in detail in Section 3.4.

To solve the selfish node problem in wireless networks, DARGT uses forwarding game in Phase 2 to encourage nodes cooperate by the trust exchange.

3.4. Trust design

Trust is a numeric value between 0 and 1 and can express as 0%-100%. The upper bound of trust is 100%, more than this value is still count as 100%. Trust determines whether a node is trustable. Once a node with high trust sends packets, other nodes will be more willing to transfer the packets. Trust can also take as benefit/packet utility to other nodes. Every time the forwarder node helps to delivery packets, sender will give forwarder trust (packet utility) as reward. We expect to encourage selfish nodes to cooperate by trust exchange.

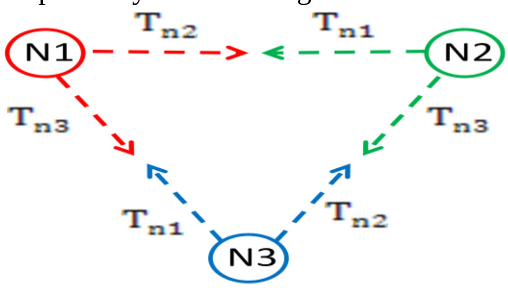


Figure 3. Trust diagram

A node measured the trust on the other nodes. Each node has its own trust table which recorded trust of neighbor nodes. Trust might be adjustable by different strategy neighbor nodes made.

The usage of trust can be classified by two phases:

Phase 1: trust is a parameter metric in formula (1) to calculate the path cost.

Phase 2: trust design in phase 2 is separated by sender part and forwarder part because nodes play different roles.

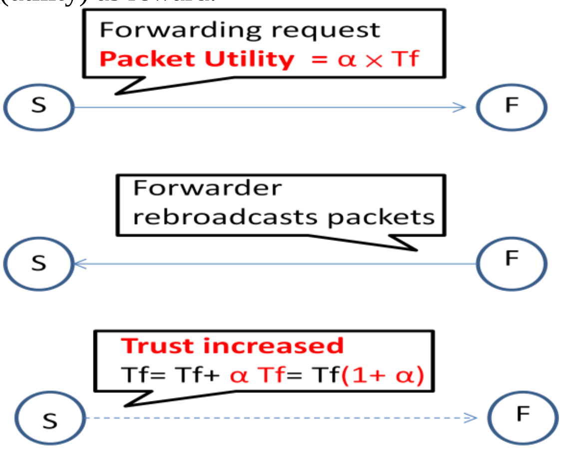
1. Sender part:

First, sender informs forwarder how much trust (packet utility) forwarder can get in transmission. The amount of packet utility depends on how much sender trust forwarder. Formula can be expressed as follows:

$$\text{Packet Utility} = \alpha \times T_f, \quad (0 < \alpha \leqq 1) \qquad (2)$$

α is an adjustable value between 0 and 1. T_f is a trust value to forwarder and is recorded in sender's trust table. The higher T_f forwarder has, the more utility forwarder can get.

When sender receives the packet rebroadcast by forwarder, sender gives the forwarder trust (utility) as reward.



The upper bound of trust is 1 or can be expressed in percentage as 100%. If a node recording in sender's trust table has 100% trust, it means sender completely trust this node.

$$\text{Trust} \begin{cases} T_f\ (1+\alpha), & \text{if } T_f\ (1+\alpha) < 1 \\ 1, & \text{otherwise.} \end{cases} \quad (3)$$

2. Forwarder part:

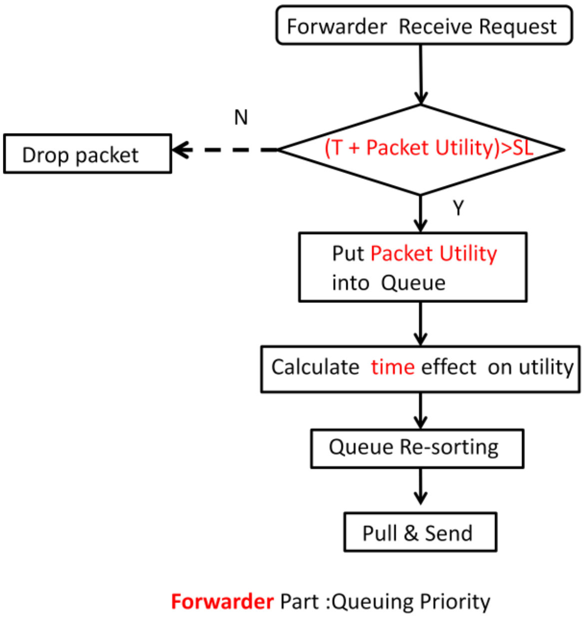


Figure 4. Forwarder part flowchart

In Figure 4, once forwarder receives a forwarding request, forwarder checks the trust of the requester. Forwarder uses its system load (SL) as a threshold. If the sum of requester's trust and utility did not exceed the threshold, forwarder reject to transmit the packet. Otherwise, the packets will be stored into the waiting queue. Forwarder calculates the time effecting to packet utility and rescheduling the packets in queue.

The strategy of forwarder can described as follows:

$$\text{Forwarder Strategy} \begin{cases} \text{Forward, If } (T_i + \text{Packet utility}) > SL \\ \text{Drop, otherwise} \end{cases} \quad (4)$$

T_i is a trust value to sender and is recorded in forwarder's trust table. Packet utility represents how much utility sender is willing to pay for this transmission. Forwarder will forward/rebroadcast the packets if the sum of above two parameters exceeds forwarder's current system loading (SL).

3.5. Delay aware utility allocation

In forwarding game, sender gives forwarder trust (packet utility) as reward. If forwarder rejected transmission or the transmission time takes too long, the packet utility decreased as time pass by. The obtained utility decreases as the delay increases as shown in Figure 5:

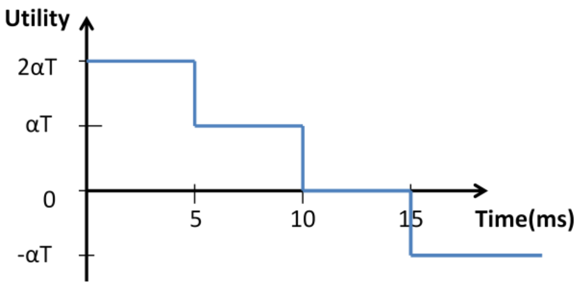


Figure 5. Delay-aware utility allocation

Figure 5 shows that if forwarder rebroadcasts packets in 5ms, the packet utility becomes twice. However, the packet utility becomes negative value if the time delays more than 15ms.

Once forwarder decides to transmit, forwarder stores packets into the waiting queue and trigger queue re-sorting. Because packets in waiting queue are not in FCFS, a packet with higher utility has higher priority. According to delay-aware utility allocation, forwarder will place the packet with the highest utility on the front-end of queue, and drops the packets without any utility.

4. SIMULATION RESULTS

In this section, we adopted NS2 (Network Simulator version 2.35) to implement the simulation experiment. We used mobility generator to create the freeway model for Simulation. The freeway model has two lines in each direction and the length of model is 1 km.

The stimulation time is 180 seconds. The detail Simulation parameters are shown in Table 2.

Table 2. Simulation parameters

Variables	Values
Mobility model	Freeway model
Range of communication	200m
Avg. speed (m/s)	20, 25, 30, 35, 40 m/s
Avg. accelerate speed	5, 10 m/s^2
Number of vehicles	20, 40, 60, 80, 100
Freeway length	1km
MAC protocol	IEEE 802.11
Simulation time	180s

In DARGT phase 1 experiment, we focus on the improvement of transmission delay. We compare the performance metric in terms of the average end to end delay and average packet delivery fraction. (1) Average end to end delay: The average time during from the first packet was broadcasted to the destination node received the packet. (2) Average packet delivery fraction: a ratio defined as the number of packets successful received by nodes to total number of broadcast packets. Finally, we implement the simple routing protocol (AODV), and the proposed routing protocol (DARGT) using ns2 to compare the performance.

4.1. Average end-to-end delay

In the simulation, we set the average vehicles speed from 20m/s (72km/hr) to 40m/s (144km/hr), and the numbers of the vehicles (n) are from 20 to 100.

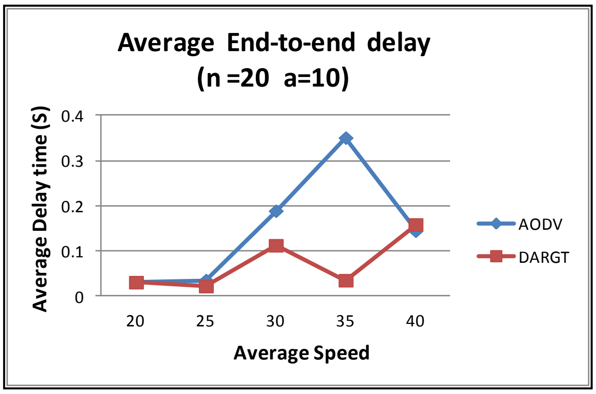


Figure 6. Avg.end-to-end delay (n20)

In the simulation, we set the numbers of vehicles adjustable and the average speeds of the vehicles are from 20m/s to 40m/s. Figure 6 shows the DARGT has lower transmission delay in low vehicular density (n=20). The DARGT is also more stable than the AODV routing protocol in different vehicular speed situations. As vehicular speed increases, the DARGT has a stable performance.

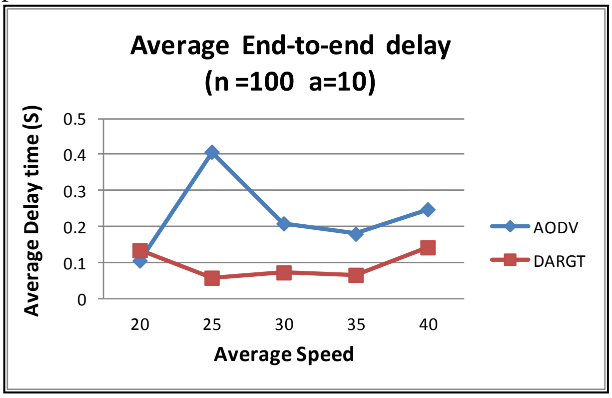


Figure 7. Avg.end-to-end delay (n100)

Figure 7 shows the average end to end delay. In the simulation, the number of vehicles is 100, average accelerates speed is 10m/s^2 and the average speed of vehicles is from 20m/s to 40m/s. We can see the DARGT has significant improvement. When vehicular density is high, the overall performance of the DARGT is better than AODV routing protocol.

4.2. Average packet delivery fraction

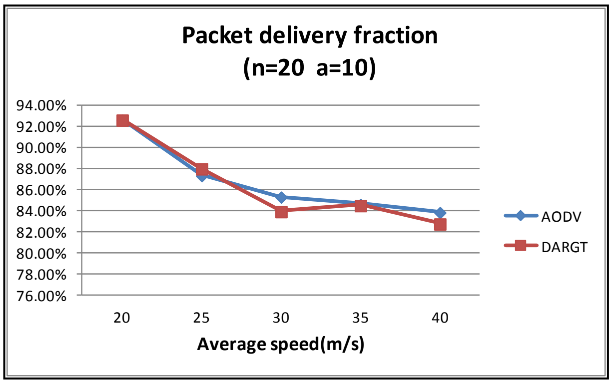


Figure 8. Avg. packet delivery fraction (n20)

Figure 8 shows the packet delivery fraction in environment of low density (n=20) for both protocols. As vehicular speed increases, we can see the packet delivery fraction of both protocols dropped slightly.

Figure 9 shows the packet delivery fraction in environment of high density (n=80). As vehicular speed increases, we can find the received rate of DARGT is higher than that of AODV. In the environment of high density and high vehicular speed, the DARGT performs better than AODV.

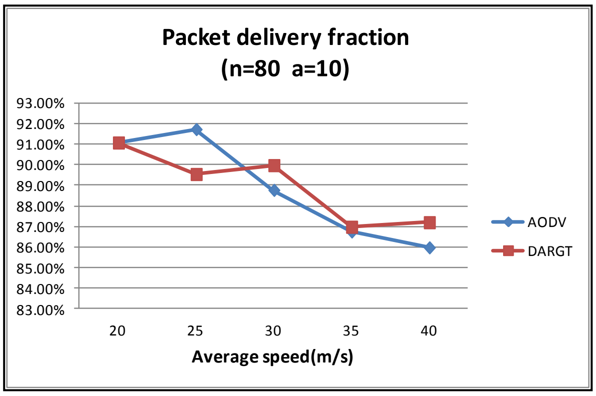


Figure 9. Avg. packet delivery fraction (n80)

4. CONCLUSIONS

The traditional AODV routing protocol may fail to route packets due to selfish nodes. Selfish nodes in wireless environment reduce the reliability of packet delivery. In this paper, we proposed a Delay-aware Routing based on Game-Theory (DARGT) to improve the transmission delay and reduce selfish behavior in vehicular wireless networks. We adopted NS2-simulator to implement the experiments. Simulation results show that DARGT outperforms the traditional routing method in terms of the average end to end delay.

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