Weighted Voting Game Based Relay Node Managemnet in VANETs

Elham Dehghan Biyar(✉) and Berk Canberk

Department of Computer Engineering, Istanbul Technical University, Ayazaga Campus, 34469 Istanbul, Turkey
{dehghanbiyar,canberk}@itu.edu.tr

Abstract. In traditional Vehicular Ad Hoc Networks (VANETs) deployments, permanent and robust connection establishment to road side units (RSU) has arisen as a crucial problem. Here it is a known fact that, this challenge has been triggered by high mobility pattern of vehicles. To handle this problem, optimal relay vehicle selection can be seen as an efficient solution. To this end, in this paper, we propose a novel optimal and fair relay vehicle selection algorithm based on weighted voting game. In our game theoretic approach, relay vehicle selections have been performed by various cooperative coalitions. Note that game theory is a perfect tool while designing such an algorithm as it is a formal applied mathematical tool to analyze and model complicated situations of interactive decision making. Our proposed weighted voting game algorithm can achieve fair and optimal results as well as increasing throughput and decreasing message transmission delay during packet dissemination as a result of using Banzhaf power measure. Performance evaluation results depicted that compared to non-cooperative methods, throughput increases by 24.4% and message dissemination delay decreases by 18%.

Keywords: Game Theory · Pay-off function · VANETs · Weighted Voting Game · Banzhaf power measure · Fair relay

1 Introduction

With the recent advances in Information and Communications Technology (ICT), VANET has become an important concept in order to provide efficient and convenient road trips for drivers by obtaining required information along the road. This information can vary from infotainment to traffic efficiency, on demand application management and updating information [1,2]. For obtaining all the mentioned infromation, packet dissemination all along the road is important. Due to the mobile nature of vehicles that results in dynamic topological changes, establishing permanent and robust connection with road side units for maintaining connectivity has arisen as a challenging issue. Furthermore, transmission failure of actual amount of packets during data transfer can happen because of Doppler effect, loss of signal, dissimilar speed of send and receive,

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and bandwidth limitation of RSU [3]. To overcome these problems and for efficient management of optimal connectivity, it is essential to use some of vehicles as a relay for compensation and reinforcement of connection. While selecting the optimal relay vehicle, we need to take into account several factors such as quality of service (QoS) [4,5], system performance, cost-efficiency role of chosen node and fairnes [6,7]. Providing a satisfying method for this selection is required and it is a challenging issue due to dynamic environment of roads.

There are works which have dealt with relay node selection. In [8] source nodes try to find the most appropriate relay node based on self optimizing algorithm called SLA. In [9] distributed relay node selection provides responsibility of rebroadcasting of alert messages to further distances. They have used bidirectional stable communication algorithm for selecting set of qualified relay nodes. The author has focused on quality of relay nodes and has not considered other metrics and optimization methods while selecting the optimal relay among multiple options. Besides, none of them did a work using Game Theory. In [3] coalitional game theory approach for solving cost-efficient content downloading has been proposed. In [10] relay vehicle selection based on game theory is proposed, pay-off functions are designed with respect to some metrics, and an optimal matching problem has been solved using Kuhn-Munkres algorithm. Although game theory has been used to optimal relay vehicle selection, defining Nash equilibrium point for cooperation is missing. Moreover, fairness has not been considered. In this paper, an algorithm based on Weighted Voting Game will be introduced that we believe is more efficient for optimization and fairness. All aforementioned works, have mainly focused on quality of chosen relay node, but few works are focused on choosing a relay among multiple number of eligible relays. Moreover, in these proposed methods fair relay node selection haven't been considered. One of the notable issues in network management is fairness [6]. In this paper, fairness is defined as an impartial relay assignment in a way that it also optimizes pay-off functions for various individual anchor users. In addition, we believe that Game Theory should be used in relay vehicle selection because it is a formal applied mathematical tool to analyze and model complicated situations of interactive decision making [11]. There are several decision makers with various intentions, which decision of each one effects the overall result of decision making process [11]. In this paper Weighted Voting Game is proposed, which is a popular model of interactive decision making in cooperative games. This model has recently been used in a wide range of research areas such as economy, science, and management [12,13]. Besides, Banzhaf power measure to designate both fairness and optimization parameters for relay vehicle selection has been introduced. Moreover, in each game with bounded number of players there exist at least one Nash equilibrium point [14,15], so that existence of Nash equilibrium point is demonstrated through using this algorithm. The main Contributions of this paper, are as follows:

– We propose an algorithm based on Weighted Voting Game to choose fair and optimal relay vehicle for anchor vehicles.

- We show that after using Weighted Voting Game (WVG) algorithm, obtained solution is a Nash Equilibrium (NE) point.
- We calculate pay off functions for both anchor and relay vehicles.
- We introduce a method to choose a fair relay node to acquire fairness.

2 Network Architecture

The abstract network is shown in Fig. 1 that consists of RSU, N anchor vehicle and M relay vehicle. These steps will occur respectively:

1. We have a message to give from RSU to vehicles.
2. If the vehicle is in the coverage area, it will try to get that message directly from RSU. In the case of failure for direct connection, it will try to use relay nodes.
3. For the vehicles which are not in the coverage area of RSU, it is not possible to get this message unless they enter that area.
4. With the proposed algorithm vehicles disseminate the RSU message among all other vehicles, even if they are not in the coverage area. After all we propose an algorithm to select the best relay node to get the message and it will be based on weighted voting game algorithm.

3 System Model

As shown in Fig. 2, we have 2 number of anchor vehicles (D, E) and 3 number of relay vehicles (A, B, C). Anchor vehicles are the vehicles that fail to establish connection directly to road side units so they try to find optimal relay node for packet dissemination. In our scenario relay nodes are the nodes that help anchors to preserve connectivity. While (D, E) enter coverage area of RSU, they try to connect to RSU in the case of connection setup failure, as shown in Fig. 2(b) they use one of (A, B, C) nodes as a relay to establish connection. One of these optimal nodes will be chosen by our proposed algorithm. Another scenario is depicted in Fig. 3 where vehicles (F, G) from other lane join to the main lane and want to access to RSU's information. In this phase (F, G) can form coalition with (A, B, C) which have RSU header as their origin [16]. By our proposed algorithm one of (A, B, C) nodes can be choosen as an optimal relay for the anchors.

Each game is consist of players, action profiles, preferences and pay-off functions. In this paper multiple anchor vehicles and multiple relay vehicles are the players of the weighted voting game and will be denoted by M and N respectively. Overall we need to consider two kind of relays:

1. Local relay node: In the presence of RSU, a relay can be selected, when vehicles fail to connect directly to RSU.
2. Mobile relay nodes: After exiting from RSU coverage area, relay node can be selected for connection maintenance. Furthermore, relays with appended RSU header [16] can act as a small RSU for other vehicles.

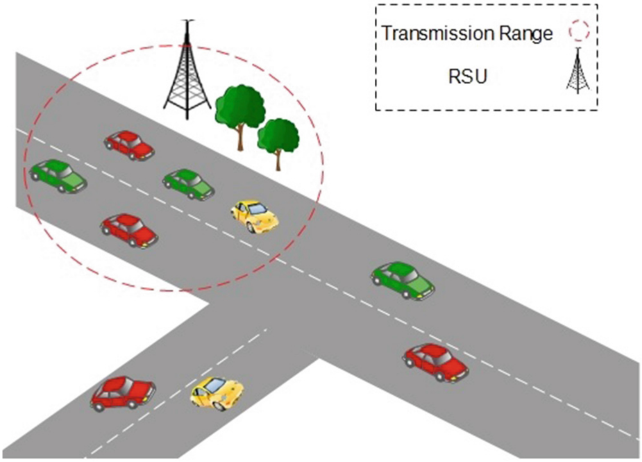

Fig. 1. Network topology

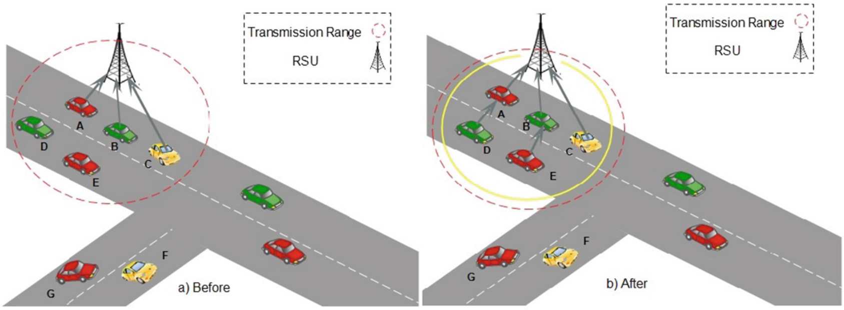

Fig. 2. Network topology example

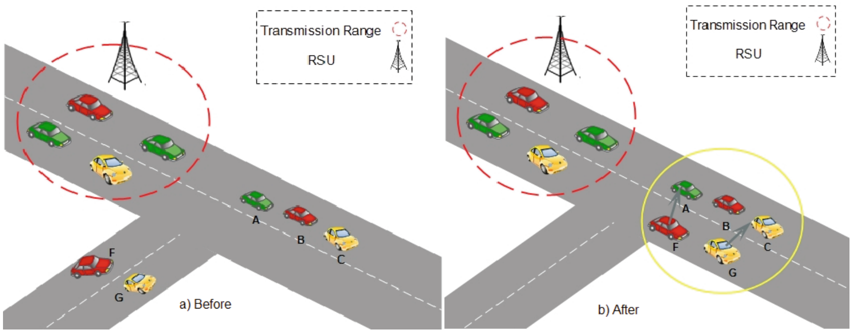

Fig. 3. Network topology example

Definition 1: In the normal-form game that has n-player $G = \{S_1, ..., S_n\}$, if player S_i changes its strategy and other players remain constant, player S_i can't acquire more benefits from that change in its strategy, this is called Nash equilibrium point. NE point will tell us how many of players are cooperating in the coalition [17].

$$u_i(s_1^*, ..., s_{i-1}^*, s_i^*, s_{i+1}^*, s_n^*) \geq u_i(s_1^*, \ldots, s_{i-1}^*, s_i, s_{i+1}^*, s_n^*) \quad (1)$$

Two steps are required to find Nash equilibrium point in each game. First, dealing with each players optimal strategy consecutively, while encountering other player's action. Second, a Nash equilibrium point is defined when whole players concurrently are doing their optimal approach [15]. In our algorithm Players, Actions and preferences are defined as follows:

1. Players: Number of vehicles in coalition
2. Actions: A = { Cooperate, Defect }
3. Preferences: at least k node should participate in a way that maximize the total utility, so in this case we will have NE point.

There are number of vehicles that their cooperation in a game cause to acquire benefits. We are looking for an action profile that each player does one of two actions, whether to cooperate or defect in a coalition. Each player has two phases and in total we have $S = M + N$ players. Therefore, number of action profiles are 2^S. As shown in Fig. 4, this algorithm is proposed to investigate optimality of each player in every coalition. Detecting data origin by appending small header for received packet will help to identify whether the data origin is RSU or relay node. The nodes with RSU header appendix have priority in voting game [16].

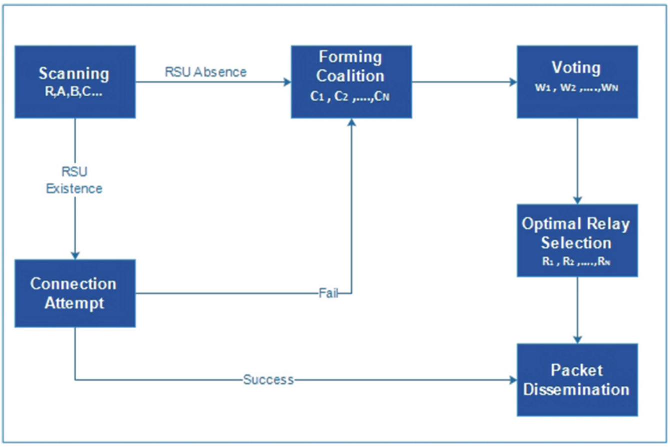

Fig. 4. The proposed system model

3.1 Scanning

In order to find neighbors for packet dissemination, utility functions for each present node must be calculated to decide whether to setup direct connection with RSU or looking for relay node. Defection in coalition for direct connection with RSU must be evaluated at first. Regarding to the amount of pay-off function, as represented as U in Eq. (2) defection may cause connection establishment or failure with RSU [17].

$$U = R - C \tag{2}$$

where R represents revenue of relay or anchor vehicle through using RSU or relays and C shows data forwarding expenses. In this step, the amount of R^r for relay vehicle can be expressed as:

$$R^r = P_{jRSU} B_j F_{ij} \tag{3}$$

where P is successful transmission probability of links between jth relay vehicle and RSU, B is bandwidth availability of RSU and F is bandwidth characteristic of relay vehicle [10].

After connection establishment with roadside unit these connected nodes can act as relay nodes. Afterward setting data origin to RSU should happen [16]. In the case of connection establishment failure with the RSU, Packet dissemination through RSU will fail.

3.2 Connection Attempt

In this step, as depicted in Fig. 4, some of vehicles start packet dissemination successfully. Otherwise, other steps are taking place.

3.3 Forming Coalition

Definition 2: Coalition is the subset of players that all vote in the same way. The number of all possible coalitions are; $2^N - 1$ [18].

By neighbor detection, anchor nodes can form coalition with relay node candidates, which are calculated and identified in previous steps.

3.4 Voting

Definition 3: Weighted voting game voters are unequal in the number of votes they control, it is depicted as:

$$[q : w_1, w_2, \ldots, w_n]$$

where q *is quota and* w *is weight* [18].

Definition 4: Winning coalitions are the coalitions that have enough number of votes to win. Voters are unequal in the number of votes they control [18].

In voting step, pay-off function computation for every neighbor that holds RSU header, is required. For this aim amount of R^a can be expressed as:

$$R^a = \frac{P_{ij} B_i A D}{T} \tag{4}$$

where P is Successful transmission probability of links between ith Relay Vehicle and jth anchor node, B is bandwidth availability of ith relay, T is data transmission time, D is distance between relay and anchor node, A is attainable rate of the link between ith relay and jth anchor [10]. The cost of service by each relay and RSU or anchor, can be modeled as a function of unit price denoted by α and spended bandwith resource [10]:

$$C = \alpha_i F_{ij} \tag{5}$$

After calculating pay-off functions, one of anchor nodes and whole relays will be chosen to decide upon the optimal relay for specific anchor. In addition, utility functions have been assigned as weights of relays. In each winning coalition the range of the quota is defined as [18]:

$$\frac{w_1 + w_2 + \ldots + w_n}{2} \leq q \leq w_1 + w_2 + \ldots + w_n \tag{6}$$

3.5 Optimal Relay Selection

In this step after calculating pay-off functions for anchor vehicles:

$$U^a = R^a - C \tag{7}$$

And assigning this pay-off function as a weight of our voting game

$$w = U^a \tag{8}$$

quota will be set to

$$q = \frac{w_1 + w_2 + \ldots + w_n}{2} \tag{9}$$

In our algorithm the amount of q is:

$$q = \frac{u_1^a + u_2^a + \ldots + u_n^a}{2} \tag{10}$$

Furthermore to acquire fairness while applying weights, Banzhaf power measure has been introduced.

Definition 5: Critical player is the player that eliminating it's weight from the whole votes cause the coalition turns into loosing one and the number of remaining votes fail to pass the quota. Some voters are more powerful [18].

Required steps for Banzhaf power measure calculation are listed as follows [18,19]:

1. Listing all achievable wining coalitions.
2. Determining critical players.
3. In succession check the number of times players are critical, this amount is shown with B_i notation
4. Calculate total number of times that players are critical $\sum_{i=1}^{N} B_i$.
5. The proportion of $\beta = \frac{B_i}{\sum_{i=1}^{N} B_i}$ gives Banzhaf power index.

The most powerful node with higher β is set to be the relay of coalition. These steps will be repeated for all other anchors. For choosing relay node in the absence of RSUs or direct connection failure with RSU, last two steps which are voting and optimal relay selection will be repeated. After these procedures each node is doing its own best strategy. After all, it is proved that the outcome of the offered algorithm is a Nash equilibrium point.

3.6 Packet Dissemination

In packet dissemination, after passing all previous steps and choosing fair and optimal relay, packet dissemination among all vehicles will start. Choosing optimal relay vehicle is important, consequently anchor vehicle's pay-off function is related to throughput function. Considering revenue function of anchor vehicle which is calculated in Eq. (4). Throughput is the rate of received packets at the destination over communication channel [20]. Our objective is to maximize throughput and minimizing message transmission delay respectively. As shown below, throughput is a function of:

$$T(u^a) = \frac{P_{ij} B_i A D}{T} - \alpha_i F_{ij} \tag{11}$$

where T is throughput.

4 Performance Evaluation

The performance of our proposed cooperative weighted voting game algorithm will be evaluated and compared with non-cooperative approach by using Matlab. In our simulation a road of 5 Km that has allocated road side units and number of vehicles that varies from 20 to 90 with randomly distributed velocities has been considered. The simulation parameters are all shown in Table 1. The aim of this algorithm is choosing a fair and efficient relay for anchor vehicles. The simulation results have validated our analysis and demonstrate better throughput and transmission delay outcomes. Our proposed algorithm can achieve 24.4% of increment in throughput as well as 18% reduction in transmission delay compared to non-cooperative approach.

Figure 5, demonstrates total throughput of all vehicles versus number of vehicles. It can be observed that during relay vehicle selection, by using Banzhaf power measure, pay-off function increases. Fair relay will be chosen considering

Table 1. Parameters for simulation

Number of vehicles	$[20, 90]$
Road length	$5\,km$
Number of lanes	2
RSU coverage area diameter	$60 \sim 350\,m$
Max speed	$25\,m/s$
Min speed	$45\,m/s$
Pricing factor α	100
SNR of transmitter	$10\,db$
Number of simulation iteration	100

Eq. 11. Pay-off function increment results in better throughput. To be more specific using weighted voting game algorithm causes optimal relay vehicle selection, which also has maximum available bandwidth B and successful transmission probability P.

Figure 6, displays average transmission delay versus number of vehicles. It is noted that by increasing number of vehicles, more coalition will occur, besides probability of successful reception is the other parameters that has been considered within our proposed algorithm which causes to consume more time in our voting game algorithm to find optimal relay. However, as depicted, this incremental results are less than non-cooperative approach.

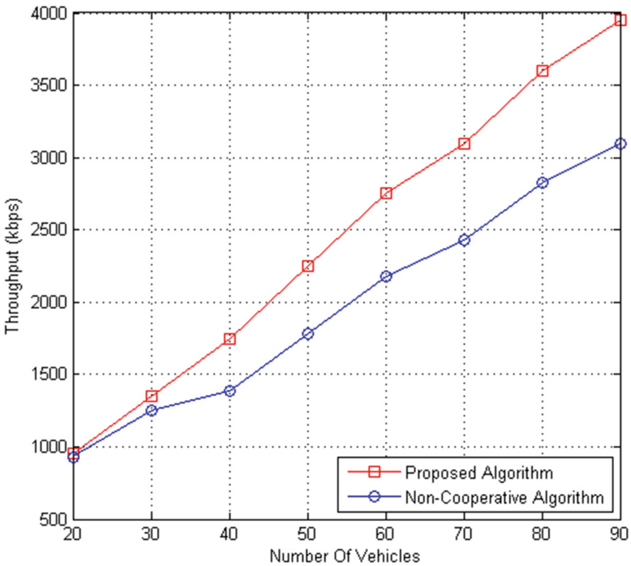

Fig. 5. Total throughput

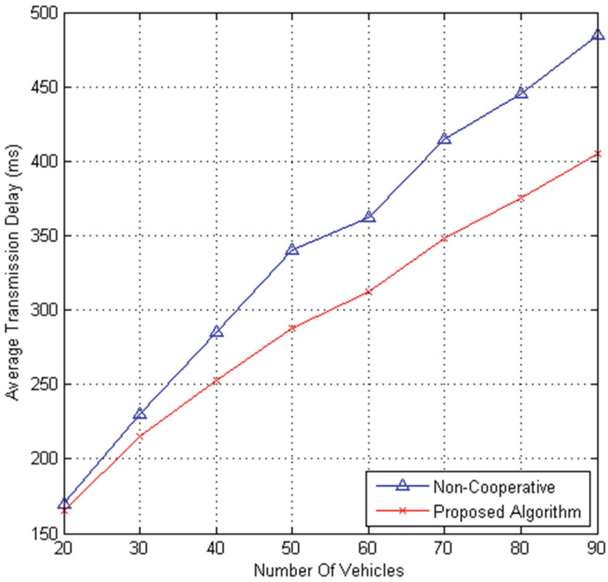

Fig. 6. Average transmission delay

5 Conclusion

A game theory based relay vehicle selection algorithm, based on weighted voting game, by applying Banzhaf power measure has been introduced. The proposed algorithm selects optimal and fair relay vehicle for packet dissemination by using pay-off functions that are derived for both anchor and relay vehicles. Our proposed algorithm, as shown in Fig. 4, is consists of scanning, connection attempt, forming coalition, voting, optimal relay selection and packet dissemination modules. Moreover, our proposed weighted voting game algorithm can achieve fair and optimal results, as well as, increasing throughput and decreasing message transmission delay during packet dissemination as a result of using Banzhaf power measure. Performance evaluation results illustrated that compared to non-cooperative methods, throughput increases by 24.4% and message dissemination delay decreases by 18%.

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