2015 The 5th International Workshop on Computer Science and Engineering
doi: 10.18178/wcse.2015.04.105

A Synopsis of Game Theory in Achieving Cooperative Vehicular Networking

Esraa Eldesouky[1, a], Ahmed Ali[2,b], Wang Dong[3,c] and Li Renfa[4,d]

[1,2,3,4]College of Information Science and Engineering, Hunan University, Changsha 410082, China
[a]compubutterfly@hotmail.com, [b]ahmed_ali@hnu.edu.cn, [c]wangd@hnu.cn, [d]scc_lrf@hnu.cn

Keywords: Game Theory, Intelligent Transportation Systems, Resource Utilization, Vehicular Networking.

Abstract. Vehicular Networking components are characterized by being highly autonomous and circumspect in share their resources. They always aim to achieve maximum profits by make best use of their shareable resources. Within a cooperative environment, these components can be stimulated in order to promote altruism. Game theory is a prominent concept that can magically motivate vehicular nodes to efficiently enhance their resources. In this article, we present a discussion of the recent literature of game theory in vehicular networking. We also focus on game theory main role in knocking several research topics to improve resource sharing. Finally, we mention current challenges and future work to achieve an efficient and robust cooperative networks.

Introduction

The evolution of IEEE802.11p and 1609 standards allows Vehicular Networking (VN) to provide users with Intelligent Transportations Systems (ITS) applications [1,2]. The diversity of these applications creates conflictions among vehicular nodes that vie to access needed resources. Accordingly, these conflictions can affect a self-interested vehicle seeking for improving its own gain. Conversely, this gain can be enhanced if and only if this vehicle is motivated to form cooperative sets with other neighbors. Consequently, both global group gain and individual benefits can be reached [3].

Game Theory [4] can mathematically model conflicts among intelligent rational nodes. This self-interested vehicle can seek for strategies and decide proper actions to increase its profits. Based on both the vehicle's own and neighbors actions, vehicles can compute their net payoff. As a result, a cooperative sets can be generated to share the available resources and obtain a whole supportive network. Several works have been proposed concerning cooperative and non-cooperative models between vehicles and roadsides. Yet in this paper, we survey the effect of using game theory to enhance the VN limited resource. We introduce the different conflicting issues in VN and our recommendation for future trends.

This paper is organized as follows. Section 2 presents a review of VN components and its applications. Section 3 briefs the main characteristics of game theory. Several conflicting situation including bandwidth sharing and content sharing is discussed in section 4. Section 5 summarizes the future work about other conflicting situations. Finally, we conclude our paper in section 6.

Vehicular Networking Overview

VN has been designed to integrate the concrete elements with telecommunication technologies as to get intelligent components. This integration helps to achieve road safety and entertainments by providing users with real-time information. In VN, connections can be among vehicles, vehicles and roadsides, or inter-roadsides [5]. On-Board Units (OBUs) are mounted to vehicles to communicate with other nodes. Yet in Vehicle-to-Infrastructure communications, Roadside Infrastructures (RSIs) can provide different services to vehicles (as illustrated in Fig. 1).

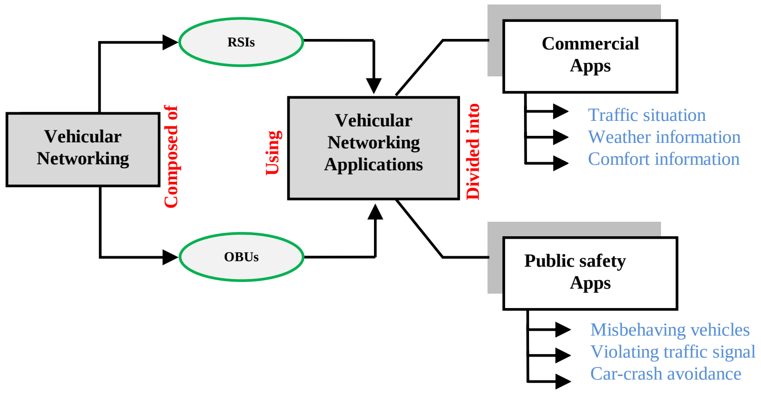

Fig.1 Vehicular Networking

A robust wireless spectrum is required to meet numerous message propagation and fragile connections in VN. Communications among users are obtained through a wireless medium known as Wireless Access in Vehicular Environment (WAVE) using Dedicated Short Range Communication (DSRC). This DSRC/WAVE assembly can provide data rates of 27 Mbps over a communication range of 300 to 1000 m to moving vehicles with speeds up to 150Km/h [5]. The established connections allow users to utilize the infotainment services including accessing multimedia data, bandwidth allocation, or Internet accessing beside the safety message warnings. According to the U.S. Department of Transportation (DOT), communications based on DSRC technology can avoid 82% of crashes in the United States [6].

Characteristics of Game Theory

Over the few past decades, game theory plays an effective role in computer networking. This powerful tool involves a mathematical construct including: a set of concepts and assumptions, fundamental theorems, plus applications to real world issues [4,7]. It can set strong criterion and models complex problem information in a game format. As shown in Fig. 2, this discipline allows nodes (i.e., players) to form supportive sets (i.e., coalitions) to achieve their objectives. Game theory only concerns sharing of payoffs among players without considering how this should be done [4]. However, it suffers from determining the cost functions of all players which is difficult to ensure in some cases.

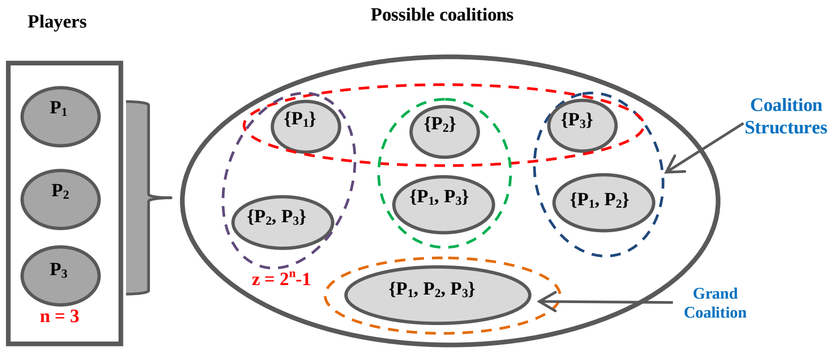

Fig. 2 An illustrative example of coalition formation in game theory

A game can be cooperative or non-cooperative depending on whether players are rational or selfless [8]. Under cooperative games, players are stimulated to form coalitions as to reach a global gain besides enhancing the individual payoffs. On the other type, players make independent decisions in order to selfishly obtain their payoffs. They are procedural games in which sets for players, actions, and their payoffs are pre-defined. In cases where there is no need to define a precise structure for the actual game, cooperative games is preferred. Since the achievements of each coalition is the main solicitude, not how this is reached.

Issues Resolved by Game Theory in VN

During the last years, the concept of game theory has been applied to computer networks to resolve competitive environments [9]. In this section, we summarize the state of art for the proposed contributions in this field. We aim to help readers to be able to identify the appropriate game type for their problem.

Channel and Bandwidth Utilization. Vehicular nodes use the available bandwidth to fetch data from RSIs [10,11]. The fragile links in VN allow rational vehicles to eagerly access higher bandwidth for caching the needed data. This manner critically degrades the Quality-of-Service (QoS) metrics of VN. Using game theory, vehicular nodes can cooperate to form coalitions that maximize the reserved bandwidth. Besides, minimize the cost paid to roadsides for bandwidth services. Consequently, nodes can assure fair distribution for the available bandwidth and enhance the total throughput.

In [12], a cooperative model to resolve bandwidth sharing problem is proposed. Coalition formation is used to raise the social welfare of all competing nodes considering two schemes. A rational coalition formation is applied where vehicles aim to increase their individual payoffs. Secondly, an optimal coalition scheme that improves the overall utility is utilized. Nevertheless, this model has the shortage of simulating only few numbers of vehicular nodes (i.e., 4 vehicles).

Compared to [13] and [14], the work proposed in [12] increases total utility by 17% and achieve better QoS. On the other hand, a non-cooperative static game that considers channel quality and finite packet rate assumptions is presented in [15]. This game uses a pure Nash Equilibrium (NE) for joint allocation game to achieve load-balancing and fairness among nodes. Lastly in [16], a dynamic evolutionary game is modelled to simulate vehicles competing for bandwidth reservations. An evolutionary stable strategy is set as a proposed solution considering vehicles velocity and package size to boost the network throughput.

Data Transfer Issues. Researchers present many proposals concerning data transfer in VN using game theory. In this subsection, data dissemination is categorized into three classes: 1) information delivery from source to destination, 2) dissemination of accurate traffic information and 3) broadcasting of emergency warnings.

In [17], researchers focus on motivating vehicles to take part in the packet relaying process. They assume that vehicles are owned by different users that may not help in forwarding messages over the network. As a result, NE strategy is used to achieve uniqueness and fairness among vehicles. Similarly in [18], NE is also used to stimulate selfish vehicles by applying an equilibrium solution. Using a non-cooperative game, different weights are assigned to packets so that participating vehicles be motivated to maximize the network total utility. Both [17] and [18] specify some relying nodes to apply their proposed mechanism.

Another coalitional game scheme is introduced in [3] and [19] to enrich data delivery protocols in heterogeneous cellular vehicular networks. Some nodes are chosen as mobile gateways for connections between cellular networks and VN. However, the scheme in [19] is time-consuming scheme due to the selection of mobile gateways. Therefore, this scheme is cannot be used in emergency cases. In [3], authors extend the presented scheme by taking into account the limited storage space of each node.

A non-cooperative game is presented for broadcasting true information among neighboring nodes [20]. The proposed approach investigates vehicles' objectives in minimizing their driving routes. In [21], a Nash Bargaining game is applied to control the rate of transmitted messages as to limit the data inserted in VN. This approach succeeds to achieve fair data distribution among participating vehicles. Moreover, it is applied to some real-world ITS applications such as parking and traffic information applications.

Content Downloading and Sharing. Although entertainment data is important to vehicular users, achieving speedy content downloading/uploading is defiance due to the dynamic topology of VN. In [22], a situation where a group of vehicles are contesting to access a content data file is modelled. Each vehicle succeeds to own some portions of that file rather than the whole file. As a result, the proposed approach allows vehicles to form cooperative coalitions to get the missing portions from their neighbors as to maximize their profits. The idea of this approach is inspired from the peer-to-peer (P2P) protocol [23] in which a vehicle can be a server at the same time.

However in [24], Cognitive radios are utilized to perform P2P transmission over the unlicensed channels. Authors aim to maximize the transmission rate by accessing other available channels.
A bargaining game is presented in [25] to model the case where roadside units distribute data packets among vehicles based on their priorities. This game targets to accomplish fairness and efficiency among competing nodes. In [26], a stochastic game is proposed where competing nodes are subjected to different cost price for streaming data at a certain roadside. In this game, a constrained NE strategy is applied to ensure cost reduction for each node using the provided service.

Other Disputes. Issues such as storage space, power consumption and security should be taken into consideration. Recently, store-and-forward message switching mechanism is involved in routing protocols to overcome the difficulty of unstable connections. Whenever a message exists for forwarding, relying vehicle stores and carries this message to other nodes within its vicinity [27,28]. Insufficient storage space problem is considered in [3] where vehicles are free to discard some messages if there is no enough storage space provided that they are not safety messages. However, this solution suffers from ignoring the significance of the deleted messages for other receiving vehicles. The s election of the unwanted message according to its relevance is presented in [29] where the sender decides whether this message is relevant to the receiver This proposed model can enhance storage space by throw away undesirable messages without affecting the receivers' decisions.

Once a vehicle receives a message it becomes no more vital and it is discarded by the driver. In [30], a history of the past-events is maintained and provided to vehicular users. The researchers introduce a cooperative scheme to aggregate the received messages using Flajolet-Martin sketches [31] and deploy this scheme to vehicles on road. They aim to extract useful information from transmitted messages in order to provide users by a complete road history. Although this scheme can achieve better statistical results such as frequent accident areas or rush areas given the exact time, it can cause large overhead over a condensed VN.

Another critical issue that should be considered is attack defending over VN. Malicious attackers are avoided by maintaining several defensive strategies in order to protect vehicular users from being cheated by misbehaving nodes. In [32], authors present three security games based on different information assumptions for vehicles. First, a classical zero-sum security game [33] is used when the payoffs of the cooperating vehicles are known to each other. However, in case that the payoffs of the participating vehicles are not exactly identified, a fuzzy game is utilized. Vehicles main objective is to achieve higher individual payoffs by using fuzzy numbers instead of accurate ones. Finally, a fictitious play is deployed if and only if there is no prior preferences information for vehicles. As a result, vehicles implement some learning mechanisms according to the best historical averages. An alternative security game based on Ant Colony Optimization algorithm is formulated in [34]. This heterogeneous game can deal with security problems such as allocation of defense resources and attack modelling. This algorithm is a heuristic optimization that allows the discovering of global best solutions for sharing among vehicular nodes. It can achieve malicious node avoidance with high probabilities.

Future Trends and Open Challenges

In this review, we present the research works that have been proposed concerning the involvement of game theory in disentangling conflicting situations over VN. Nonetheless, more efforts should be exerted to cover other hot topic issues as listed in this section.

Bandwidth sharing and allocation using cooperative mechanisms have shown progress in improving network throughput and accomplishing greater data transfer rates [12,15,16]. More work should consider the cooperation among vehicles without relying on any infrastructure as in [35]. Enhancing bandwidth allocation for vehicles competing for accessing rich multimedia contents should be paid more attention to achieve fairness and stability. Also, optimal roadside unit selection and the cache buffering of data transferred in V2I communications should also concerned. Several topics including bandwidth allocation rate in network layer and interaction among layers should be studied.

In data transfer communication failures should be reduced by controlling the probability of link failures while transmitting public information. Moreover, truthful packet delivery has to be ensured as to prevent misbehavior nodes from disseminating false route information [20]. In broadcasting messages related to safety application, time metrics should be handled to save lives and possessions. More studies are required to achieve content data exchanging between two vehicles in different transmission ranges. Furthermore, precise models are needed to compute the duration of data exchange completion and the success probability of the transferred data among vehicles. In VN security, researchers should examine suitability of game theory for discovering malicious attacks concerning cognitive radios [36] and smart grid [37]. Generally, all the proposed work concerning game theory in VN aim to increase vehicles individual payoffs and as a consequence provide better total utility

Conclusion

Vehicular networking is a rapid emerging type of the mobile ad hoc networks family having highly dynamic topology over predefined roads. In these networks, vehicular users are usually competing to access a resource or accomplish a specified task. This competitive environment should be fairly organized in order to make use of the limited available resources and the short connectivity time. In this paper, we address the recent literature on the game theory concept focusing on VN. Different game strategies are included to resolve the conflicting issues among vehicular components. Using numerical results, we show the effect of solving of these conflicts using cooperative games compared with other approaches. All the proposed game models seek to maximize the vehicles benefits and reduce any cost paid by forming different coalitions. The cooperation among vehicular nodes succeeds to achieve fairness and meet the QoS requirements of VN. Moreover, uniqueness is accomplished as vehicular components participating in any game model follow a defined strategies and actions to reach their goals. As mentioned above, there are more hot topics that need to be explored using theoretical game models to enhance the sharing of the limited resources over VN.

Acknowledgements

This work was supported by The National High-Tech Research and Development Plan of China under Grant No.2012AA01A301-0, and The National Natural Science Foundation of China (61173036).

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