An Evolutionary Game Theoretic Approach for Stable Clustering in Vehicular Ad hoc Networks (VANETs)

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"Nothing is impossible if you have faith in God and you set your mind to it"

(Ammara Khan)

Abstract

Finding and maintaining efficient routes for data dissemination in VANETs is a very challenging problem due to the highly dynamic characteristics of VANETs. Clustering in Vehicular Ad hoc Networks (VANETs) is one of the control schemes used to provide efficient and stable routes for data dissemination in VANETs. The rapid changes in the topology of VANETs have instigated frequent cluster formation and reorganization which has seriously affected route stability in Vehicular Ad hoc Networks. Considerable work has been reported into the development of clustering protocols while keeping in view the highly dynamic topology of VANETs, but the objective of imbuing the system with a stable underlay is still in the infant stage. The analytical models used for studying the behaviour of Vehicular Ad hoc Networks have been scarced due to distributed, highly dynamic and self-organizing characteristics of VANETs. In contrast, game theory is emerging as a novel analytical tool that can be used to tackle the technical challenges concerning the current and future problems in wireless and communication networks. A two-layer novel Evolutionary Game Theoretic (EGT) framework is presented to solve the problem of in-stable clustering in VANETs. The aim of this research is to model the interactions of vehicular nodes in VANETs, to retain a stable clustering state of the network with evolutionary equilibrium as the solution of this game. A stable clustering scenario in VANETs is modelled with a reinforcement learning approach to reach the solution of an evolutionary equilibrium. Performance of the proposed "evolutionary game based clustering algorithm "is empirically investigated in different cases and the simulation results show that the system retains cluster stability.

Declaration

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature:

Ammara Anjum Khan

Dedication

To my beloved mother Najma khan and my father Salah Uddin Khan .

Acknowledgements

Thanks to ALMIGHTY ALLAH for giving me strength and ability to understand learn and complete this thesis. No doubt he is the best disposer of all affairs.

Life is the name of ongoing struggles and efforts. Being thankful gives us an appreciation for what we have. People, things and events come and go in ones life for some reason. Every person is a paragon in his entirety and it is important to treasure people. Besides, the completion of this dissertation is really a credo to learn the love, support, and faith of the people in my life.

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Chapter 1

Introduction

1.1 Thesis Statement

Due to an ever increasing demand of transportation safety in Intelligent Transportation Systems (ITS), the need for an attractively efficient data dissemination has been growing day by day to the point, where it is clearly understood that many future ITS systems should be instilled with a stable system underlay. To their end, clustering plays an imperative role to provide an efficient and steady state routing in Vehicular Ad hoc Networks (VANETs) [6], [7], [4], [8], [9]. There are several clustering schemes proposed in the arena to provide an efficient and stable routing in VANETs [6], [10], [8], [11]- [12], each having their own advantages and disadvantages. Nonetheless, the highly dynamic intrinsic characteristics of VANETs are seriously affecting cluster stability and has resulted in frequent cluster reformation and reorganization in VANETs [13]. The traditional analytical models are struggling to get the pace in the market shoulder to shoulder to provide an efficient and robust clustering in VANETs, however, they are not able to tackle with distributed, highly dynamic and self-organizing characteristics of VANETs. In contrast, game theory is mounting as an innovative analytical framework to handle the technical challenges related to inherent characteristics of VANETs. In order to efficiently relay data in VANETs, that is the most demanding challenge in Intelligent Transportation Systems, we have to have a very sophisticated and robust clustering technique that helps in efficient and stable routing in VANETs. A two-layer Evolutionary Game Theoretic (EGT) framework is presented to model the interactive decision making between vehicular nodes to provide stable and optimized clustering in VANETs. The gist of this dissertation is to investigate cluster stability in VANETs by using the proposed EGT framework with further discussion on possible potential areas of improvement. This thesis is largely focused on testing the performance of proposed protocol in terms of providing stable and optimized clustering in VANETs.

1.2 Thesis Organization

The dissertation is organized into the following chapters.

- The second chapter is divided into two sections.
    - First section gives an overview of VANETs including a detailed discussion about the infrastructure and applications of VANETs. Furthermore, a detailed review of the network layer operations in VANETs along with their pros and cons is also presented in this section. Based on this review, a generalised categorization of network layer operations in VANETs is also presented in this section. In addition to this, the importance of clustering in VANETs along with some currently proposed clustering protocols describing their advantages and disadvantages is also included in this section.
    - Second section introduces game theory, its components and application areas. It further compares the traditional analytical tools with game theory. Moreover, the applications of game theory in the field of wireless and communication networks are also explored in this section. More specifically, the Evolutionary Game Theory (EGT) along with the reasons "Why Evolutionary Game Theory "is also debated in this section. A very brief discussion about some evolutionary games in wireless Networks is also a part of this section. In addition to this, a brief introduction about evolutionary potential games is also discussed.

- The third chapter gives a detailed description of the proposed two layer Evolutionary Game Theoretic (EGT) framework. First, the main contributions of this research are discussed. After that, the detailed description of proposed two layer Game framework is presented. Upper layer takes a tentative set of predefined clusters in the network as an input and applies the proposed lower-layer Evolutionary Potential Game Theoretic (EPGT) approach to this input to resolve the problem of cluster instability in VANETs. The main components of the proposed two-layer framework are also summarized in this chapter. Furthermore, a detailed explanation of proposed lower-layer EPGT framework is presented. In this part, the payoff and utility function that are used in the proposed game are presented to solve the problem of instable clustering in VANETs. In brief, payoff in the proposed game is determined by the net utility. The utility function is the difference between reward and cost of the strategy played by the vehicle. The utility function can be computed from the total throughput capacity of the entire cluster. Shannon's capacity is used to calculate the capacity of each node in the cluster. The objective of the utility function is based on maximizing the utility function. A simple cluster formation approach that is "least distance criteria "is used as a clustering metric in the proposed scenario. The cost function is a function of cluster size and is implemented at the cluster size of five or less to achieve the purpose of optimized use of resources from the central controller. For the sake of simplicity to test the adeptness of the proposed game, free space path loss is used as a propagation model for the simulation of the proposed VANET clustering scenario. This chapter also gives some explanation about the flow chart of the proposed model in addition to the system model and assumptions made for the proposed model. The solution approach that is proposed deals with finding an evolutionary Nash equilibrium. A reinforcement learning approach using a central controller RSU is used to reach at the solution of the proposed game. The vehicles learn and adapt their strategies through repeated simultaneous interactions between vehicles and the centralised controller RSU to reach the state of Nash equilibrium and that state is considered to be a stable clustering state of the system. The vehicles select their action profiles based on the objective to maximize their expected net utility. Moreover, the strategy in this scenario corresponds to the expected net utility of the group behaviour of vehicles within a cluster, rather than depending on the individual behaviour of nodes. In the end , the list of parameters along with the list of algorithms is provided.

- The fourth chapter presents the performance evaluation approaches that are used to test and analyse the performance of the proposed game.

  - First, the proposed game is tested in a simple static scenario with the random deployment of nodes in an area. The purpose of this evaluation is to investigate the efficiency and performance of results in a simple scenario. Another enchanting fact to use this approach is that, one can use this game to solve the problem of in stable clustering in any type of scenario.

  - The second approach that is used to evaluate the performance of proposed game is to use the mobility of vehicles for the implementation of our proposed game. Manhattan grid is used as a mobility model to analyse the performance of cluster stability in VANETs. Some changes are also made in the default setting of Manhattan grid by setting some probability of vehicles to turn back in either direction when they reach at the borders of the simulation area. The description of simulation setup, assumptions made for the simulation and the list of network configuration parameters is also provided in this chapter. The trajectories obtained after running the simulation experiments at different speeds of vehicles, N and cost function ς are also provided via figures. The trajectories of the obtained results reflect that the proposed clustering protocol is robust and efficient in terms of retaining cluster stability in the network and is able to cope with different speeds of vehicles in the network.

- The conclusion part reaches a finale to the research and concludes this dissertation with a summary in addition with the future plans that can be carried out to perform some further investigations.

1.3 Contributions and publications

Contributions:

The main contributions of the research are illustrated as

- A two layer Evolutionary Game Theoretic approach is presented to solve the problem of in-stable clustering in VANETs that is caused due to frequent cluster reformation and reorganization in a VANET clustering scenario.
- The proposed game framework gets a pre-assumed number of randomly distributed clusters from upper layer as an input and applies the proposed lower-layer Evolutionary Potential Game Theoretic (EPGT) approach to this scenario. The proposed lower-level game solves the problem of cluster in-stability in VANETs and provides an optimum and stable clustering thus reducing the overhead of frequent cluster reformation in VANETs.
- The solution of the proposed game is presented to be an evolutionary Nash equilibrium. For that, a reinforcement learning approach is used by using a central controller Road Side Unit RSU. The vehicles learn and adapt their strategies gradually through repeated simultaneous interactions with the centralised controller RSU and reach the stable clustering state.
- The payoff and the utility function for the proposed game are also presented and further details are mentioned in chapter 3.
- The proposed game is analysed on different values of cost function and the optimal cost is suggested that defines the optimum clustering.
- The stability of clusters on different populations and speeds of vehicles is analysed. It is concluded that the proposed game provides a robust and diversified solution for stable and optimized clustering in VANETs.

Publications :

1. Ammara Anjum Khan, Mehran Abolhasan and Wei Ni. ***An Evolutionary Game Theoretic approach for stable and optimized clustering in VANETs*** to be submitted to the Journal of Networks.

2. Ammara Anjum Khan and Mehran Abolhasan. ***A review of clustering strategies in VANETs*** to be submitted to the Journal of Networks

3. Ammara Anjum Khan and Mehran Abolhasan. ***A review of network layer operations in VANETs*** to be submitted to the Journal of Networks.

Chapter 2

Literature Review

2.1 Vehicular Ad hoc Networks

Vehicular Ad hoc Networks (VANETs), a sub class of Mobile Ad hoc Networks (MANET), provide wireless communication services among vehicles and vehicle to road side infrastructure [14],[15]. The main idea is to provide ubiquitous connectivity to the mobile users while travelling on the road [6]. VANET has been an esteemed choice of researchers during the past few years due to the wide variety of new potential applications they can provide. Their applications range from providing efficient Vehicle-to-Vehicle (V2V) communication that enables Intelligent Transportation Systems (ITS), comfort applications to the passengers, at one hand, and on the other hand providing traffic and environment efficiency as well [16],[14]. It can also be considered as a potential core of Intelligent Transportation Systems (ITS) that aims to increase people safety on roads and improve transportation efficiency and traffic management.

2.1.1 Application Areas

With the increasing demand of new techniques in Vehicular Ad hoc Networks, several new applications are emerging in the field of VANETs to integrate the capabilities of next generation wireless networks to vehicles [6].

VANET applications can be categorized into the following major groups

- *Safety and Warning Applications*
- *General information services and Comfort Applications*

- ***Safety and Warning Applications***: These type of applications are considered to be the major applications that are used as components of Intelligent Transportation Systems (ITS). Application of this class have a strict delay requirements for dissemination of safety and time critical messages and they mostly demand Vehicle to Vehicle (V2V) communication. Examples include emergency warning systems, lane changing assistance, intersection coordination, traffic signal violation warning, road condition warning, accident avoidance(cooperative collision avoidance, pre post-crash warning and roll-over warning), controlling traffic jam, blind crossing (a crossing without light control), better utilization of roads and resources such as time and fuel (improving environmental efficiency indirectly).
- ***General Information Services and Comfort Applications:*** These type of applications improve traffic efficiency and provide entertainment and comfort applications to the passengers. Passengers are allowed to avail the facility of internet, play interactive games with other passengers while travelling on road. This class of applications usually demands Vehicle to Infrastructure (V2I) communication. Examples include traffic information systems, weather information, better route (road) selection, better traffic balance and shorter travel time, value-added applications such as entertainment and business advertisements, gas station or restaurant location and interactive communication services(Internet access, music download and playing games) [16],[14].

2.1.2 Basic Components of Vehicular Communication (VC)

The basic components required for Vehicular communication are

- ***Road-side Units (RSUs)***: RSUs are also called as central controllers which are static components that provide direct wireless communication services from

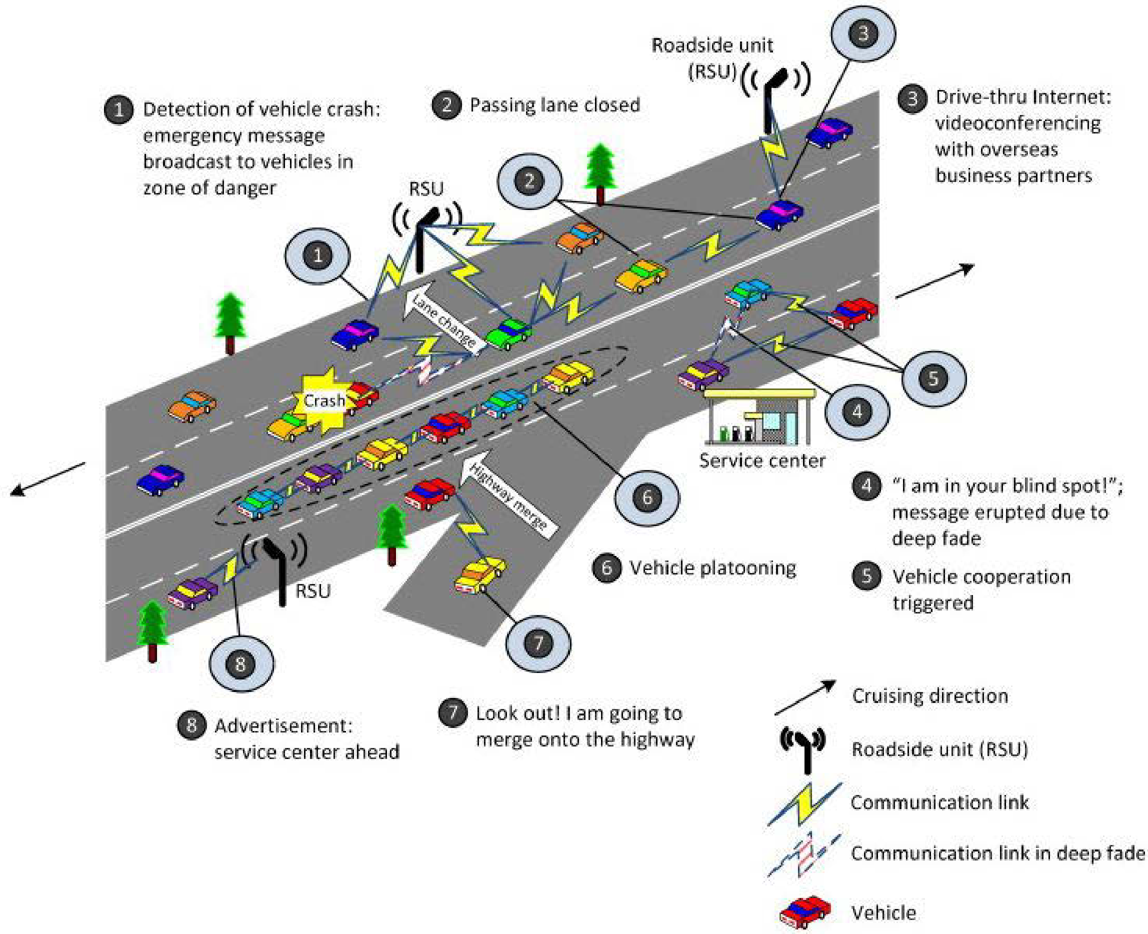


Figure 2.1: A schematic of ITS services in VANETs [1]

Figure 2.2: An Example of Comfort Applications using video streaming applications in Smart vehicles [2]

Backseat child navigation concept for kidsavailable online at http://www.slippery brick.com nearby vehicles to the Vehicle to Infrastructure (V2I). Road Side Units can be any hotspots such as GSM, WLANs, and WiMAX hotspots, infostations or sensors that are connected to the backbone networks. They are currently very sparsely deployed. Their ubiquitous deployment is futuristic and expensive. The distribution and deployment of RSUs are also dependant on the communication protocol to be used. For instance, some communication protocols demand RSUs to be evenly distributed throughout the network, some protocols demand RSUs to be placed only at intersections and some protocols require RSUs only at the border regions. However, in all cases the main focus is to provide intermittent connectivity to the vehicles with Road Side Unit [16].

- ***On Board Units (OBU)***: Each vehicle is equipped with a central processing unit (CPU) to run protocols, a wireless transceiver, a Global Positioning System (GPS) or Differential Global Positioning System (DGPS) receiver (to provide information on location), wireless router, sensors to measure various parameters and an I/O interface for human-vehicle interaction, with small additional hardware cost for car manufacturers. Most of the applications provided by ITS systems depend on the geographical positions of the sender and receiver, therefore, it is very compulsory to have an On Board Unit equipped with GPS or DGPS receivers.

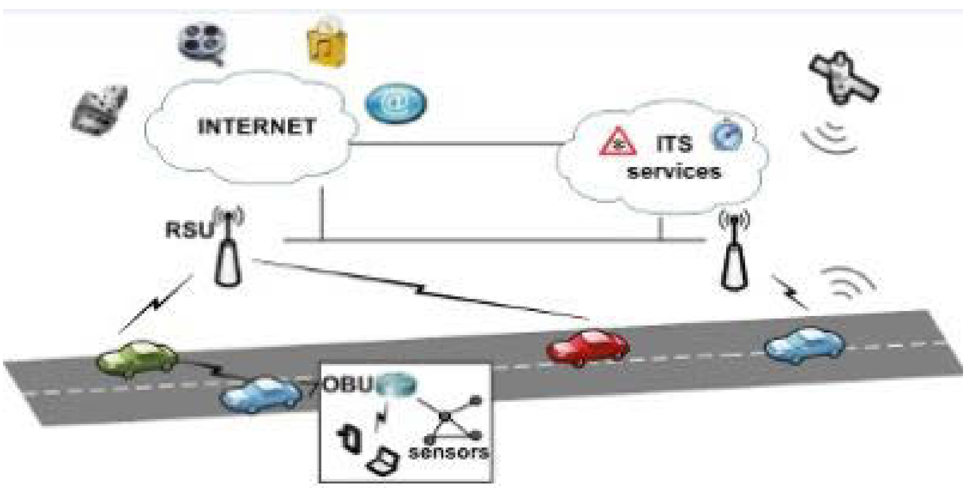


Figure 2.3: Components of Vehicular Communication [3]

2.1.3 Vehicular Communication Infrastructure VCI

Though Vehicular Ad hoc Networks are aimed at providing ubiquitous connectivity to the mobile users, therefore, they do not rely only on the fixed infrastructure for dissemination of messages between vehicles [14],[6]. For that reason, the Vehicular Communication Infrastructure (VCI) of VANETs that is used for ITS applications can be categorized as follows

- ***Vehicle to Vehicle(V2V) Communication***: This type of communication is also called as Inter Vehicle communication (IVC). It uses multi-hop multicast or broadcast mechanism for the dissemination of traffic related messages over multiple hops. In ITS applications, this type of communication is applied when a vehicle is not directly connected to an RSU and the vehicles. The bandwidth demand for V2V is comparatively less as compared to the bandwidth demand for V2V or I2V.

- ***Vehicle to Infrastructure(V2I) or Infrastructure to Vehicle (I2V) Communication*** : This type of communication is also called as Roadside Vehicle Communication (RVC). In this type of communication, the message is shared between RSU and vehicles. For instance, the RSU sends or broadcast message to all vehicles that come within the vicinity of RSU using a single hop transmission or the vehicles sending their location information to the RSU.

  The bandwidth demand for V2I communication is higher as compared to bandwidth demand for V2V Communication. For instance, one of the ITS applications like speed warning or broadcasting speed limits requires RSU to broadcast speed limits of vehicles. For that, the RSU will determine the appropriate speed limit by checking its internal database information and traffic conditions and will periodically broadcast the speed limit message to vehicles coming within its vicinity. Moreover, RSU will also compare the directional limits with vehicle data to check the applicability of the speed warning issued to all vehicles coming within its vicinity. Also, if a vehicle is going to violate the desired speed limit rules, RSU will also issue an audio or visual warning to warn the vehicle to reduce its speed [16], [4]. Sparse Roadside Vehicle Communication(SRVC) and Ubiquitous Roadside Vehicle Communication (URVC)

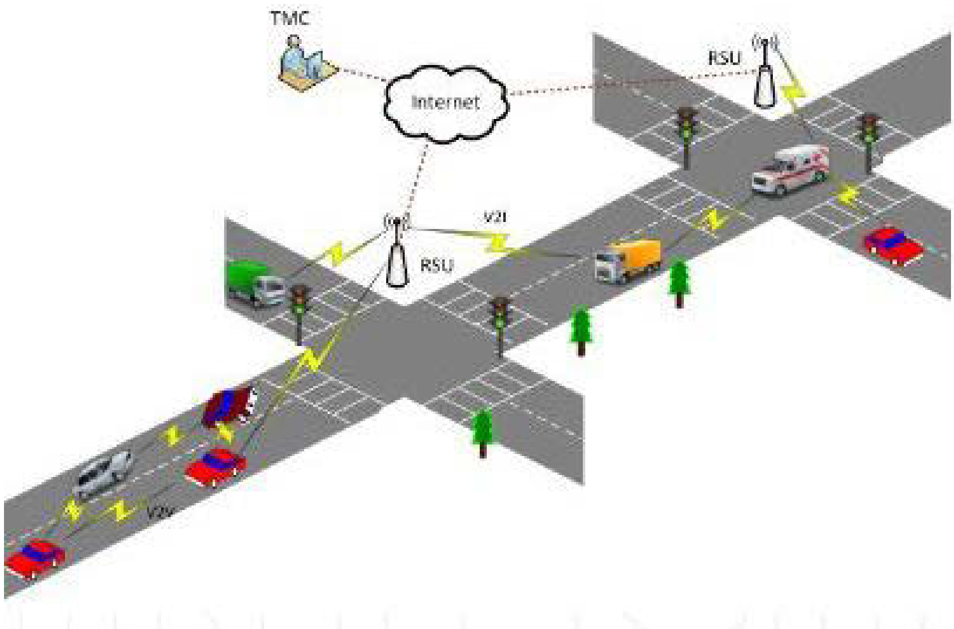


Figure 2.4: A Vehicular Communication Infrastructure Scenario [4]

are also some subtypes of this V2V or I2V infrastructure.

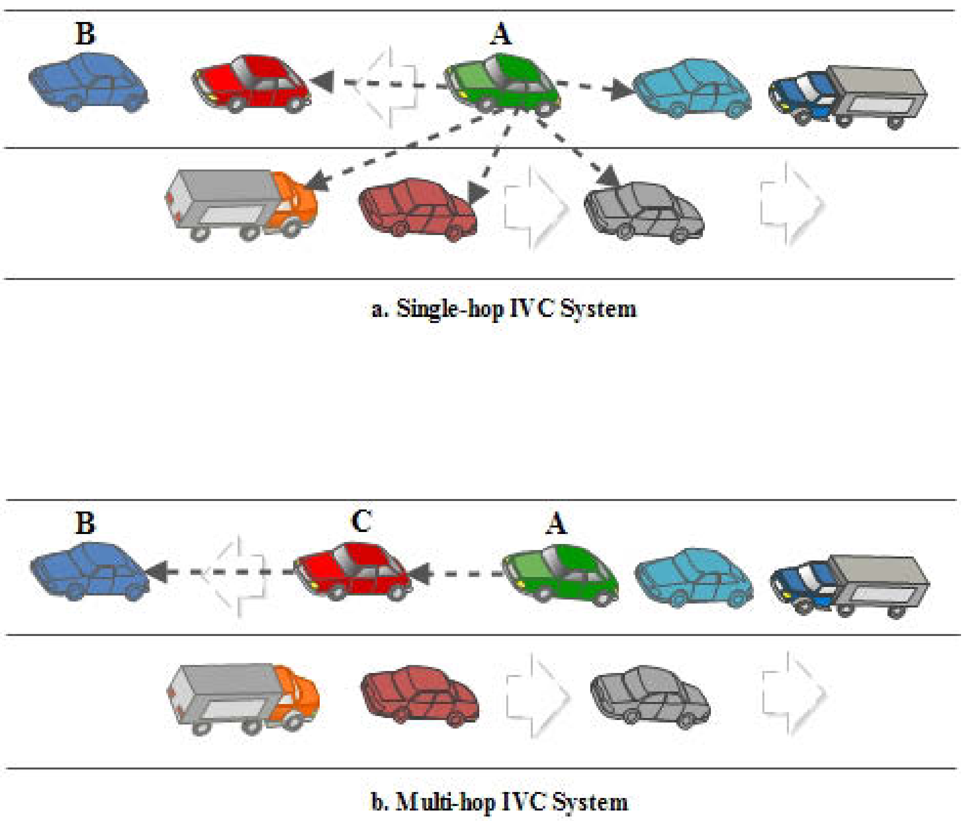


Figure 2.5: An example of Single hop and Multihop IVC System in VANETs

- ***Hybrid Vehicle Communication (HVC)***: This type of communication infrastructure relies on both inter-vehicle (V2V) and road-side (V2I) or (I2V) access. Mainly the huge range of cooperative applications provided by the ITS systems like services providing information to the drivers, road accidents warning, interactive game playing, infotainment, traffic management, enhanced routing, road condition sensing and many other applications use this type of communication infrastructure [4].

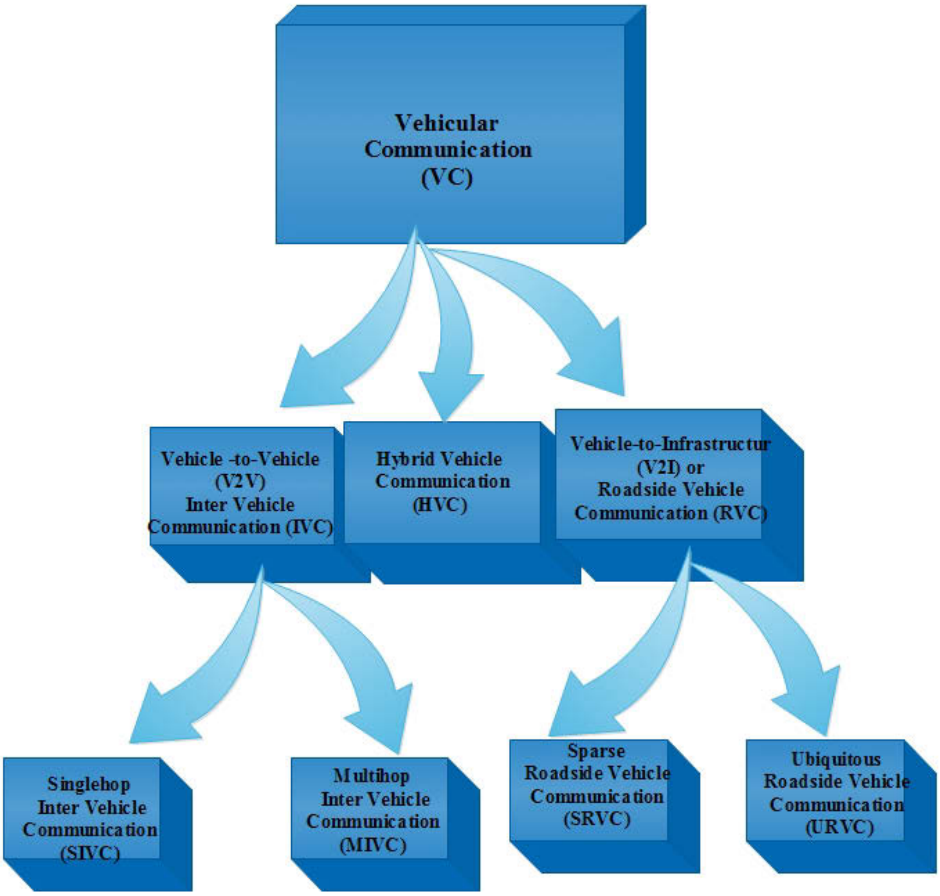


Figure 2.6: Vehicular Communication Infrastructure VCI

2.1.4 Distinguishing Features of VANETs

In addition to the similarities with other Ad hoc networks, such as self organization, self management and low bandwidth, VANETs have some other intrinsic features based on which they can be distinguished from other kinds of Ad hoc Networks [16], [6], [4]. To design a scalable and robust VANET protocol, following characteristics of VANETs are important to be considered .

- ***Rapidly changing topology :*** VANET topology is dependent on the mobility of vehicles. Due to the frequent changes in the speed of vehicles, there is recurrent change in the topology of VANETs. To design a VANET protocol, this feature must be kept in consideration.

- ***Rich resources:*** VANET nodes are rich in power, memory and processing capabilities as the nodes in VANETs are vehicles that are equipped with On Board Units OBUs, therefore, they have enough resources like memory and processors.

- ***Frequently disconnected Network:*** Due to the rapid changes in the topology of VANETs, the connectivity between vehicles could not be maintained. This effect is more visible especially when the vehicle density is low, as there is higher probability for network disconnection. One solution is to deploy several relay nodes or the fixed points known as RSUs that could retain network connectivity in case of low density traffic on the roads. This network disconnection problem should also be kept into consideration to design a VANET protocol.

- ***Mobility models and prediction of future positions***: Movement of vehicles is usually restricted by road directions and traffic patterns. These mobility models and predictions play a vital role to help the designer to design VANET protocols by predicting the future directions of vehicles.

- ***Hard delay constraints:*** Some of the applications of ITS Systems, for instance, in an emergency brake warning, when a brake event happens, the dissemination of that message is very time critical. This message should be reached in time to avoid car crash, therefore, in this situation, it is more important to control high delay constraints rather than to provide high data rates. In this type of application, the maximum delay is considered to be critical as compared to average delay.

- ***Various traffic environments:*** VANETs operate in two different type of traffic scenarios that is *city* and *highways.* The highway scenario is simple and easy whereas the city traffic scenario contains a lots of streets, buildings and obstacles, therefore, it becomes complex to deal with the city scenarios. While designing a VANET protocol, one should consider the affects caused in communication due to shadowing and path loss caused due to city environments.

- ***Geographical addresses:*** In contrast to other networks, that use unicast or multicast where the end points of communications are identified by ID or group ID, the VANET addressing schemes is based on geographical areas where the data is forwarded.

- ***GPS equipped on board sensors:*** VANET devices are assumed to be equipped with on board sensors that provide information to the routing protocols and provide other communication services.For instance, GPS and DGPS receivers are increasingly become common in OBUs that help in locating a vehicular node that is used for routing purposes.

2.2 Network layer operations in VANETs

The promising improvements of VANETs in the field of Intelligent Transportation Systems are traffic monitoring, control of traffic flows, blind crossing (a crossing without light control), easing traffic jam, enhancing driving safety, accident avoidance and better utilization of roads and resources such as time and fuel. Another important category of VANET applications is providing internet connectivity to the vehicular nodes while on the move to provide entertainment applications to the passengers like music download, sending emails or playing games [17]. The wide range of applications in VANETs demand efficient and stable routing operations to ensure in time delivery of messages.

Different applications in VANETs have different QOS requirements, such as safety and warning applications are very time critical. These type of ITS applications should have minimum end-to-end delay as the late arrival of warning message at destination could not help in preventing an accident on the road. In addition, these safety and warning applications also require an efficient and intelligent broadcast mechanism to distribute warning messages[18]. It is also observed that broadcasting in VANETs is very different from routing in MANETs due to several reasons like varying network topology, mobility patterns and traffic patterns in different timings of the day and so on. These differences imply that conventional routing protocols for MANETs like Dynamic Source Routing (DSR) and Ad hoc On Demand Distance Vector (AODV) will not be appropriate in for most vehicular broadcast applications. Therefore, routing in VANETs is addressed separately [9].

The network layer of VANETs holds the following types of routing operations [16], [7], [9], [19], [20], [21].

1. Unicast/Forwarding
2. Multicast/Geocast
3. Broadcast
4. Clustering
5. Beaconing
6. Position based
7. Delay tolerant
8. Topology-based based

The details of these network layer operations in VANETs are discussed as

1. ***Unicast Routing:*** It is a source-to-destination routing. In this type of routing operation, the main goal is to transmit data from single source to single destination via *wireless multihop transmission* or *carry-and-forward* techniques. In wireless multihop transmission or multihop forwarding, the intermediate vehicles within a routing path relay the packet from source to destination as soon as possible. Whereas, in carry-and-forward technique, the source vehicle carries the packet as long as possible to reduce the number of data packets. As a result, the delivery delay time cost will be longer in carry-and-forward technique as compared to multihop forwarding technique. In unicast routing, the routing protocols are classified into two categories that is *min-delay routing* and *delay bounded routing*. The aim of min-delay routing is to reduce

the delivery delay time from source to destination and in delay-bounded routing, the channel utilization is maintained at low level within the constrained delivery delay time. The are some VANET applications that require unicast routing. For instance, envisioned comfort applications, as on-board games and file transfer, will likely need unicast routing with fixed addresses. Many papers have proposed unicast protocols for VANETs but some papers suggest that VANET applications should use already existing unicast routing protocols suggested for MANETs, as AODV [22], [23] or cluster-based protocols [24], [25]. There are few papers that propose new unicast protocols for VANETs [26], [27]. Various unicast routing protocols have been proposed in VANET like Greedy Perimeter Coordinator Routing (GPCR), Vehicle Assisted Data Delivery (VADD) , Connectivity Aware Routing (CAR), Diagonal-Intersection-Based Routing (DIR). In brief, the unicast routing operation is used to enhance the safety of drivers and provide comfortable driving environments, messages for different purposes like playing games and file transfer and is sent to vehicles through inter-vehicle communication [9], [28].

Future work in Unicast Routing

The next challenging issues in the design of min-delay and delay-bounded unicast routing protocols is to utilize the driver behaviour along with the consideration of density variability and unreliable transmission.

2. ***Multicast Routing:*** This is defined by delivering packet from single source to all multicast members by multihop communication. Many VANET applications require position based multi casting (that is for disseminating traffic information to vehicles approaching the current position of source. A natural match for this type of routing is *geocast* routing which delivers the packet to the destination in a specific geographic area. The goal of distributed robust geocast muticast protocol is to deliver packets to all nodes within a geographic area. A vehicle located in this specific geographic region should receive and forward the geocast packets, otherwise the packet will be dropped [9], [28]. According to the property of geographic region, existing multicast and geocast routing protocols can be classified into *multicast/geocast* protocol and *spatiotemporary multicast/geocast* routing protocols [7], [9]. Distributed Ro-

bust Geocast DRG, Inter Vehicle Geocast IVG and ROVER [29] are examples of multicast/geocast routing whereas *mobicast* routing is an example of spatiotemporary multicast/geocast routing [30], [29], [31].

The performance of DRG, IVG and mobicast was evaluated [9] and the following future challenges need to be addressed. It was observed that both the DRG and IVG considered the static multicast/geocast region except mobicast routing protocol. The goal of DRG is to deliver the packets in a specific static geographic region and the packet should be received or dropped only by the vehicle depended on its current location. If the vehicle is within a specific *Zone of Relevance* ZOR as described in [30], this vehicle receives a packet otherwise it drops that packet. The Zone of Relevance ZOR is defined as a geographic region within which the vehicles should receive a geocast message. For frequent changing topologies a *Zone of Forwarding* ZOF is defined to enhance the reliability of receiving geocast messages. The goal of IVG [29] is to inform all vehicles on a highway in case of any danger or accident. The risk area is defined by driving directions and positioning of vehicles and a multicast group is formed by the vehicles located in the risk area. The multicast group is temporary and it changes dynamically by location, speed and driving direction of vehicle. To overcome temporary network fragmentation due to dynamic changing topology, IVG uses periodic broadcasts to deliver messages to vehicles in multicast groups. The rebroadcast period is calculated based on maximum vehicle speed. IVG also reduces the number of hops by using the deferring time. A vehicle having the farthest distance from the source vehicle waits for lesser deferring time to rebroadcast. Robust Vehicular Routing (ROVER) [9], [32] protocol is based on geographical multicasting. The main difference between geocasting and ROVER is similar to the difference between flooding and a MANET Reactive routing protocol such as AODV. Both in ROVER and in AODV only control packets are flooded in the network and data packets are unicasted thus potentially increasing the reliability and efficiency and decrease congestion. Each vehicle is assumed to have a Vehicle Identification Number VIN as well as a GPS receiver and access to a digital map. In ROVER, an on demand multicast tree is formed within a ZOR based on geographical addressing. This tree can be used to forward multiple data packets from the same source. This protocol can be used by a reliable transport protocol to ensure end-to-end QOS. Thus ROVER is well suited for VANET applications that require end-to-end QOS.In spatiotemporary multicast/geocast routing protocol the time factor is also taken into account in addition to the location of the vehicle. The distinctive feature of this new form of spatiotemporary multicast/geocast routing protocol is the delivery of information to all nodes that happened to be in a prescribed region of space at a particular point in time [9].

Future work in multicast/geocast Routing:

(a) The above mentioned routing protocols investigate the single source multicast and geocast routing. The future work should be focussed on developing a scalable multi-source(that is each member can be the source of the message sender of the other members) multicast and geocast routing protocol in city environments as multimedia VANET applications are also becoming an increasing demand of the passengers.

(b) Another area that can be focussed in future is to develop an efficient and scalable multicast/geocast routing protocol for comfort applications with delay-constraint and delay-tolerant capabilities with low bandwidth utilization. As comfort applications are usually tolerant of delay, meanwhile the network bandwidth can be served for emergency messages[9]. In brief, the multicast/geocast routing protocols in VANETs should be designed by keeping in view the low communication overhead, low time cost and highly scalable factor for city, highway and rural environments.

3. ***Broadcast Routing:*** Broadcast Routing is generally utilized for information dissemination such as weather conditions, emergency and warning alerts and road conditions. In this routing method, the packet is sent to all other vehicles in the network using flooding. When message needs to be disseminated beyond the radio transmission range, a multihop mechanism is utilized. Thus in a pure broadcast implementation, all receiving vehicles simply rebroadcast the

received messages resulting a broadcast storm problem. The broadcast storm problem occurs when multiple nodes attempt to transmit at the same time, causing packet collision and extra delay at Medium Access Control (MAC) layer. To avoid message duplication, a broadcast message is sent only once by using a time to live parameter. But the performance of this routing scheme degrades with the increase in network size. Therefore, to design a broadcast protocol for VANETs, one must consider two major problems that is the broadcast storm problem and the disconnected network problem. The disconnected network problem occurs when the number of nodes in the area are not sufficient to help disseminate the broadcast message. The broadcast routing suggested for VANETs defines the following three schemes such as the broadcast problem, Distributed Vehicular Broadcast Protocol for Vehicular Ad Hoc Networks (DV-CAST) and Broadcast method for V2V communication [18], [9], [19].

Future work in broadcast routing protocols:

Research has shown that the existing broadcast routing protocols are developed for safety applications to transmit emergency messages. However, there are still some comfort applications which require an efficient routing protocol such as public information, advertisements and navigation information. Some future work should include designing a scalable and efficient broadcast routing protocol for comfort applications with delay -constraint and delay-tolerant capability and low bandwidth utilization which can work well in large metropolitan-scale VANETs. The broadcast message should be able to disseminate under low network density as well [9].

4. ***Clustering:*** This approach is based on grouping of nodes located within a given region (that is nodes with direct link with each other) in a single group. A *cluster head* node is selected for each cluster which is responsible for managing inter and intra-cluster communication. The remaining nodes are served by the cluster head. Moreover, clustering structure acts like a virtual network infrastructure whose scalability favours routing and media access protocols. However, an overhead cost is paid when clusters are formed in highly mobile network environments thus resulting in network delays in

large networks [8]. There are many benefits of using cluster based routing protocols such as clustering helps in organizing and managing the network in a more efficient and hierarchical manner. It also helps in reducing the routing overhead by just assigning the tasks of routing to the main controller *cluster head*. There are many clustering schemes proposed in VANETs [8], [33] and research has shown that clustering helps in improving the route efficiency and provides fast convergence rates with minimum routing overhead. Some VANET clustering protocols are discussed in more details in section 2.4.

Future work in cluster based routing protocols: The suggested future challenges of cluster based routing protocols in VANETs are discussed in more details in section 2.5.

5. ***Beaconing:*** Another routing scheme is beaconing which is suitable for applications that require periodic sharing of information with other vehicles for instance, exchange of local traffic information between vehicles. In this routing scheme, a node announces information periodically and the receiving nodes integrate and store received information on their local information cache and do not re-broadcast the received message immediately. On the next beacon, a message is constructed using both local and the incoming information and broadcasted to the neighbouring nodes [19].

6. ***Position-based Routing:*** For position-based routing schemes to work, the information on the location of each node is fundamental. For routing, nodes obtain geographical location information from different sources like street maps, traffic models and on-board navigational systems like GPS. Routing decisions at each node are made by taking into consideration the position of the destination node and the location information of each node. There is no overhead incurred on maintaining and establishing routes as there is no need for routing tables [19]. Most of the routing protocols fall within the category of position-based routing as they depend on location information services to locate the position of nodes [13], [34], [35], [36], [37], [38].

7. ***Delay-tolerant Routing:***Delay-tolerant routing scheme is suitable for low density vehicle scenarios where end-to-end route establishment is not possible.

For instance, at nights traffic in cities can be really low and available vehicles may not be close enough to receive and forward messages. Also, in rural areas vehicles density may be low. In sparse networks like those, a delay-tolerant protocol can be utilized. This routing mechanism is based on the concept of carry and forward, where a node carries messages and forwards that message only if another node moves into its locality; else the message is simply carried [19].

8. ***Ad-hoc (address-based/topology-based)*** This category tests the routing protocols initially designed to operate in Mobile Ad-hoc Networks (MANET) environments like AODV, DSR and etc. for VANET scenarios but the characteristics unique to VANET like rapidly changing topology, make these protocols less suitable .So far, we have discussed the various kinds of routing schemes in Vehicular Ad-hoc networks along with the future challenges required in improving these protocols. However, finding a suitable routing mechanism in urban areas for efficient data forwarding suitable for ITS applications with improved end-to-end QOS is highly required. Additionally, the architecture design of the VANETs also needs to be focussed while designing VANET routing protocols.

Based on the above mentioned review, we have categorized the basic network layer operations in VANETs as follows

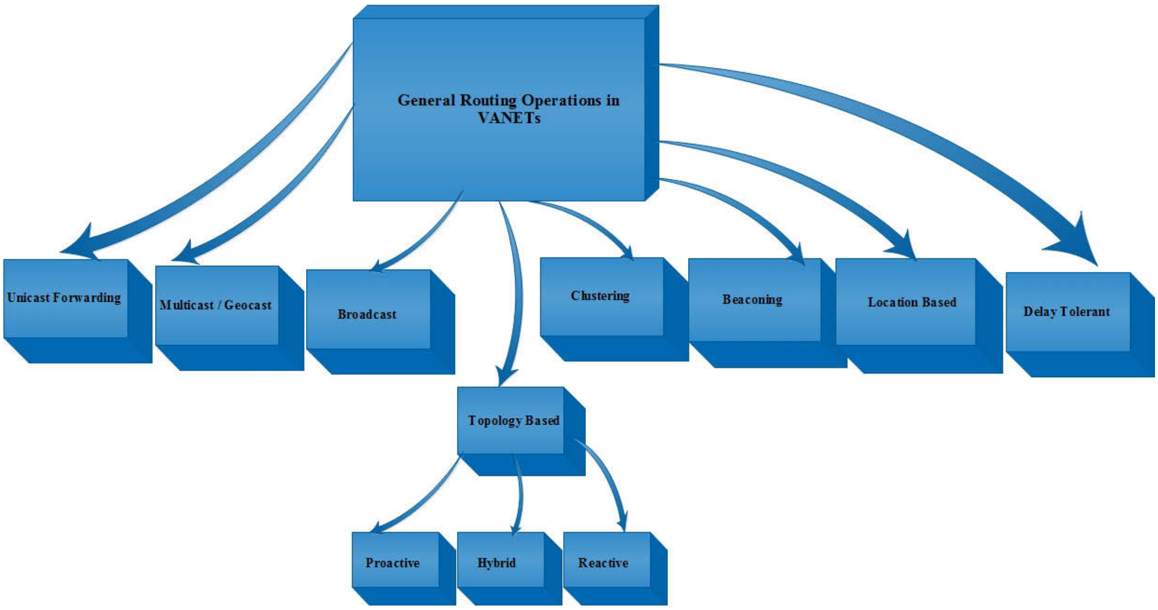


Figure 2.7: Network layer operations in VANETs

2.3 Clustering

2.3.1 Cluster Structure

A cluster structure in VANETs is the division of nodes into different virtual groups based on certain rules. The nodes in a cluster may be assigned a different status or function such as cluster head, cluster gateway, or cluster member. A cluster head acts as a local coordinator for its cluster and is responsible for performing intra cluster transmission arrangements, data forwarding and so on. A cluster gateway is a non-cluster head node with inter cluster links and is responsible for providing inter cluster communications. A cluster member, which is a non-cluster head node, acts as an ordinary node without any inter-cluster links as shown in fig. 2.8

2.3.2 Clustering in VANETs

For the last few decades, clustering has emerged as an important research topic in Vehicular Ad Hoc Networks (VANETs) to organize and manage the network in a more efficient way. Clustering offers benefits like stabilizing the dynamic topology of VANETs, making an optimum utilization of network resources, improving the routing efficiency by providing hierarchical routing, providing fast convergence rates with minimum overhead and saving power consumption. Clustering improves net-

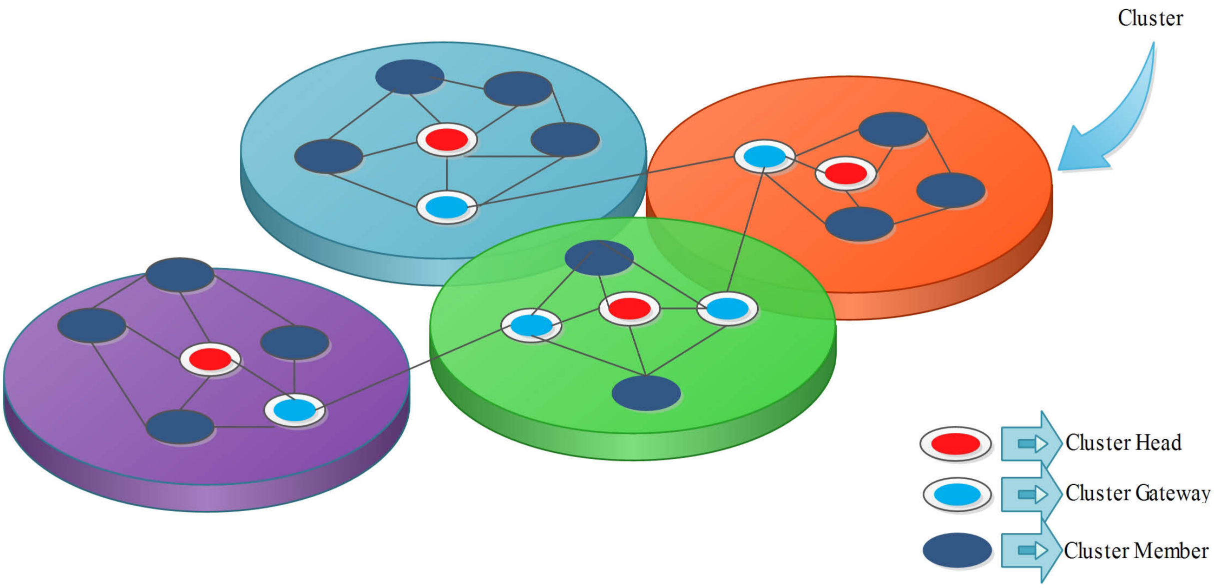


Figure 2.8: Basic Structure of Clustering

work scalability of large scale VANETs as the routing overhead does not become tremendous in large scale VANETs due to clustering. Moreover, an efficient dissemination of messages in VANETs depends mainly on stable clustering. Stable clustering in VANETs is making the dynamic topology of VANETs to appear less dynamic and large network to seem much smaller and easily manageable. There is a need to provide more stable cluster architecture for upper layer protocols to calculate the route efficiently and thus lead to the performance improvement of large scale VANETs. The route stability in VANETs is indirectly related to stable clustering schemes in VANETs. Research has shown that routing on the top of clustering architectures is more scalable and stable as compared to flat routing [14], [4], [10], [8].

2.3.3 Benefits of Clustering in VANETs

Clustering vehicles into different groups offers many benefits for Vehicular Ad hoc Networks [4], [8], [39] as summarized below

- Clustering demonstrates to be an effective topology control in VANETs, offers better reuse of resources to increase system capacity. The non-overlapping clusters may use the same frequency or code set if they are not neighbouring clusters.

- The transmission events of a cluster are better controlled by a mobile node that is called a cluster head. Cluster heads can also save the resources like bandwidth used for retransmission if there is a transmission collision between the nodes within a cluster.

- The virtual backbone for inter cluster routing is formed by the set of cluster heads and cluster gateways, thus making the task of routing much easier by restricting the routing information within the set of nodes.

- A cluster structure makes a VANET appear much smaller and stable in view of each mobile terminal. The concept of clustering is to offer an optimum use of system resources like memory and processor of mobile nodes in VANETs. When a mobile node changes its attaching cluster, only the mobile nodes residing in the corresponding cluster need to update this information. Thus the local changes need not to be updated globally by the entire network. This result in reducing the amount of information processed and stored by each mobile node.

2.4 VANET Clustering Protocols

Clustering in Vehicular Ad-hoc Networks is one of the control schemes used to organize media access and to support reliable and scalable multihop communications in VANETs thus making the dynamic topology of VANETs as less dynamic [40]. Moreover, clustering in VANETs also supports Quality of Service (QOS) requirements for both delay tolerant (road and weather information) and delay intolerant (safety messages) applications [41]. It is also shown that clustering in VANETs has effectively reduced data congestion [42]. The clustering schemes already proposed for conventional wireless ad-hoc networks are not suitable for VANETs due to inherent characteristics of VANETs such as high speed, mobility, sufficient energy. Therefore, the VANET clustering models should be designed and modelled by keeping in view the unique characteristics of VANETs as mentioned in section 2.1.4.

The clustering schemes proposed for VANETs vary in the selection of metric for the formation of clusters [33]. Some schemes propose cluster formation (grouping of vehicles) based on a single metric and some propose a multi metric cluster formation. Another categorization of clustering in VANETs is illustrated in [4] as

- ***Centralized or Infrastructure Centric Clustering :*** In centralized clustering or Infrastructure Centric Clustering, the cluster formation is done via Road side Units RSUs based on periodic message sharing between RSU and the vehicular nodes. Road side units are acting as central controllers backbones that are usually fixed and are used to control all types of data transmission between the vehicular nodes.

- ***Decentralized or V2V Clustering :*** In Decentralized Clustering or V2V Clustering, the cluster head election and cluster formation is usually done via exchange of 'Hello Messages' between vehicles.

Now we discuss a short review of some of the clustering proposed for Mobile Ad hoc Networks and more specifically for VANETs. This review outlines the clustering algorithms specifics that are favourable for VANETs new or uncommon compared to others.

- *Lowest ID Clustering:* The simplest and easiest clustering scheme is lowest ID clustering algorithm [11] which is to cluster mobile nodes based on lowest id. Using this algorithm, the mobile nodes broadcast beacon messages in which node IDs are encapsulated. These node IDs are uniquely assigned. The node which has the lowest ID in its neighbourhood is selected as the cluster head node, whereas the other nodes are selected as cluster member nodes. The following clustering schemes are based on this basic idea to broadcast the beacon message but the encapsulation metric is different. The drawback of this scheme is that the mobility of nodes is not considered.

- *Mobility based clustering:* Another scheme *MOBIC* [43] is designed for Mobile Ad hoc Networks and it also works for VANETs. This scheme uses the signal power level mobility metric to represent the relative mobility of nodes which are at one hop distance. An aggregate local mobility metric is the basis for cluster formation. Using MOBIC, the mobile nodes broadcast beacon messages at every predefined broadcast interval. When a mobile node receives two consecutive beacon messages from its neighbouring nodes, it measures the relative mobility between the two nodes as the ratio of the received signal strength of the new beacon message and the received signal strength of old beacon message. The mobile nodes then calculate the aggregate mobility metric based on relative mobility. The mobile node having the least aggregate mobility is selected as a cluster head node. The performance of this scheme is moderate as it is not designed specifically for VANETs but this schemes is most commonly used for comparison with other VANET clustering protocols.

- *Mobility based clustering using Affinity propagation:* A clustering scheme using affinity propagation is also proposed to solve data clustering problems and this scheme can generate clusters more efficiently as compared to other traditional clustering schemes[35]. Affinity PROpagation for Vehicular networks (APROVE) is used to cluster vehicular nodes in a distributed manner. The vehicular nodes exchange messages with their neighbouring nodes to transmit availability and responsibility and make decisions based on availability and responsibility values for constructing clusters.

- *Density based clustering (DBC):* In [44], they proposed a stable and long life clustering approach with a complex metric which takes into account the density of connection graph, traffic conditions and link quality for reliable communication. The clustering metric is derived by using the movement prediction of vehicles from GPS or other services and the Signal to Noise Ratio (SNR) of the link. Moreover, to avoid unnecessary re-clustering a 'group membership lifetime counter' is used to check the reliability of vehicular node before it gets attached with cluster head. It is also seen that in sparse and dense environments of VANETs, the algorithm behaves differently. It is also observed that the cluster head change ratio is less in the proposed scheme as compared to lowest ID clustering.

- *Direction based clustering:* A direction based clustering approach is proposed in [34] that is suitable for urban areas for VANETs. The cluster of vehicles is formed based on the prediction of directions of vehicles before intersections. The vehicles that turn in the same direction at intersection are clustered together. It is assumed that each vehicle is having a good digital map and accurate location information GPS or equivalent that can calculate the moving path based on the source address and the destination address. Knowing the destination could be a problem, as most of the users usually do not use the GPS navigation systems for the destinations that are already known.

- *Distributive and Mobility Adaptive Clustering (DMAC):* As proposed in [35], the DMAC is used to calculate weight based on link quality and mobility of nodes. The mobile nodes having the biggest weight are selected as cluster head nodes.

- Another modified DMAC [36] is also proposed to improve the original DMAC as proposed in [35]. The goal of this algorithm is to improve cluster stability by avoiding re-clustering when two vehicles meet in different directions. The process of re-clustering is avoided if vehicles are moving in opposite directions. For the implementation of the modified features, each vehicular node needs to know its current location, velocity and moving direction as received from GPS or other location services. A new parameter "Freshness "is introduced for additional safety factor for unneeded re-clustering. The value of this parameter is calculated between two vehicular nodes by receiving hello messages and their movement direction data. The time to live (TTL) parameter helps in the construction of multi-hop clusters, which is usually not a common feature but that feature is highly appreciated.

- *An Adaptive Mobility Aware Clustering Algorithm AMACAD* is also proposed in [45] that aims to accurately follow the mobility patterns of vehicles in VANETs. This algorithm also tries to prolong cluster lifetime and reduce global overhead. The clustering metric that is used for the decision of cluster heads considers the current location, speed and both relative and final destinations of vehicles. There might be a problem to know the final destination as prior to as most of the drivers usually do not use navigation system for known routes in advance. The size of cluster varies with different parameters like speed, density of vehicles in a specific area, minimum bandwidth required or QoS and these parameters can be redefined or provided by the vehicle sensors and application profiles.

- A multi-hop clustering scheme is presented in [46] that uses relative mobility as a metric between vehicles that are at multi-hop distance. In this scheme, a radio propagation delay based on beaconing is calculated at each node and is aggregated and propagated back to other vehicular nodes. The node with smallest aggregate mobility value is chosen as an appropriate cluster head. Moreover, cluster stability is increased by postponing the process of re-clustering for some interval of time when two cluster heads come within the communication range of each other. The benefit to wait for few seconds in case, two cluster heads meet with each other is to avoid unnecessary re-clustering when, for example, two cluster heads from different directions come within the communication range of each other for a few seconds. The performance of the protocol is evaluated using Manhattan grid mobility model and freeway model using 2, 3 and 5 hop clustering. Results show that cluster life time is prolonged using multi-hop clustering. Moreover, the frequent role switching of cluster heads is also reduced.

- In [47], they proposed a clustering algorithm VWCA based on a complex metric that is used to increase the stability and life time of clusters in VANETs. The metric is calculated from distrust value, vehicle movement direction and the number of neighbours that are based on dynamic transmission range. They also propose a monitoring algorithm to detect the abnormal vehicles within the network and a technique for adaptive allocation of transmission range. Moreover, the clustering protocol also provides a compensation for the variable node density.

- In [48], cluster overlapping is discussed that is one of the very erratic features of clustering in VANETs. Cluster overlapping is achieved with vehicular nodes having twofold states, for instance, a cluster head of one cluster is a member node of one or more than one clusters. This cluster overlapping feature has been utilized for routing the communication between clusters through cluster heads only. It is not possible that all nodes within the range of cluster head necessarily belong to that cluster. However, all cluster member nodes are within the communication range of their cluster head. Speed, location and travelling direction is used as a the clustering metric and the data is provided via GPS or other location services. Moreover, a circular area ‘Zone of interest ’that is centred on a node with a limited predefined radius is also introduced as an extension to the communication range.

- ASPIRE [49] focuses on local network criticality and clustering in a distributed fashion. The main goal of this clustering protocol is to form large clusters and provide high connectivity. This protocol mainly focuses on providing better connectivity but at the same time it bears the cost of low cluster head durations or high cluster head switching. Cluster stability is also increased by avoiding the re-clustering process for some time when two cluster heads come within the range of each other. This avoids unnecessary re-clustering when, for instance, two cluster heads meet each other for few seconds with different directions.

- *A fast randomized clustering and scheduling and algorithm HCA* as presented in [50] uses a different approach as compared to other clustering protocols. This protocol tries to form randomized clusters as fast as possible and the process of cluster optimization is taken care of by cluster maintenance phase instead of initially focussing on stable cluster formation. The protocol does not rely on location services because of its simplicity. The limiting factor in cluster size is radio propagation but this is avoided by 2 hop clustering.

- In [37], a MAC layer clustering solution is provided that is focused on improving the MAC layer by clustering vehicles and allowing the cluster heads to communicate with each other regarding medium access control. Since the cluster formation criteria used by this clustering protocol is vehicle movement direction, therefore, the clustering metric relies on some location service such as GPS some other location services. The main objective of this protocol is to guarantee real-time delivery of safety messages. This protocol also focuses on making non real-time V2V communication more efficient.

- Authors of [38] use three different metrics that is vehicle density, link quality and link sustainability for the formation of clusters and compare them with passive clustering approaches. The algorithm defines the “cluster head ”as the first node that will dominate the rest of nodes within its communication range. Moreover, a single cluster has atleast two cluster gateway nodes for providing intra-cluster communication between vehicles. The received beacon frames are counted from neighbouring vehicles to calculate the Vehicle density. A bi-directional transmission quality of link is used to express Link quality. Link expiration time is used as a link sustainability metric. A vehicle uses GPS or other location service to know position and movement parameters to calculate the value of clustering metric.

- In [12], cluster formation assures reliability in inter-vehicle communication in an effective way by overlapping clusters to share the medium more efficiently. This clustering protocol uses passive clustering model that requires no clustering protocol specific packets or signals for the purpose of clustering. The Vehicular nodes within the cluster are identified and are assigned some specific task. All the information regarding cluster formation is included in the packet header. The vehicles are divided into different groups with respect to speed and these speed groups are then divided into clustering groups. Each vehicle knows its speed and from its speed a vehicle knows its clustering group. Vehicles form a cluster by selecting a cluster head inside a cluster group. Vehicles from different clustering groups in geographical neighbourhood are separated by different Code Division Multiple Access orthogonal codes. These CDMA orthogonal codes also help the overlapping clusters to share the medium more efficiently.

- *Aggregate Local Mobility ALM* [13] represents a new beacon based clustering approach that uses aggregate mobility as a clustering metric. This clustering protocol is aimed at prolonging the lifetime of a cluster in VANETs. The ALM weight is calculated similar to [43] except one difference that instead of using the Received Signal Strength RSS, which is highly unreliable, it uses location information of nodes using GPS or any other location services. The ratio of two consecutive measures of the distance between a node and its neighbour is calculated by using location information of nodes. The variance of the relative mobility over all neighbours of a node is then calculated and is called as nodes ALM. A node with low value of ALM relative to its surroundings is a better choice to become a head as it is moving slowly thus ensures less instability in cluster formation and reorganization. Relative mobility of node l with respect to node k and is given by [13]

$$M_{l^{rel}}(k) = log \frac{Dist_{current}}{Dist_{Previous}} \tag{2.1}$$

where $Dist_{current}$ is the current distance of a node l with respect to node k and $Dist_{Previous}$ is the previous measure of distance of node l with respect to its neighbour k. The calculations of nodes ALM is the variance of the relative mobility over all neighbours k_j of a node and is given as

$$M_l = var_0(M_{l^{rel}}(k_j)) \tag{2.2}$$

2.5 Challenges of VANET Clustering

Compared to flat structure VANETs (that has no clusters), cluster-based VANETs have more challenges in modelling and implementation due to a large number of mobile nodes and high dynamic scenario of VANET topology. Based on the above review of clustering protocols in VANETs, we discuss the summary of the challenges of clustering protocols proposed in VANETs [33], [8].

- It is observed from the above review of clustering protocols in VANETs that two different approaches are normally used for clustering of vehicles in VANETs. The *first* approach uses location service dependency such as GPS or other location service and uses speed, location and movement direction as an information for clustering metric. Whereas, the *second* approach uses different measurable parameters such as radio propagation, relative mobility, vehicle density, connectivity and etc. It is observed that all of these measurable parameters are not used together. Both approaches use mathematically measurable parameters and ignore sociological aspects [51], for instance, why the driver is on the go and in what context the drive is taking place. There is plenty of room open for the new research proposals that take into account the sociological aspects of the drivers of the vehicles.

- Some clustering schemes may cause the cluster structure to completely rebuild over the whole network in case of the occurrence of a local event that is the movement or the ‘die ’of a mobile node resulting in cluster head re-election. This ripple effect of re-clustering affects the structure of other clusters as well and it also degrades the performance of other upper-layer protocols.

- The dynamic changing scenario of VANETs often requires an explicit information exchange between mobile node pairs. When the underlying topology changes quickly due to motion, the cluster related information exchange is also affected that results in frequent information exchange. Moreover, this frequent information exchange may also affect the bandwidth and energy of mobile nodes and may indirectly affect the implementation of upper layer protocols due to the inadequacy of mobile node resources.

- Some clustering schemes separate cluster formation and maintenance phase and assume that mobile nodes are kept in frozen state when cluster formation is in progress. This assumption is not applicable in an actual scenario of randomly moving nodes in VANETs.

- The clustering schemes based on multi hop clustering protocols should be focused more.

- Most of the clustering schemes discussed above are based on providing some location prediction information from digital maps. To provide highly accurate digital maps as required by some clustering protocols, offers a challenging task and moreover it could slow down the processing of that protocol. There is a need to design clustering protocols that are location independent as it may not be possible to have the needed location information accuracy of vehicles everywhere and at all times.

- Another metric that is computation metric indicates the number of rounds in which a cluster formation procedure can be completed. For clustering schemes relying on frozen period of motion, the computation round is an important metric, since the more rounds required for cluster formation, the longer the frozen period will be which is not suitable for the frequently changing topology of VANETs with the movement of mobile nodes.

- It is also observed that most of the clustering schemes proposed are aimed at achieving one particular objective that is cluster stability, fast cluster formation and overhead minimization. Though the most popular among all objectives is definitely the cluster stability. More research effort should be put in defining and ranking the goals and objectives of the clustering schemes should be tried to achieve.

- There is also a need to study self learning or self adapting cluster formation metrics.
- Moreover, more focus should be put on evaluation of some common metrics used for cluster formation. This would help the researchers community to ponder on extending and optimizing the most prospective ones.
- Different clustering schemes have been proposed but still there is a lack of stability of clusters. There is a need to vary the cluster head election policy as well as to present a stable scheme to avoid re-clustering overhead. During the formation of cluster, there is a need to introduce the lifetime to check the connectivity duration between cluster head and its member nodes.

Based on the review of network layer operations of VANETs in section 2.2, it is clear that the routing protocols that use clustering approaches, show better performance in terms of delay, packet throughput and packet forwarded ratio. The packet receiving time for various protocols like DSDV, AODV and DSR without using cluster concepts is compared with the protocol that uses cluster concepts [5]. The packet receiving time for DSDV yields lesser value than other protocols. From the simulation results in fig. 2.9, it is noticed that the proactive routing protocol DSDV has a better packet receiving time among the three. But AODV offers better performance in terms of packet throughput, packet forwarded ratio and packet delay time. The link failure requires new route discoveries in AODV, since it has almost one route per destination vehicle in its routing table. The delay in AODV is less than DSR because AODV creates routes only when it is needed. In spite of all the advantages of clustering in VANETs, still there is a lot to travel on this path to achieve the challenges of clustering protocols in VANETs as discussed in section 2.5. The aim of this research is to cope with the challenges of VANET clustering that will help in efficient data dissemination in VANETs.

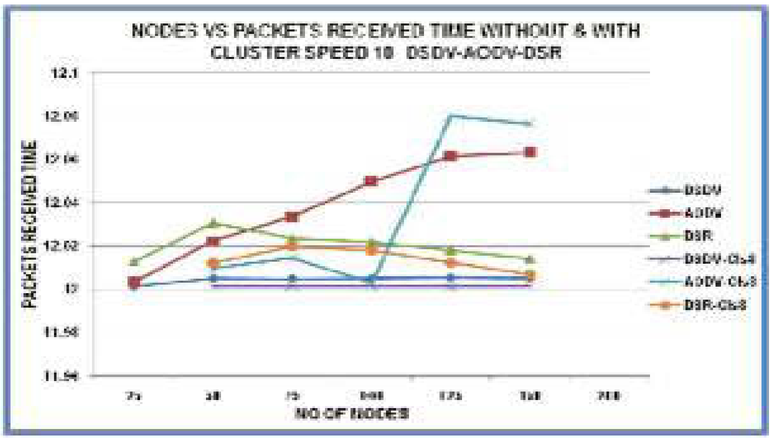


Figure 2.9: Some investigations on routing protocols in VANETs with and without clustering [5]

2.6 IEEE 802.11p

In order to standardize and optimize vehicular communication , IEEE 802.11p is approved as a recent standard used for vehicular communication in VANETs. IEEE 802.11p is an approved amendment to the IEEE 802.11 standard that adds wireless access in vehicular environments (WAVE), a vehicular communication system [3]. This standard defines the enhancements to 802.11 required to support Intelligent Transportation Systems (ITS) applications in VANETs. These enhancements includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). The FCC allocated 75 MHz in the 5.9 GHz band for DSRC (Dedicated Short Range Communications) in VANETs in 1999. IEEE 802.11p standard uses channels of 10MHz bandwidth in the 5.9 GHz band (5.850-5.925 GHz).

2.7 Game Theory

Game theory is a collection of mathematical tools that are used to analyze the interactive decision making problems between players. Game theory models how players make decisions and handle conflicts. It is also used to predict the outcomes of interactions and to identify the optimal strategies of the players of the game.

Fundamental components:

- *Players* are the decision makers.

- *Strategies* are the set of all possible actions.

- *Payoffs* are the numbers which represent the motivations of players. Payoffs may represent profit, quantity, utility, or other continuous measures (cardinal payoffs) or may simply rank the interest of outcomes (ordinal payoffs).

Figure 2.10: Game Theory http://somervillelawoffice.com/divorce-preparation-2/divorce-game-theory/

Game theory has been used in the field of social sciences most notably in economics due to its great potential to solve different problems. It has also been penetrated into a variety of different disciplines such as political science, sociology, biology, philosophy, law, computer science and now becoming more popular in wireless and communication networks [52].

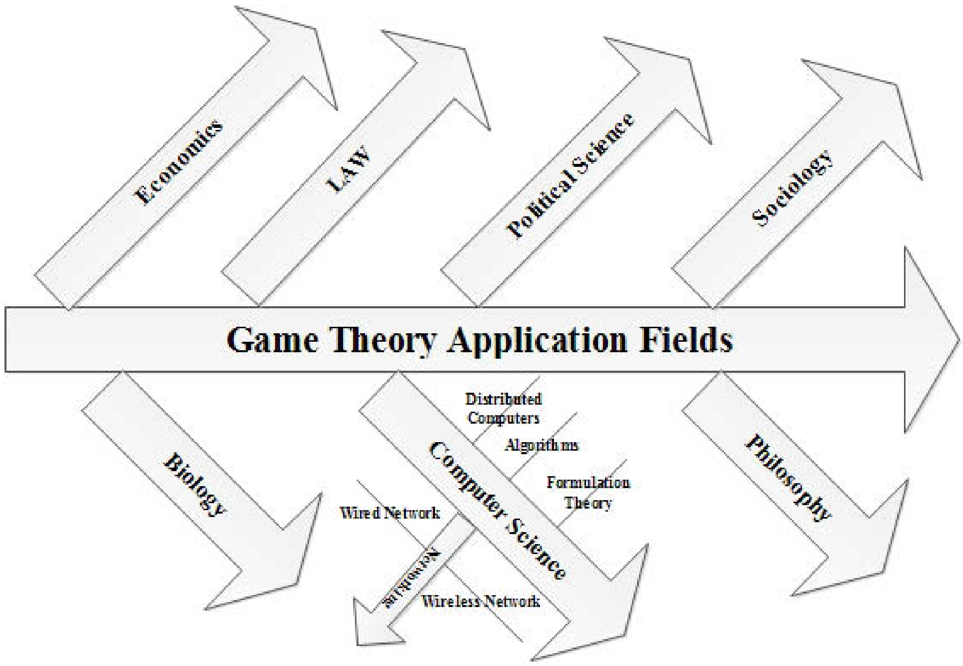


Figure 2.11: Applications of game theory

2.8 Applications of Game Theory in Wireless Networks

The traditional analytical models used for studying the behaviour of wireless and communication networks have been limited due to the nifty nature of wireless and communication networks. Recent advances in the field of wireless and communication networks and an ever growing need for pervasive computing has led to a relentless need for a novel analytical framework to tackle the current and future technical challenges faced by wireless and communication networks. Game theory is emerging as a novel analytical tool to design the future wireless communication challenges. This is mainly due to the need to incorporate interactive decision making rules and techniques into next generation wireless and communication nodes [52]. Game theory has been used into a wide variety of Wireless communication Networks networks as mentioned

- Emerging Networks.
  - Cellular networks in a shared spectrum
  - Hybrid ad hoc networks (also called Multi-hop cellular networks).

  - Small operators, community networks
  - Mesh networks
  - Cognitive radio communication
  - Autonomous ad hoc networks
  - Vehicular Ad hoc Networks
  - Sensor and RFID networks

- Emerging properties
  - Centralized to Distributed
  - More sophisticated user devices

Now we discuss a very brief overview of the applications deigned in wireless and communication networks using game theory.

Game Theory is applied to solve the radio resource management problem in wireless networks. A non-cooperative game for admission and rate control scheme for CDMA systems is presented in [53]. In this game, the game formulation considered the choice of a user to churn from one service provider to another service provider in the CDMA systems. Nash equilibrium was considered as a solution of the game to make a decision on whether a new user can be allowed to be admitted or not. The decision of the allocated transmission rate was also solved using Nash equilibrium. Another approach to solve the problem of admission control in WLANs is presented in [54]. In [55], the authors presented an evolutionary game to model the problem of network routing. There were other few approaches presented in heterogeneous wireless access networks that considered pricing or cost as a mechanism for resource allocation, admission control and network selection. Mainly three different approaches namely auction based [56], optimization based [57] and demand supply based[58] were applied to solve different problems in heterogeneous wireless access networks. Another approach was presented in [56] in which the mobile users used a bidding scheme for radio resource allocation from multiple radio access technologies by informing the service providers about the price and quality of service requirements. The service providers make resource allocation decisions in different wireless access networks to maximize the revenue.

2.9 Introduction to Evolutionary Game Theory (EGT)

Evolutionary Game theory was originated by John Maynard Smith formalization of evolutionary stable strategies as the mathematical theory of games in the context of biology in 1973 [59]. The development of Evolutionary Game theory was started slightly after other games were developed [60]. Evolutionary Game theory has been developed as a mathematical framework to model the interactions between rational biological individuals in a population [61]. Evolutionary game theory explains game models in which players of the game use a trial-and-error process to adapt their strategies in which they learn over time that some strategies work better than others [62]. An evolutionary game is based on an evolutionary process in which the game is played repeatedly between individuals who are randomly chosen from a large population. The individual adapts the chosen strategy based on its fitness that is payoff and both the static and dynamic behaviours of the game (that is Equilibrium) can also be analysed. In decision making process, the individuals involved in decision making, take their decisions based on the their own choices and those of others. There are two basics mechanisms of evolutionary process in EGT, which the can be described as [52]

- ***Mutation :*** Mutation is the mechanism of modifying the characteristics/strategy of an individual playing a game. In other words, mutation defines the diversity of population that is individuals with new characteristics/variety are introduced in the population. The mutation mechanism is described by Evolutionary Stable Strategies (ESS). In other words, ESS is used to study the static behaviours of EGT.

- ***Selection*** The selection mechanism is then applied to promote individuals with higher fitness over others. In other words, it is used to retain the individuals with high fitness while eliminating individual with low fitness. The selection mechanism is described by replicator dynamics which is used to study the dynamic interactions among individuals (dynamic evolutionary game) [63]. Replicator dynamics can be used to model the evolution of group size over time.

The Evolutionary process [52] has been divided into the following steps

- ***Finding an ESS (Evolutionary Stable Strategies:*** By applying a mutation mechanism that is a group of individuals choosing one strategy will not be replaced by other individuals choosing different strategy.

- ***Finding replicator dynamics:*** Once the population is divided into multiple groups and each group adapts a different pure strategy, replicator dynamics is used to model the evolution size over time. Unlike ESS, in replicator dynamics, pure strategies are played by the dynamic individuals. Replicator dynamics determines how the different strategies in a system change over time. In other words, it highlights the role of selection.

Cooperative and Non-Cooperative games

A cooperative game is a type of game in which the players have the option of planning as a group before choosing their strategies. Unlike a cooperative game, a non-cooperative game is a game structure in which the players do not have the option of planning as a group in advance of choosing their actions and strategies [64].

2.10 Why Evolutionary Game Theory (EGT)

The EGT has the following advantages over other traditional non-cooperative games

- Traditional non-cooperative games have mostly been developed to solve the static interaction among players. They cannot capture the adaptation of individuals playing game to change their strategies and reach at equilibrium over time. Non-cooperative games can model the dynamics of decision making process in extensive forms but the extensive forms become complex and inflexible for most game settings [52].

- The decision making of individuals is based on the beginning of the game, therefore, these traditional non-cooperative games cannot observe the opponent's behaviour during the decision making process. EGT has the potential to solve the games in which the individuals can observe the opponent's behaviour and make optimized strategy selection based on the knowledge gained.

- EGT is based on evolutionary process, which is dynamic. Therefore, EGT can model the dynamics of the interactions among individuals in a large population. This feature of EGT has helped us to model the interactions between cluster-heads and members in a VANET scenario, which is highly dynamic in nature.

- It is observed that Nash equilibrium is the most common solution for most of the non-cooperative games and the strategy of the player at this point is the best response to the strategies of the other players again at Nash equilibrium. With Nash equilibrium, it would be possible for all the players in a game to benefit from a collective behaviour so it may not necessarily be efficient. Additionally, if more than one Nash equilibrium exist in a game, and a player is restricted to adopt only pure strategies, the Nash equilibrium may not exist. Therefore, ESS is considered to be a refinement of Nash equilibrium especially in the case when more than one Nash equilibrium exists.

- In traditional non-cooperative games, the players are assumed to be rational. The rationality behaviour requires complete information as well as well-defined and consistent sets of choices that is *actions*. In reality this assumption rarely holds. A number of results have shown [52] that the strong rationality behaviour rarely exists in real scenarios because people usually take decisions irrationally. Therefore, EGT can be used to model the interactions between players that may not necessarily display hyper rational behaviour.

Potential Games:

Potential game is the type of non-cooperative game that is widely used to formulate the distributed optimization problems of wireless and communication networks. In potential games, the Nash equilibrium is determined based on the objective of maximizing a single function that is called as a potential function [52]. The concept was first introduced by Monderer and Shapley [65]. The potential function is used as a beneficial tool to analyse the equilibrium, properties of the game since the goals and objectives of all the players are mapped into a single function that is *potential function*. Moreover, one can find the set of pure Nash equilibrium by simply locating the player to player optima of the potential function. It is also proved that any potential game has at least one steady state, and all states that maximize the potential function are Nash equilibrium states [66].

2.11 Summary

This chapter has illustrated introduction to Vehicular Ad hoc Networks, their application areas, characteristics and Communication Infrastructure of VANETs. Moreover, a review of network layer operations and the current promising clustering protocols in VANETs is also discussed in this chapter. This review serves as a guide to promote understanding and proliferation of some thoughts to improve clustering algorithms in VANETs. In addition, this chapter demonstrates an introduction to Game Theory, applications areas, some introduction of Evolutionary Games and potential games along with a very brief discussion of related work done using Evolutionary Game Theory in wireless and communication networks.

Chapter 3

Proposed Two Layer Evolutionary Game Theoretic Framework

3.1 Introduction

This chapter theoretically describes our proposed model which is aimed at solving the problem of distributed in-stable clustering in VANETs. An Evolutionary Potential Game Theoretic(EPGT) approach is presented that defines a distributed stable and optimized clustering in VANETs. The main contributions of this dissertation can be summarized as follows.

- A two layer Evolutionary Game Theoretic framework is presented to solve the problem of distributed in-stable clustering that is caused due to frequent cluster reformation and reorganization in VANETs.
- The proposed game framework gets a pre-assumed number of randomly distributed clusters from upper layer and applies the proposed lower layer EPGT approach to this framework. The proposed lower level game solves the problem of cluster in-stability in VANETs and provides an optimum and stable clustering thus reducing the overhead of frequent cluster reformation in VANETs.
- The solution of the game is presented to be an evolutionary Nash equilibrium that is achieved through repeated simultaneous interactions between vehicular nodes and the central controller RSU.

- The proposed game is analysed on different values of cost function and an optimal cost is suggested that defines an optimum clustering.

- The stability of clusters on different populations and speeds of vehicles is analysed. It is concluded that the proposed game provides a robust and diversified solution for stable and optimized clustering in VANETs.

3.2 Proposed two layer Game Framework

A two-layer Evolutionary Game Theoretic (EGT) framework is presented to solve the problem of in-stable clustering in VANETs. An upper layer decides a set of tentative cluster heads in VANETs. The lower layer dynamic cluster head selection is modeled by an Evolutionary Potential Game Theoretic (EPGT) framework with Nash equilibrium as an optimum solution for stable clustering. The proposed lower layer Evolutionary Potential Game Theoretic (EPGT) game model is based on the competition among vehicles to maximize the present value of the utility (objective) function. Moreover, the lower layer evolutionary game of cluster head selection describes the state of the upper layer decision of the number of cluster heads.

The main schematic of the proposed two layer Evolutionary game framework is shown in figure.

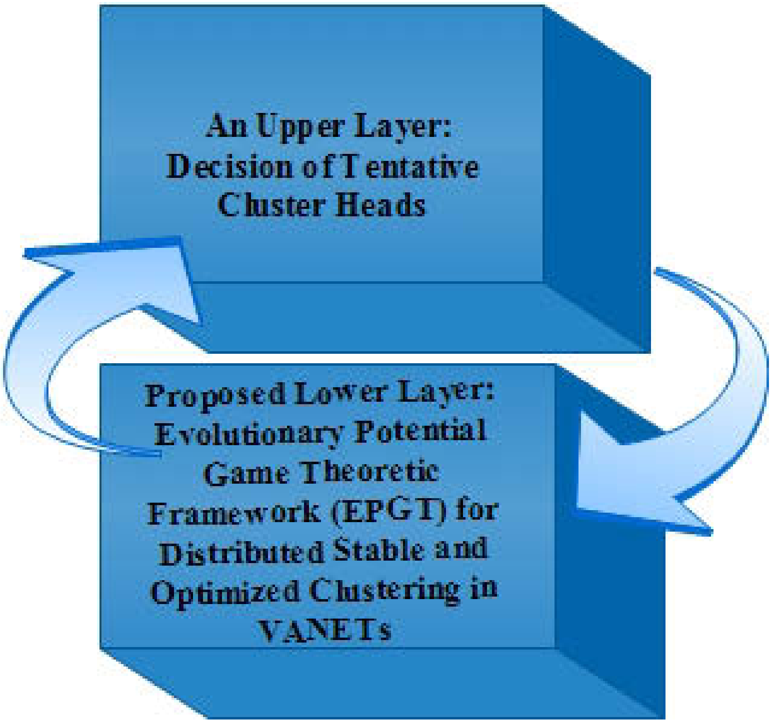


Figure 3.1: Two layer proposed game framework

3.3 Main components of proposed Game Framework

The main components of our proposed game framework with respect to VANETs are summarized as

Components of proposed two-level game framework	**Components of Vehicular Ad hoc Network**
Type of game	Two-level Evolutionary game framework
Upper layer	Decision of a given number of tentative clusters as discussed in section 3.4
Lower layer	An Evolutionary Potential Game Theoretic EPGT framework $G = \langle N, S, U \rangle$ to provide stable clustering in VANETs as discussed in section 3.5.
Players of upper layer	Vehicular nodes $N = \sum_{i=1}^{n} N_i$.
Players of lower layer	Vehicular nodes $N = \sum_{i=1}^{n} N_i$ from the upper layer
Strategies for lower layer EPGT framework	The strategy of each node corresponds to the selection to become a head or a member and is represented by the strategy set $S = \{H, M\}$
Population	The population in this proposed two layer game framework is assumed to be finite.
Payoff function	The payoff of a node i is determined by its net utility which is the difference between reward of strategy and cost. We use eq. 3.2 as a concave utility function to compute the payoff.
Objective of Utility function	The main objective of a vehicular node i playing a strategy S_i is to maximize the utility function as given in 3.2

Table 3.1: Basic components of proposed game with respect to VANET clustering

3.4 Upper layer Evolutionary Game Framework

For upper-level game

- We assume a predefined number of vehicular nodes $N = \sum_{i=1}^{n} N_i$ that are randomly distributed in our VANET clustering scenarios.

- We also assume a predefined number of clusters in our network that are randomly distributed in our VANET Clustering scenarios.

  We take this upper layer framework as an input and apply our proposed lower layer Evolutionary game to analyse the stability of clusters in the network.

3.5 Lower layer Evolutionary Potential Game Theoretic(EPGT) Framework

The lower layer evolutionary game for clustering between vehicular nodes in VANETs is formulated as $G = \langle N, S, U \rangle$, where $N = \sum_{i=1}^{n} N_i$ is the set of vehicles that are chosen from the upper layer responsible for the decision of nodes. Let the strategy space corresponds to two choices that is $S = \{H, M\}$. Let the payoff for a vehicular node i is represented by the utility $U_i = \{u_H, u_M\}$ whereas u_H represent the utility for heads and u_M represent the utility for members as explained below.

3.5.1 Utility function

The payoff of a vehicular node i playing a strategy s_i from the strategy set $S = \{H, M\}$ is determined by its net utility. The net utility is the function of the difference between the reward of the strategy and cost and it can be expressed as $U(\tau(s_i) - \varsigma_i(s_i))$ where $\tau(s_i)$ is the throughput of a node i, $\varsigma_i(s_i)$ is the cost function and U is the utility function [67]. It is assumed that $U(i) \geq 0$ and $\varsigma_i \geq 0$. The throughput of each node can be computed from Shannon's capacity for the corresponding set of strategies.

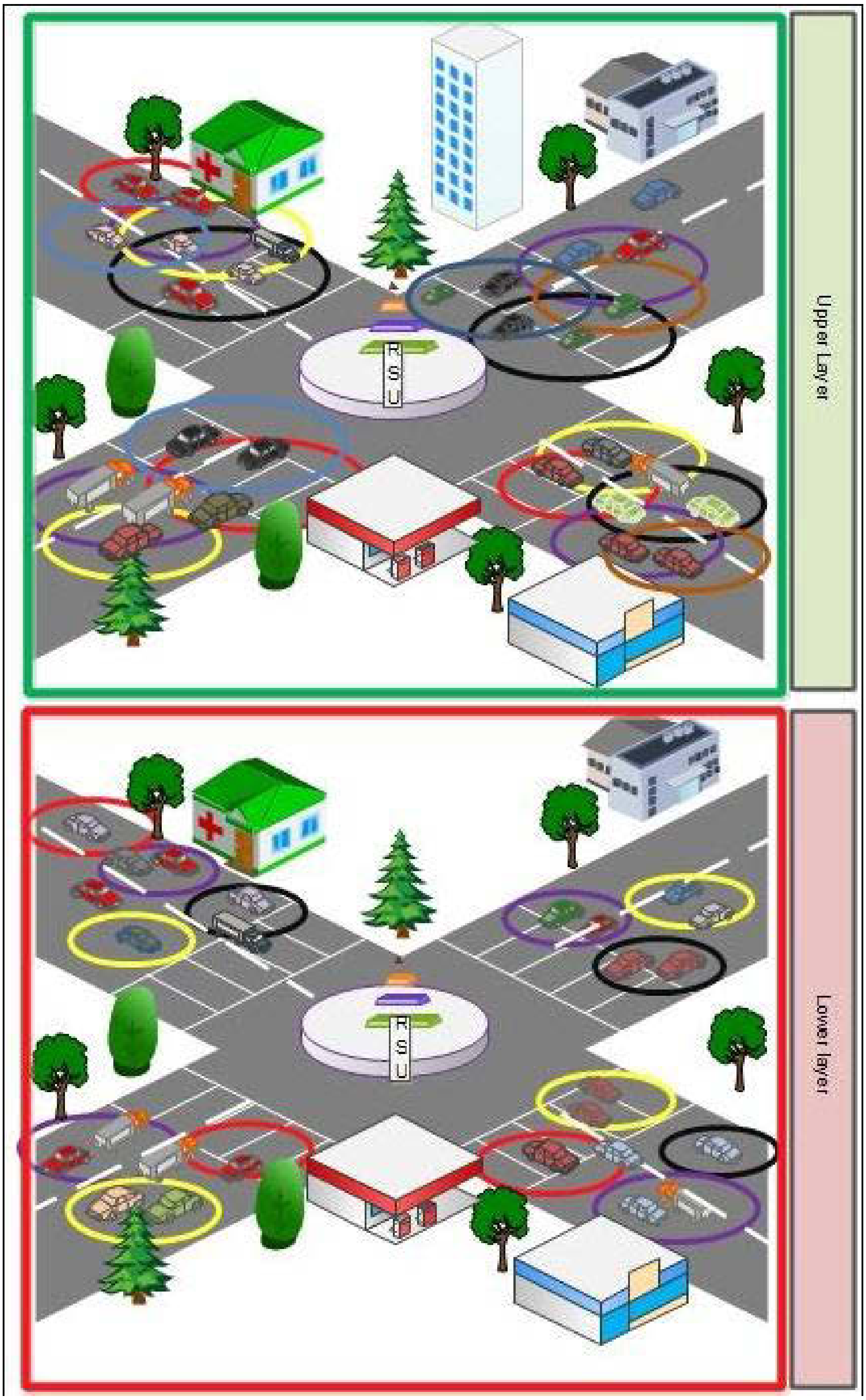


Figure 3.2: Schematic of two layer proposed game framework

Therefore, the net utility function can be computed from total throughput associated with the entire cluster and is defined as

$$U_i(s_i) = \begin{cases} Total_{\tau C} = c_1/n + \sum_{j=2}^{n} \frac{1/n}{\frac{1}{c_j}+\frac{1}{c1}} - \varsigma_i(s_i) & if s_i = H \\ c = w * log(1 + SNR(d)) & if s_i \epsilon \{H, M\} \end{cases} \quad (3.1)$$

where $c1$ is the capacity for head with respect to Road Side Unit (RSU) and c_j where $\sum_{j=2}^{n}$ is the capacity of a member with respect to head. w is the bandwidth allocated to the vehicular node i and and SNR is Signal to interference and noise ratio and d is the distance between nodes and is measured as

$$(d = d_H = Head \longrightarrow RSU)$$

and

$$(d = d_M = Member \longrightarrow Head)$$

where d_H is the distance of head H from Road Side Unit(RSU) and d_M is the distance of a member M from head. Therefore, the total throughput of the entire cluster is given by

$$Total_{\tau C} = c_1/n + \sum_{j=2}^{n} \frac{1/n}{\frac{1}{c_j} + \frac{1}{c1}} - \varsigma_i(s_i) \quad (3.2)$$

Where n is the number of nodes in the cluster and c_1 is the capacity of node playing head (node 1) and $\sum_{j=2}^{n} c_j$ are the capacities of the nodes served by vehicular node acting as a head.

3.5.2 Objective of Utility function

The objective of a node i playing a strategy S_i is to maximize the utility function as given by eq.3.2. This objective reflects the benefit gained by the a vehicular node i to become a cluster head and the cost paid for resources as discussed in section 3.5.4. Therefore, the expected utility of a node i playing a strategy S_i is given as

$$EU_i(s_i) = argmax(U_i(s_i)) \quad (3.3)$$

3.5.3 Cluster Formation

We use least distance criteria as a metric for the formation of clusters. It is assumed that all the vehicles know their positions based on GPS or other localization services. Assuming that vehicles already know their x and y coordinates, the relative distance between a member and a head is calculated by the following formula

$$d_M = \sqrt{(x_H - x_M)^2 + (y_H - y_M)^2} \tag{3.4}$$

where x_M and y_M represent the x and y coordinates of a member and x_H and y_H are the x and y coordinates of head. Cluster head election criteria is based on maximizing the utility function as proposed earlier in section 3.5.1. For cluster head election, the relative distance d_H of a vehicular node head and Road Side Unit RSU (Access point) is calculated by the following formula

$$d_H = \sqrt{(x_{rsu} - x_H)^2 + (y_{rsu} - y_H)^2} \tag{3.5}$$

where x_H and y_H represent the x and y coordinates of head and x_{rsu} and y_{rsu} are the x and y coordinates of RSU.
The members pick up the head that is located very nearest to them. The algorithm for cluster formation is illustrated in appendix.

3.5.4 Cost Function

As discussed in section 3.5.1, our utility function is the difference between the reward of the strategy played by a vehicular node and the cost incurred by the cluster from the central controller RSU. We take ς_i as the coefficient of linear pricing function used by the Road Side unit RSU to charge a head for used resources like bandwidth and the congestions caused on a particular link of a cluster. This cost function also helps in defining an optimum clustering and controlling the size of clusters in terms of keeping the cluster size and usage of capacity as an optimum.

3.5.5 Propagation Model

As our main focus is to test and analyse the adeptness of our proposed two layer game framework, hereafter, for the sake of simplicity, we use free space path loss as a propagation model for the simulation of VANET clustering scenarios. In free space path loss, the received power depends only on three factors that are transmitted power, antenna gain and distance between the transmitter and receiver. Moreover, the power decreases with the increase in distance between transmitter and receiver. Following are the formulas used for free space path loss as propagation model.

$$pRX(d) = \frac{pTX * \Lambda_{Tx} * \Lambda_{Rx} * \lambda^2}{(4 * pi)^2 * d^\alpha * \iota} \tag{3.6}$$

where

pRX is the received power, Λ_{Tx} is transmitter antenna gain, Λ_{Rx} is receiver antenna gain λ is the wavelength, ι is system loss and α is path loss exponent that is 2 in free space environments. It is also assumed that the antennas of transmitter and receiver are matched, therefore the values of Λ_{Tx}, Λ_{Rx} and ι are set to 1 [68]. Therefore, after setting these values we get

$$pRX(d) = pTX * (\lambda/(4 * pi * d))^2) \tag{3.7}$$

The signal to interference and noise ratio SNR is given as

$$SNR(d) = pRX/Rx_{noise} \tag{3.8}$$

where Rx_{noise} is the received noise.

3.6 Flow chart

The flow chart of our proposed two layer game for stable clustering in VANET is given as

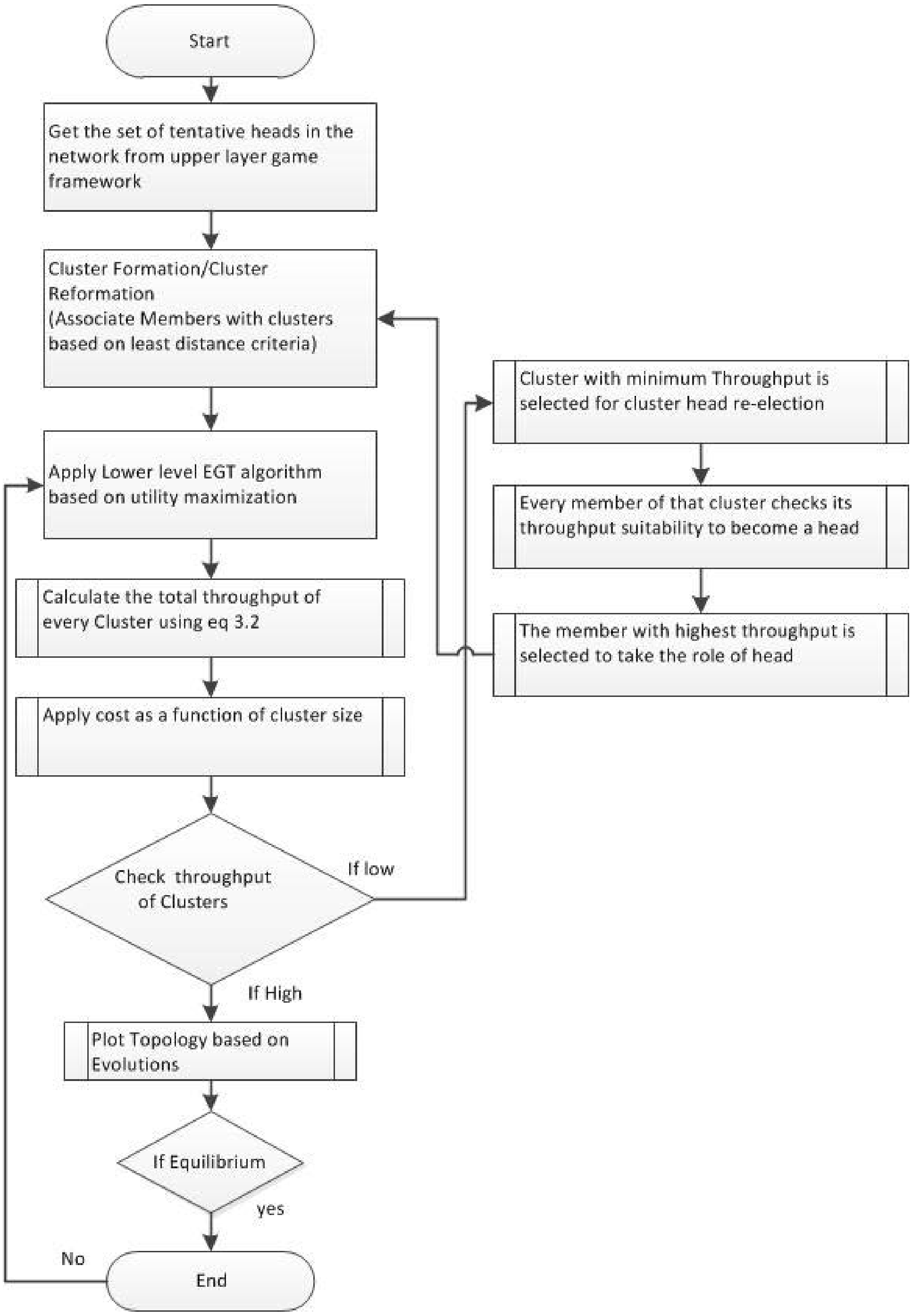


Figure 3.3: Flow chart of proposed Game

3.7 System Model and Assumptions

In this section, a profound explanation of the proposed game framework is presented in addition with the assumptions made for the implementation of game. List of used variables is also given in table 3.2

- We use a centralized controller approach for handling the problem of in-stable clustering in VANETs. We assume that the set of vehicles $N = \{1, 2, ..., n\}$ playing a strategy from strategy set $S = \{H, M\}$ acts as client and the central controller Road Side Unit (RSU) acts as the receiver.
- The objective of utility function is based on maximizing the utility function. Therefore, the vehicle play their strategies based on maximizing their utility.
- It is assumed that the vehicles served by the cluster head are each allocated with the same time duration for data transmission.
- It is also assumed that the bandwidth allocated to different clusters from the Road side unit uses a Frequency Division Multiple Access FDMA.
- It is also assumed that all vehicles have the same transmission range.
- Vehicles are assumed to know their own positions by using GPS or other localization services. Vehicles are assumed to be deployed in a two dimensional grid of roads $\prod = [x_{min}, x_{max}] \times [y_{min}, y_{max}]$. Vehicles broadcast their location by $loc_i = \{x_i, y_i\}$ represented by x and y coordinates using the built in DSRC/IEE 802.11p communication system.

The proposed two layer game prototype aims to address the problem of distributed in-stable clustering in VANETs. We analyse the long term behaviour of the interactions of vehicular nodes with respect to cluster creation and cluster reformation. We initialize our game by taking a predefined number of heads and members from the upper layer in which the set of $N(t)$ vehicles (players) are active at time t. We allow the vehicles to simultaneously interact with each other in each evolution via a central controller RSU. At time $t > 0$, in each evolution, the vehicles play a strategy based on an objective of maximizing the expected utility. The payoff in our game is the utility representing the throughput and the total throughput of the entire cluster as shown in eq. 3.1. At each time interval t, the simultaneous interactions between the nodes are modelled as an evolutionary game and the game is repeated until we reach a Nash equilibrium where the utility of all vehicles is maximized and no vehicle deviates to change its strategy.

Another enthralling fact about the game is that the decision making process of the vehicles is not only dependent on their own actions or strategies but it also depends on the payoffs of other vehicles in the network. So this fact helps to provide a distributed optimized clustering objective in the sense that the vehicular nodes are just having their own local information about their payoffs on one hand, but on the other hand, the distributed global objective is achieved.

3.8 Solution Approach

In this study, we propose a solution of distributed stable clustering in VANETs. We deal with the problem of finding an evolutionary Nash equilibrium as a solution of our game. We use a reinforcement learning approach through repeated simultaneous interactions with a central controller RSU. A vehicular node can gradually learn and adapt the decisions related to clustering via a central controller RSU, to reach an evolutionary equilibrium without any interaction with other nodes. The competition among vehicular nodes to maintain a stable clustering state of the system is formulated based on utility maximization. Moreover, our proposed game is also capable to achieve the objective of distributed global optimized clustering since the nodes make their decisions by just relying on the local information about their own payoffs. The vehicles adapt their strategies from a finite set of action profiles through distributed payoff based strategy adjustment process or reinforcement learning [69]. In payoff based distributed learning, at any stage t, the vehicles know only their own actions and payoffs from $t-1$ previous stage and vehicles have no information about the actions taken by other vehicles. The vehicles adjust their behaviours based on the observed behaviours of other vehicles through RSU in the previous stages and maximize their utility. Therefore, at each time $t \geq 0$, each vehicle $i \epsilon N$ selects an action profile $s_i \epsilon S$ to maximize its expected utility. At every time step t, this game is repeated and after a sufficiently large number of repetitive stages, vehicles action profile reaches an evolutionary Nash equilibrium. The more successful actions of a vehicle $i \epsilon N$ playing a strategy $s_i \epsilon S$ in the previous two stages or iterations is given as

$$\eta_i(t) = \begin{cases} t & if u_i(s_i(t)) \geq u_i(s_i(t-1)) \\ t-1 & otherwise \end{cases} \tag{3.9}$$

It is important to note here that our proposed game is a non cooperative game that is formulated based on the group behaviour of the vehicles for cluster formation and reorganization rather than depending upon the individual behaviour of nodes as it happens in evolutionary games. The strategy in this scenario corresponds to the net utility of the group of vehicles forming clusters. The payoff of the vehicle is the total net utility of a group of vehicles in a cluster [69]. Therefore, Nash equilibrium is considered as a solution of this game and is defined as

DEFINITION (Nash equilibrium ref:) : *An action profile* $s^* = (s_i^*, s_{-i}^*)$ *of a vehicle* $i \epsilon N$ *is a pure Nash equilibrium of the game* $G = \langle N, S, U \rangle$ *if for all* $s_i \epsilon S$ *the following condition is met*

$$u_i(s^*) \geq u_i(s_i, s_{-i}^*)) \tag{3.10}$$

An action profile that satisfies a Nash equilibrium represents a state of the game where no vehicle has an incentive to deviate unilaterally. Therefore, at this state of the game an optimized distributed clustering is achieved.

3.9 List of Parameters

Table 3.2: List of parameters

Parameter	Description
$G = \langle N, S, U \rangle$	Lower layer Evolutionary potential Game
N	Total number of vehicular nodes
$S = \{H, M\}$	Strategy set for vehicular nodes
s_i	Current strategy of node i
$N = \{1, 2, ..., n\}$	set of vehicular nodes
U	Utility Function
u_H	Utility of head
u_M	Utility of member
EU_i	Expected utility of a node i
ς	Cost function
i	Index of node
τC	Throughput
w	Capacity/Bandwidth
$Total_{\tau C}$	Total throughput of entire cluster
$c1$	Capacity of a node to become head
pTX	Transmission power of node
pRX	Received power
Rx_{noise}	Received noise
λ	wavelength
$c_j where \sum_{j=2}^{n}$	Capacities of neighbouring nodes surrounding heads

Table 3.2: List of parameters

Parameter	Description
SNR	Signal to Interference and Noise Ratio
d	Relative distance between nodes
d_H	Relative distance between head and Road Side Unit
d_M	Relative distance between member and head
loc_i	location of a node i
x_i	x-coordinate of node i
y_i	y-coordinate of node i
x_{rsu}	x-coordinate of RSU
y_{rsu}	y-coordinate of RSU
x_H	x-coordinate of Head
y_H	y-coordinate of Head
x_M	x-coordinate of Member
y_M	y-coordinate of Member

3.10 Summary

We propose a two-layer evolutionary game theoretic framework that is aimed at solving the problem of distributed in-stable clustering in VANETs. Upper layer is modelled by deciding a tentative set of clusters in the network. The Lower layer dynamic cluster head selection is modelled by using an Evolutionary Potential Game Theoretic (EPGT) framework. The lower layer models the competitions among vehicles based on maximizing their utility function. In this game, the strategy profile of vehicles is based on the group behaviour of vehicles within a cluster. We use a reinforcement learning approach using a central controller RSU in which the vehicles learn and adapt their strategies through repeated simultaneous interactions with the central controller RSU. When the vehicles reach the state of evolutionary Nash equilibrium, this state is considered to be the stable state where the system is converged. Our utility function is the difference between the reward and the cost of strategy played by the vehicular node. The utility function is a function of total throughput of the entire cluster as given by eq. 3.2. We use Shannon's capacity to calculate the capacity of each node in the cluster. We use least distance criteria as a cluster formation metric. This chapter also provides the lists the lists of parameters used for our proposed game framework.

Chapter 4

Performance Evalutaion

We present two approaches for analysing the behaviour and performance of our proposed Evolutionary game framework with respect to stability and optimization of clusters in VANETs. The main notion behind using these two approaches is to first analyse the efficiency of our proposed game in static environment and then deploy that game in real VANET clustering scenarios. Another captivation behind using a static deployment approach is that, one can use this as a framework to solve the problem of cluster instability in any type of scenario in which the nodes are randomly deployed.

4.1 Performance Evaluation using static scenarios

Our first approach basically focuses on analysing the performance of our proposed game framework in static scenarios with random deployment of nodes in a predefined area. This approach evaluates the performance of our proposed game in the above stated scenario with respect to stability and optimization of clusters.

4.1.1 Simulation Setup in static scenarios

Our first performance evaluation approach is made via simulations using MATLAB 2014. The wireless standard used in our simulation is IEEE 802.11p. In this scenario, the geographical area of VANET consists of an area of a road length of $1000m \times 1000m$. Vehicles are assumed to be randomly deployed in the network. All vehicles act as clients and the Road Side Unit RSU acts as a receiver. The details of network configuration parameters are also listed in section 4.1.3

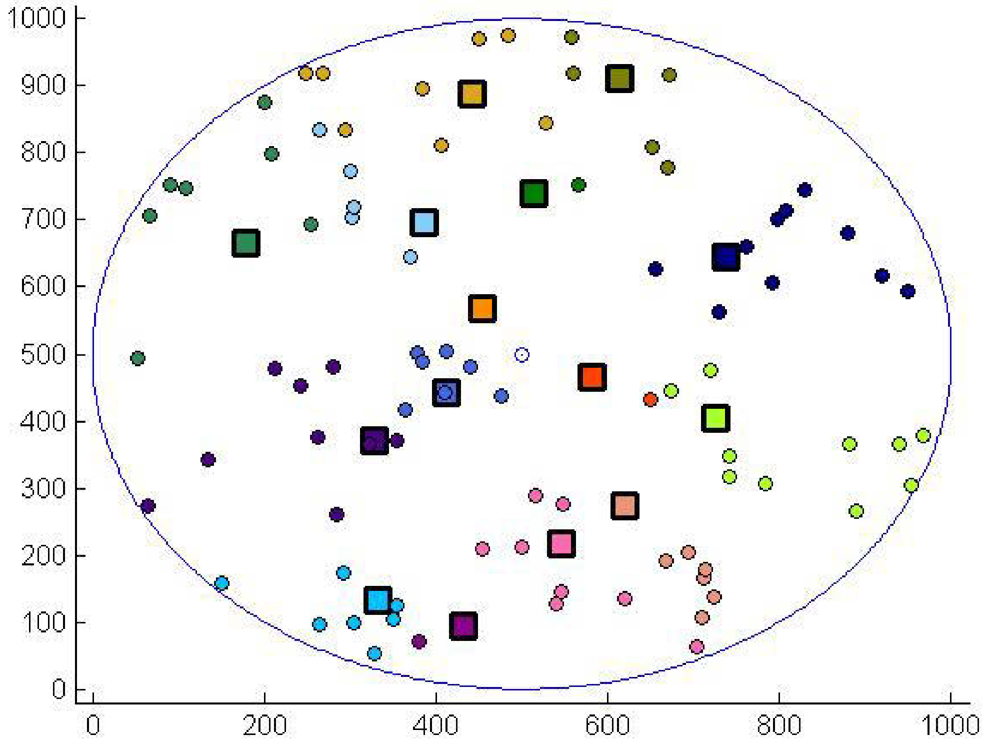


Figure 4.1: A snapshot of proposed EPGT running simulation in a static scenario

4.1.2 Assumptions

Following are the assumptions for our simulation.

- Each vehicle in the network broadcast its position using built-in GPS service.
- The Road Side Unit RSU is assumed to be located in the center of road and is fixed.
- The transmission range of Road Side Unit RSU is set to be $500m$.

Now we discuss the performance evaluation with reference to the proposed two layer Evolutionary game framework as discussed in sections 3.2,3.4 and 3.5. We first consider upper layer as an input for our proposed lower layer EPGT framework. For that, we first consider a tentative set of randomly deployed heads in the network.

We use a centralized controller approach via RSU for exchange of information. All vehicles start at the same time and the vehicles within the range of RSU establish connection with the Road Side Unit. The vehicular nodes join the clusters with respect to least distance criteria as mentioned in algorithm 2. We calculate the distance between vehicles and RSU by using eq. 3.5 and eq. 3.4. We apply our lower layer EPGT approach based on utility maximization by using eq. 3.1. We assumed cost ς as a function of cluster size and we analysed results on different values of cost function.

4.1.3 Network Configuration Parameters

The details of network simulation parameters used in our simulation setup are given below

Parameter Name	**Values(Units)**
Length of Road	$1000m$
Number of Vehicles	100
Position of RSU	$x = 500, y = 500$
Bandwidth W	$20MHz$
Transmission range of RSU	$500m$
Mobility Model	Random and Static
PHY and MAC layer protocol	IEEE 802.11p
Normalized Transmit power PTx	$20mW$
$Rx_{noise}(-90dBm)$	$1e-9mW$
Wavelength λ	$0.125m$
Path loss exponent (Free Space)	2.0
Average Speed of vehicles	$0m/Sec$
Simulation interval	$.01sec$

Table 4.1: Network configuration parameters in static scenarios

4.1.4 Results and implications of static scenarios

For performance evaluation, we first consider a system with a set of $N = 100$ vehicular nodes randomly deployed in an area of $1000X1000m$. For IEEE 802.11p network, the value of bandwidth allocated for each cluster is assumed to be $W = 20MHz$ from central controller. The transmission power of nodes is assumed to be $20mW$ and as this investigation is being carried out in static scenarios, therefore, the speed of nodes is set to $0m/sec$. We initially assume different numbers of randomly deployed clusters $2, 5, 10, 15, 20$ as an input from upper layer and apply our proposed lower level EPGT game to investigate the performance of clustering on these different numbers of clusters. We investigate the performance of our proposed game in terms of stability of clusters in the entire system. To ensure the accuracy of our results, approximately 100 trials are executed for each experiment. The dynamic behaviour of clustering of vehicles under total group capacity of clusters as given by eq. 3.1 is investigated and the convergence of network under different numbers of clusters is shown in the following figures.
The trajectory of evolutionary equilibrium shows that the system converges to a certain point where the stability of number of clusters taken as an input from upper layer is retained in the network and every cluster receives the same total throughput capacity. We investigated the performance of game at different numbers of clusters taken as an input from upper layer and analysed that the system converges to a stable state. We also investigated the real objective of our utility function by taking different numbers of clusters as an input and investigated the point where the average total throughput capacity of clusters is maximized. This is the point where we achieved the optimum number of clusters for our proposed scenario.

Following are the snapshots of running simulations in static scenarios for different numbers of clusters and the trajectories are showing the stability convergence of different numbers of clusters to evolutionary equilibrium.

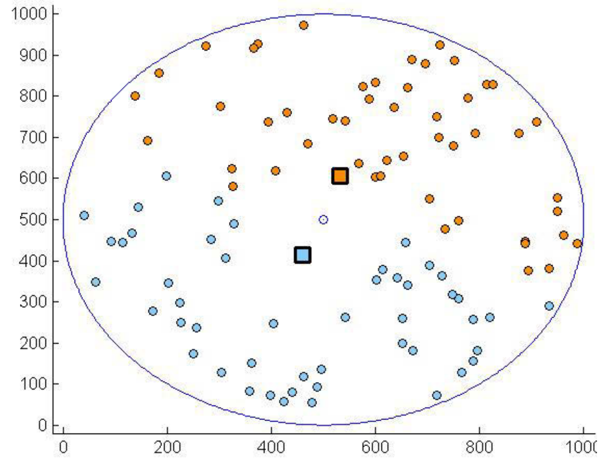


Figure 4.2: Proposed EPGT running simulation in a static scenario with 2 clusters

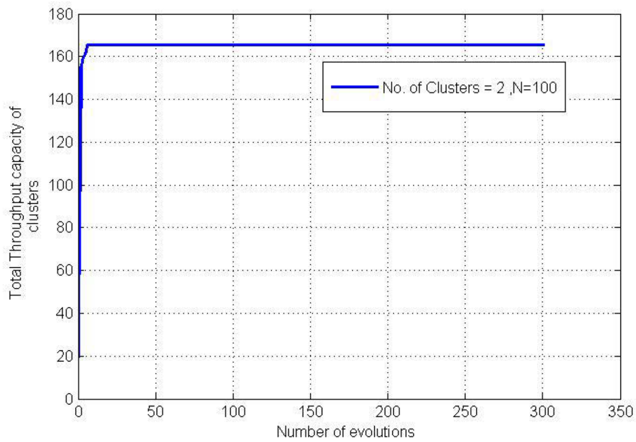


Figure 4.3: Stability convegrence of System with two clusters

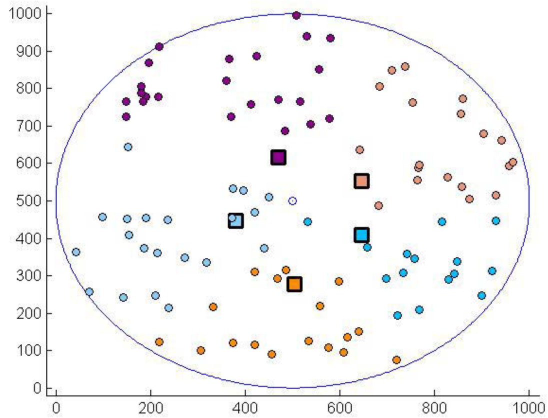


Figure 4.4: Proposed EPGT running simulation in a static scenario with 5 clusters

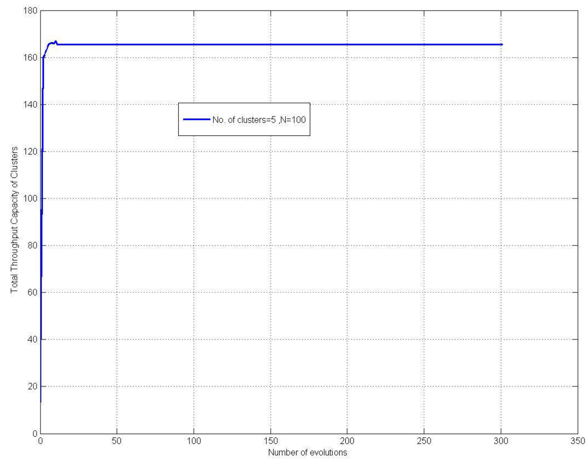


Figure 4.5: Stability convegrence of System with five clusters

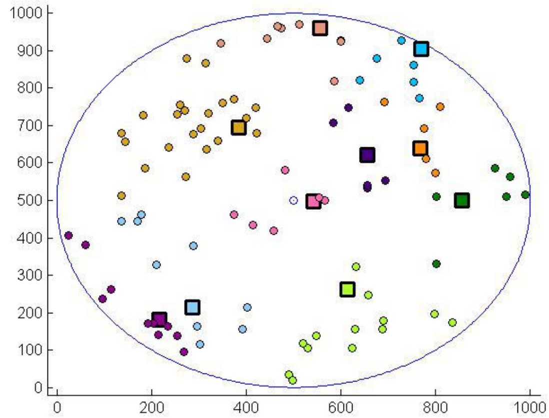


Figure 4.6: Proposed EPGT running simulation in a static scenario with 10 clusters

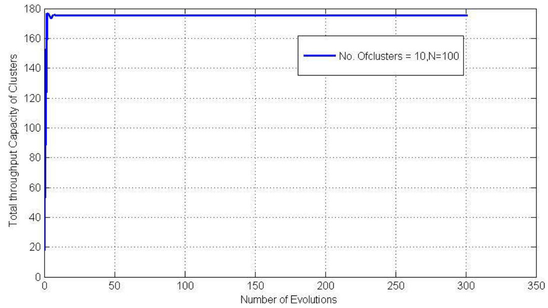


Figure 4.7: Stability convegrence of System with ten clusters

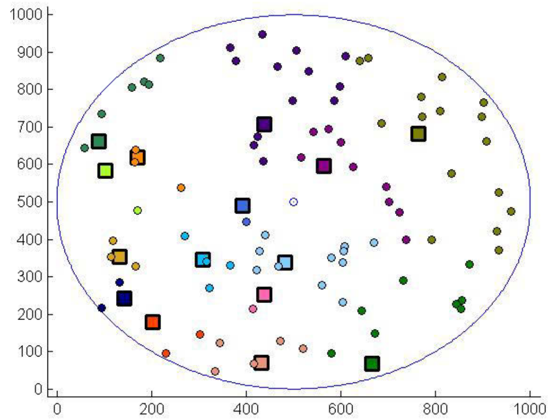


Figure 4.8: Proposed EPGT running simulation in a static scenario with 15 clusters

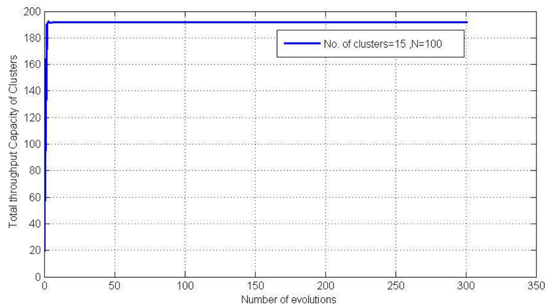


Figure 4.9: Stability convegrence of System with fifteen clusters

In the same way ,we tested the system with different inputs from the upper layer with $N = 25, 30, 35, 40, 45, ...$ and found that the system converges to a state where there is no more switching of clusters and the stability of clusters is retained at this point of evolutionary equilibrium.

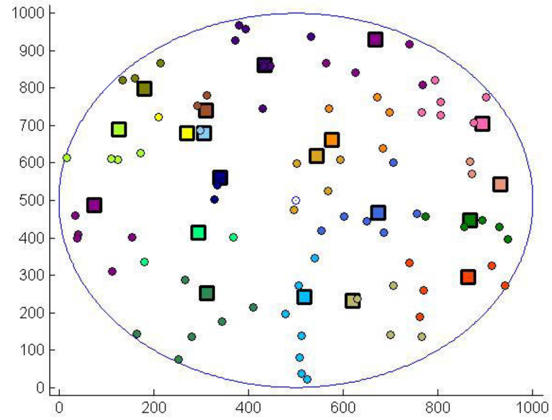


Figure 4.10: Proposed EPGT running simulation in a static scenario with 20 clusters

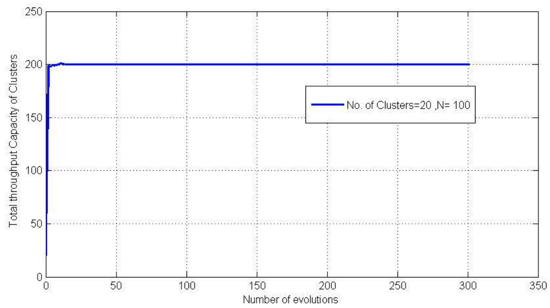


Figure 4.11: Stability convegrence of System with twenty clusters

Optimization of Average Total Throughput

Next, we discuss the optimization issues that can be attained by changing the pricing function ς. We investigate the optimal number of clusters for $N = 100$ nodes in the network and we obtained the following curves for our concave utility function 3.1 at different prices. We observed that it is important to adapt pricing ς as being the function of density of nodes within a cluster as well the total number of clusters in the network. It is also observed that at lower price $\varsigma = 0.2$ applied at a cluster size of 5 or less, the total average throughput of clusters increases as the number of clusters in the network increases as there is an indirect decrease in the size of cluster as shown in fig. 4.12. Therefore, we are not able to achieve utility maximization at lower cost.

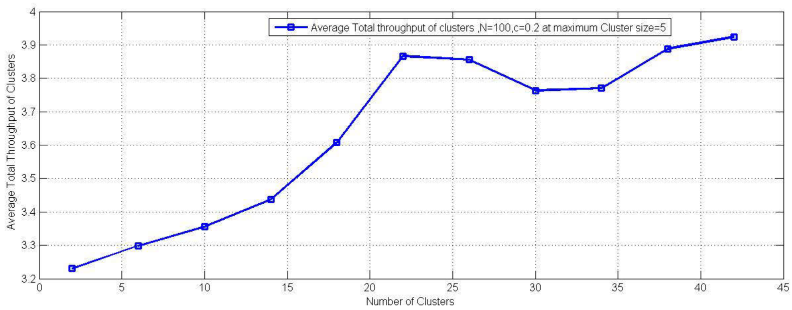


Figure 4.12: Utility Curve at lower price

It is observed that we get better results at higher price $\varsigma = 0.5$ applied at cluster size of 5 or less. Therefore, for an optimum use of bandwidth allocated by the RSU, we observed that better performance is achieved at higher price in terms of achieving utility maximization for the optimum number of clusters in our network. We got the following concave utility curve showing an optimum number of clusters in our network.

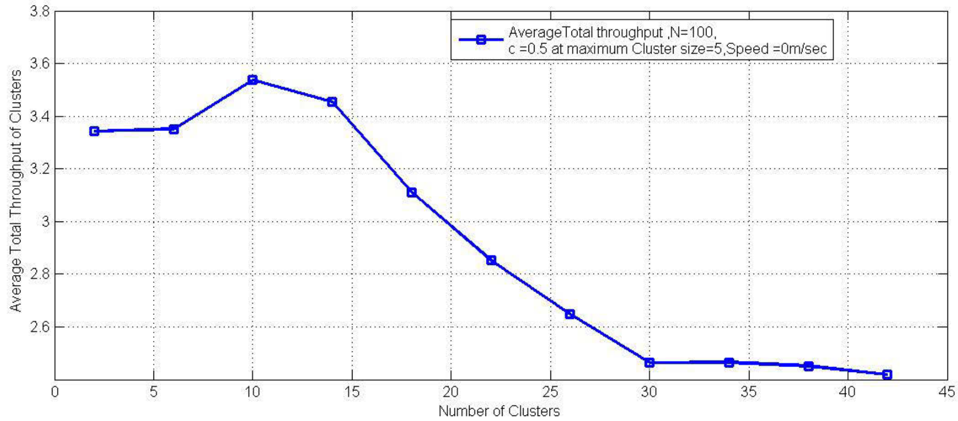


Figure 4.13: Concave Utility Curve

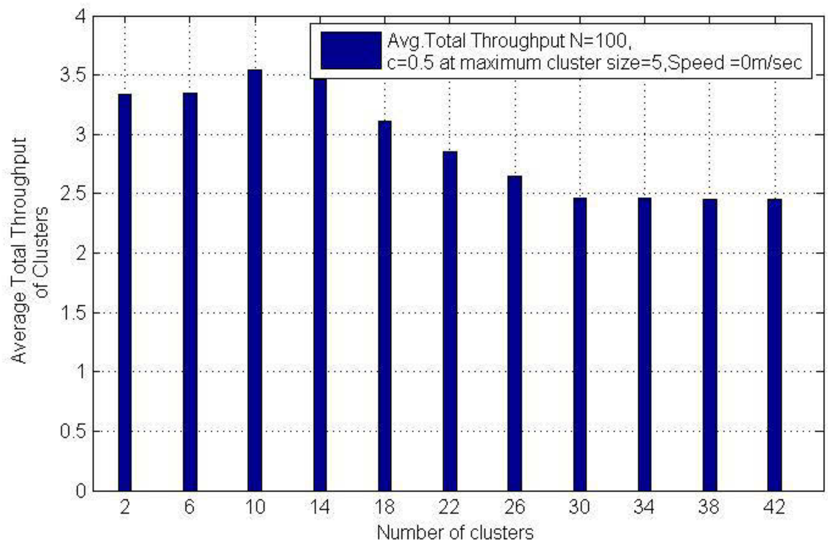


Figure 4.14: Optimum Numberof clusters

4.2 Performance Evaluation Using Mobility

In our second approach, we analyse the efficiency and performance of our proposed game in a real VANET mobility scenario. We use the Manhattan grid as a VANET mobility model to analyse the efficiency of our proposed game.

4.2.1 Manhattan Grid Mobility Model

This model offers more realistic mobility patterns on streets and in urban areas. The geographical area of VANET is partitioned into two dimensional bidirectional grids of roads assuming two way roads. The grid of roads is placed after every $250m$. Initially all the vehicles are deployed randomly in an area of $1000X1000m$. After a node begins to move and reaches at the next street intersection, the direction of vehicular node is decided probabilistically. A node has 50% chance of continuing in the same direction and 25% chance of turning to the west/South directions and an equal 25% chance of turning to east/north direction. In our simulation, if a node reaches at the boundary of VANET simulation area, it again has a 50% chance to move in the reverse direction 25% chance of turning to the west/South directions and an equal 25% chance of turning to east /north direction. As our main focus is to check the performance of our proposed game ,therefore, we consider only free space path loss environment as a propagation model during our simulation in the Manhattan grid.

4.2.2 Simulation Setup of Mobility

The performance evaluation is made via simulations using MATLAB 2014. The Wireless standard used in our simulation is IEEE 802.11p.The mobility model we chose to run the set of experiments is the Manhattan grid mobility model as mentioned in the above section 4.2.1. The network is divided into grids comprising of vertical and horizontal streets. The central controller RSU is placed in the middle of roads. The vehicles are initially deployed randomly in an area of $1000X1000m$ of the Manhattan grid. All Vehicles act as clients and the Road Side Unit RSU acts as a receiver. The details of network configuration parameters in the Manhattan grid mobility implementation are also listed in section 4.2.4

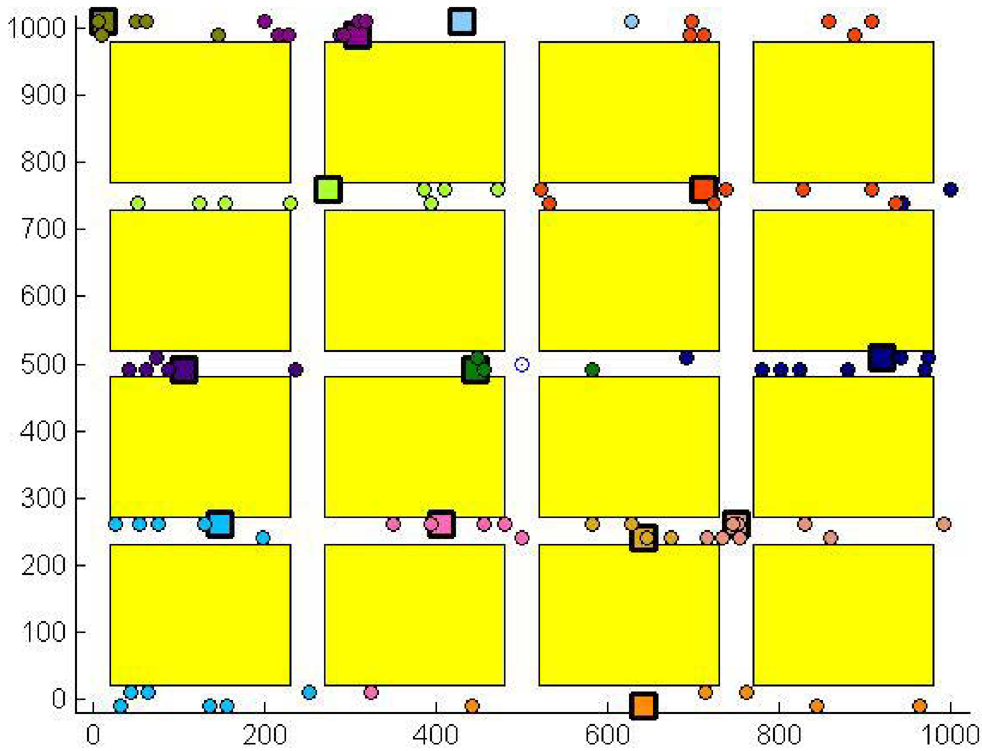


Figure 4.15: A snapshot of proposed EPGT running simulation of VANET in the Manhattan grid Mobiliy

4.2.3 Assumptions

Following are the assumption made for the simulation in the Manhattan grid.

- Each vehicle in the network broadcast its position using built-in GPS service.
- The Road Side Unit RSU is assumed to be located in the center of road and is fixed.
- The transmission range of Road Side Unit RSU is set to be $500m$.
- It is assumed that a node does not change its speed between the pause intervals.

Now, we discuss the performance evaluation of the proposed two layer Evolutionary game framework as discussed in sections 3.2,3.4 and 3.5 using the Manhattan grid. We use a centralized controller approach via RSU for exchange of information in the grid. All vehicles start at the same time and the vehicles within the range of RSU establishes connection with the Road Side Unit.

We consider upper layer as an input for our proposed lower layer EPGT framework. For that, we first consider a tentative set of randomly deployed heads in a predefined $1000X1000m$ area of roads partitioned into grids. Our Lower layer proposed EPGT is then applied to investigate the problem of in-stable clustering in VANETs. In our experiments, we tried different numbers of heads initially taken as an input from upper layer and analysed the performance of our proposed protocol to devise an optimal solution for stable clustering in VANETs on different values of cost function.

We use least distance criteria as a metric for cluster formation as discussed in section 3.5.3. We use the same equations as mentioned in a static scenario to calculate the distance between vehicles and RSU. For reference we use eq. 3.5 and eq. 3.4. We apply our lower layer EPGT approach based on utility maximization by using eq. 3.1. We assume cost ς as a function of cluster size and investigate the results on different values of cost function ς.

4.2.4 Network Configuration Parameters

The details of network simulation parameters used in our simulation setup are given below

Parameter Name	**Values(Units)**
Length of Road	$1000m$
Number of Vehicles	100
Position of RSU	$x = 500, y = 500$
Bandwidth W	$20MHz$
Transmission range of RSU	$500m$
Mobility Model	Manhattan Grid Mobility
PHY and MAC layer protocol	IEEE 802.11p
Normalized Transmit power PTx	$20mW$
$Rx_{noise}(-90dBm)$	$1e-9mW$
Wavelength λ	$0.125m$
Path loss exponent (Free Space)	2.0
Average Speed of vehicles	$20m/sec, 30m/sec, 45m/sec, 65m/sec$
Simulation interval	$.01sec$

Table 4.2: Network Configuration Parameters using mobility

4.2.5 Results and Implications of Mobility

For performance evaluation, we first consider system with a set of $N = 100$ vehicular nodes randomly deployed in an area of $1000X1000m$. For IEEE 802.11p network, the value of capacity/bandwidth allocated for each cluster is assumed to be $W = 20MHz$ from the central controller RSU. The transmission power of nodes is assumed to be $20mW$. We initially assume different numbers of heads like $5, 10, 15, 20$ as an input from upper layer and apply our proposed lower level EPGT game on these different numbers of clusters. We use the Manhattan grid mobility model to investigate the performance of clustering on these different numbers of clusters. To ensure the accuracy of our results, 100 trials are executed for each experiment. The dynamic behaviour of clustering of vehicles under total group capacity of clusters as given by eq. 3.1 is investigated at different levels of speed and cost. The trajectory of evolutionary equilibrium shows that the system converges to a certain point where the stability of number of clusters taken as an input from upper layer is retained in the network and every cluster receives the same total throughput capacity at this point. We investigated the performance of proposed game at different numbers of clusters taken as an input from upper layer and found that the system converges to a stable state. We also investigate the optimum number of clusters in our network at different speeds of vehicles and found that the average total throughput capacity of clusters or the net utility of clusters is maximized at the same point and we achieved the real objective of our proposed utility function that is utility maximization.

Following are the snapshots of running simulations in the Manhattan grid for different numbers of clusters and the trajectories are showing the stability convergence of different numbers of clusters to evolutionary equilibrium.

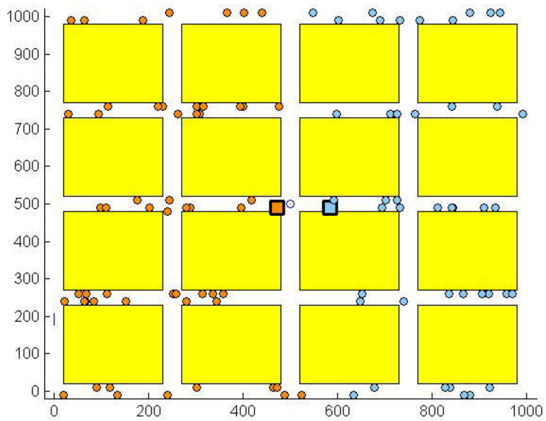


Figure 4.16: Proposed EPGT running simulation using Manhattan grid with two clusters

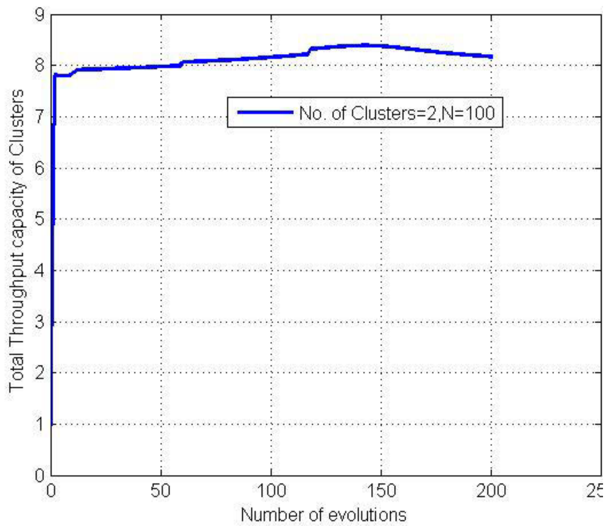
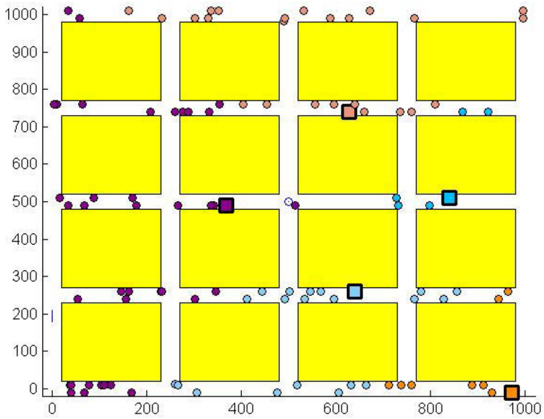


Figure 4.17: Stability convegrence with two clusters using Manhattan grid



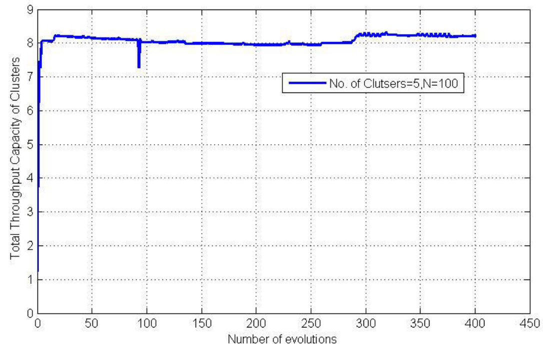
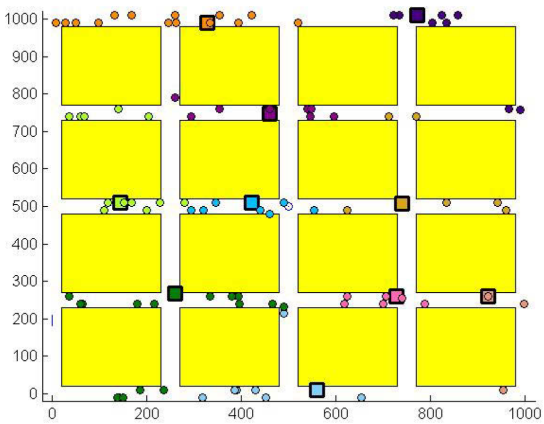


Figure 4.18: Proposed EPGT running simulation using Manhattan grid with five clusters

Figure 4.19: Stability convegrence with five clusters using Manhattan grid



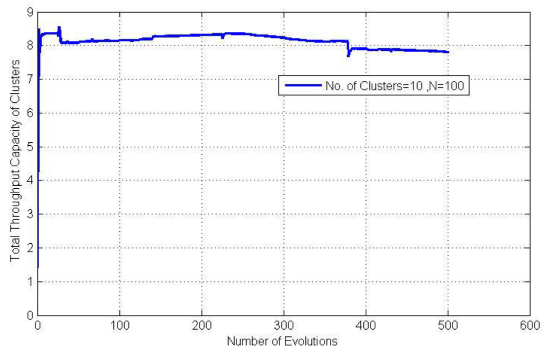


Figure 4.20: Proposed EPGT running simulation using Manhattan grid with ten clusters

Figure 4.21: Stability convegrence with ten clusters using Manhattan grid

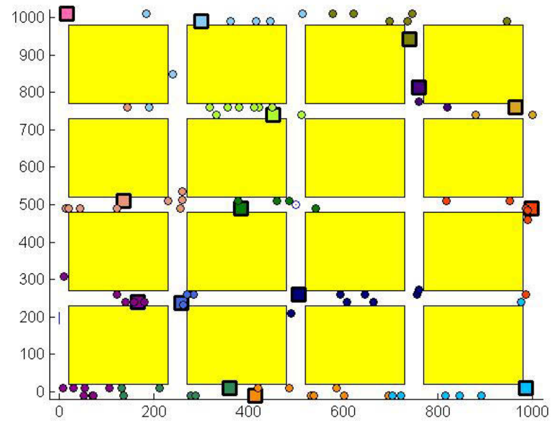
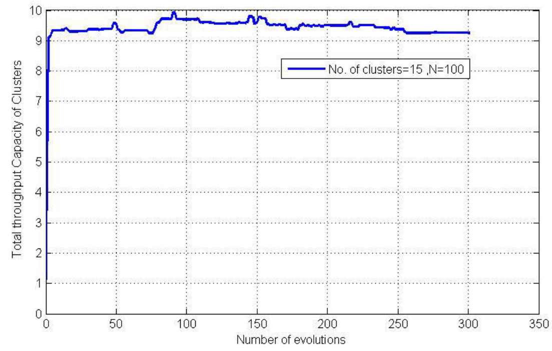



Figure 4.22: Proposed EPGT running simulation using Manhattan grid with fifteen clusters

Figure 4.23: Stability convegrence with fifteen clusters using Manhattan grid

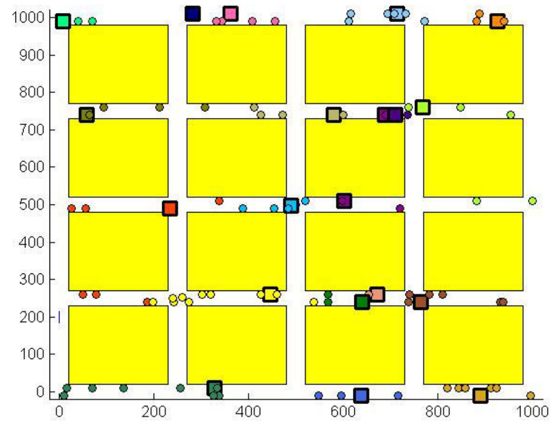
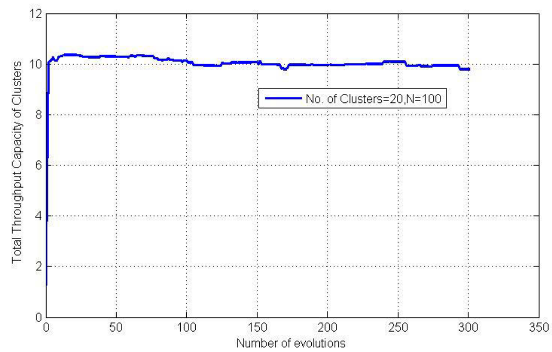



Figure 4.24: Proposed EPGT running simulation using Manhattan grid with twenty clusters

Figure 4.25: Stability convegrence with twenty clusters using Manhattan grid

In the same way, we tested the system with different inputs from the upper layer with $N = 25, 30, 35, 40, 45, ...$ and got the same results as the system converges to a state where there is no more switching of clusters and the stability of clusters is retained at this point of evolutionary equilibrium. The results conclude that the system is stable and our proposed game is capable to retain cluster stability for different number of clusters.

Optimization of Average Total Throughput

Next, we discuss the optimization issues related to pricing function ς using mobility. We investigate the optimal number of clusters for $N = 100$ nodes in the network using the Manhattan grid mobility model at different levels of speed and cost function .The trajectories we obtained for our concave utility function 3.1 at different speeds and prices are shown in the following figures.

The results we obtained for pricing ς during simulations of mobility show that at lower price $\varsigma = 0.2$ applied at cluster size of 5 or less, the total average throughput of clusters increases as the number of clusters in the network increases as there is an indirect decrease in the size of cluster as shown in fig. 4.26.

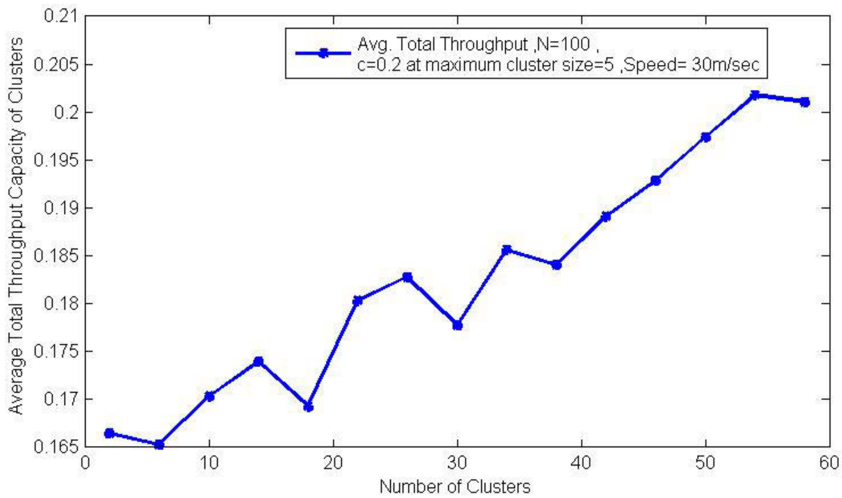


Figure 4.26: Utility Curve at lower price

It is observed that we get better results at higher price $\varsigma = 0.5$ applied at cluster size of 5 or less as shown in fig. 4.27. Therefore, for an optimum use of bandwidth allocated by the RSU, we observed that better performance is achieved at higher price in terms of achieving utility maximization for the optimum number of clusters in our network. We got the following concave utility curve showing an optimum number of clusters in our network using the Manhattan grid mobility model as shown in fig. 4.27.

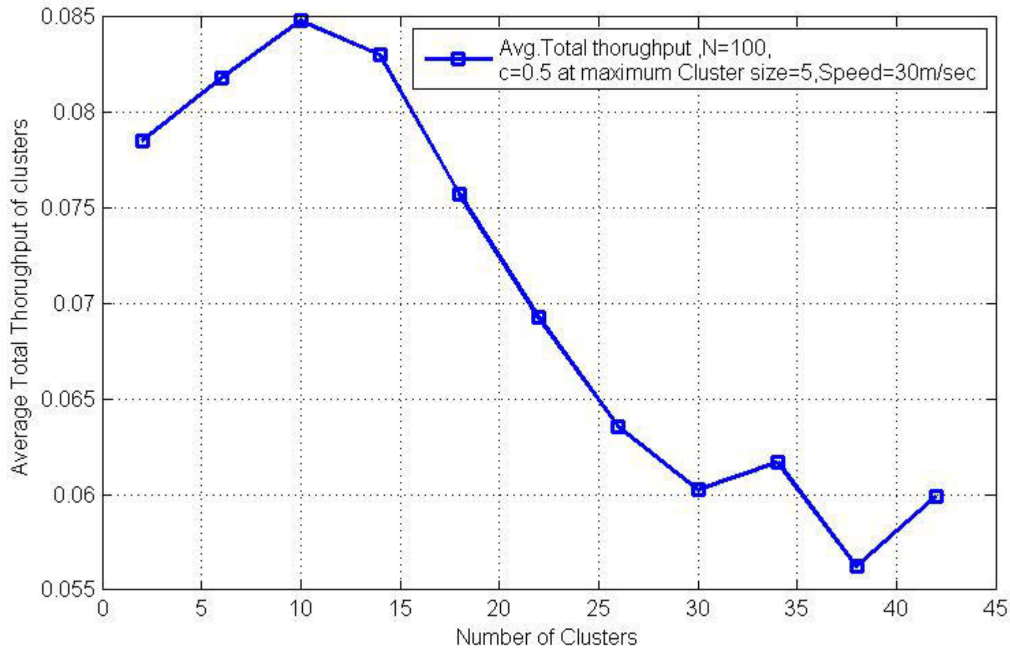


Figure 4.27: Concave Utility Curve

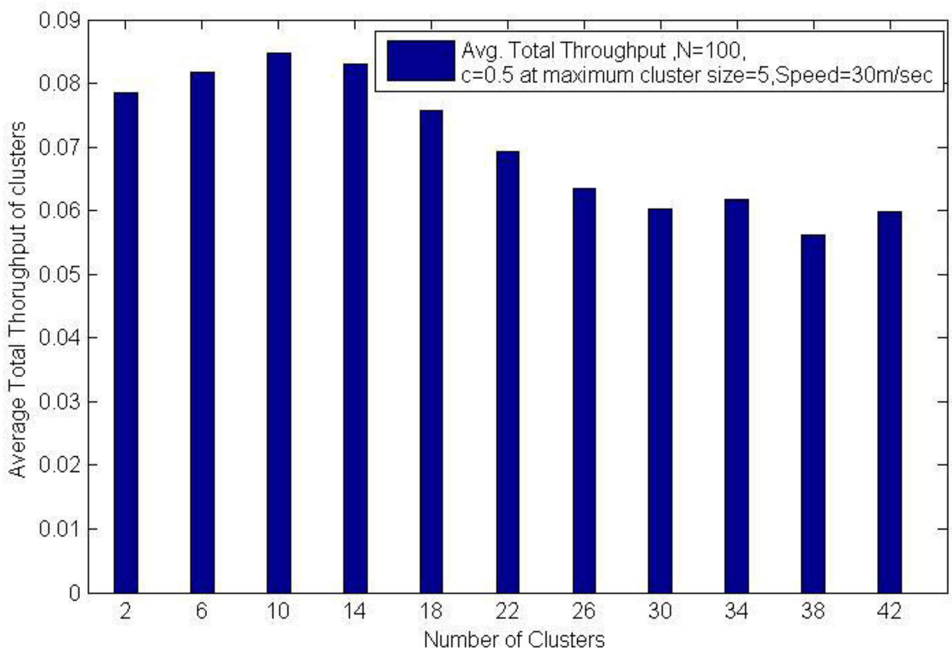


Figure 4.28: Optimum Numberof clusters

We also investigate our proposed game at different speeds of vehicles and we got the same optimum number of clusters for all speeds. This shows that the resulting protocol is extremely efficient and robust and is capable to deal with different levels of speeds as shown in figure

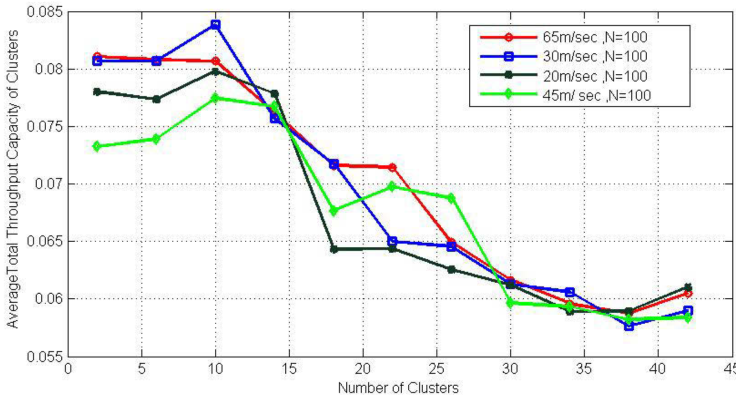


Figure 4.29: Comparison of Concave utility curve at different speeds

We also investigated the average total throughput capacity of clusters for $N = 200$ and we conclude that for different speeds, the average total throughput of clusters is same and we get the same optimum number of clusters even at different speeds of vehicles as shown in fig. 4.30.

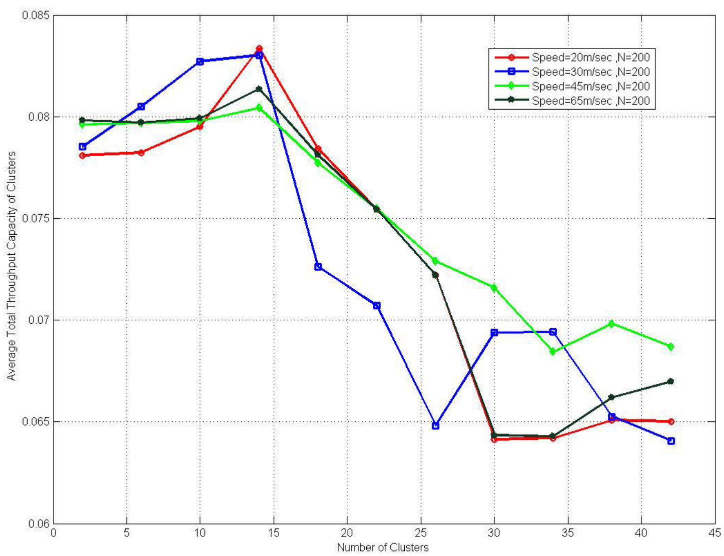


Figure 4.30: Comparison of Concave utility curve at different speeds

4.3 Summary

We used two performance evaluation approaches to investigate the efficiency of our proposed two-layer game framework. Our first approach is to test the performance evaluation of proposed game using static scenarios and our second approach is to test the performance evaluation of our game using a mobility scenario. We use the Manhattan grid as VANET mobility model for our second performance evaluation approach. In both approaches, we conclude that we are able to achieve the objective of our proposed utility function. We simulated our proposed two level game framework at different speeds of vehicles and different values of N and cost function ς. Our results show that we attain the same maximum average total throughput of clusters for all speeds of vehicles for the same value of N. This reflects that our proposed clustering protocol is robust and efficient and is able to even cope with different levels of mobility of vehicles in VANETs. The simulation results demonstrate the effectiveness of proposed clustering protocol in terms of stability and optimization of clusters in the proposed simulation framework.

Chapter 5

Conclusions and Suggested Future Research

5.1 Conclusions

We have formulated the problem of distributed in-stable clustering in VANETs as a two layer evolutionary game theoretic framework. An upper layer has been modelled by the decision of a tentative set of randomly deployed clusters in the network. The lower layer takes these randomly distributed clusters as an input and applies our proposed lower layer Evolutionary Potential Game (EPG) to this framework. We have investigated the dynamics of clustering in VANETs by modelling the competition among vehicles based on utility maximization. We use a reinforcement learning approach using a central controller RSU, through repeated simultaneous interactions between vehicles and RSU. The competition among vehicular nodes is framed to achieve the objective of distributed stable and optimized clustering in VANETs. The vehicular nodes learn and adapt their strategies through a process of repeated simultaneous interactions with the RSU [69]. This knowledge gained from learning through interactions is used in best decision making for clustering in VANETs. Once the vehicles action profiles reach the state of an evolutionary Nash equilibrium, this state is considered to be the stable solution. At this stage, all the vehicles receive an identical net utility and the system converges to the state of cluster stability. In addition, we have also tested our game on different number of clusters for different populations and cost function. We conclude that the proposed protocol exploits stable and optimized clustering for different speeds of vehicles by maintaining same average total throughput capacity of clusters. We also conclude that we are able to achieve the objective of optimum clustering by using the cost function. Our results show that the system is stable and provides optimum clustering at higher cost incurred from the central controller RSU to the clusters. In brief we conclude, our proposed game is robust and efficient with different populations and speeds of vehicles.

5.2 Suggested Future Research

This work paves a way towards stable and optimized clustering in vehicular Ad hoc Netowrks, however, there is a lot to travel on this road.

1. Nevertheless, there is a need to focus on more realistic channel models for our prosed game for vehicular communication in VANETs. For instance, in future we will use more realistic shadowing models to test and analyse the efficiency of our proposed game.

2. The game could also be tested under different utility functions designed for the capacity assigned to the clusters from the central controller RSU and the cost incurred to the clusters from the RSU at different cluster sizes.

3. Moreover, we will analyse the long term behaviour of proposed game by doing the stability analysis of the our game at fixed point of evolutionary equilibrium using Lyapunov stability [70].

4. Since we are using a central controller approach to learn and adapt strategies, therefore, at the time when a vehicular node makes a decision it is relying on the historical information. That information is not up to date and may be delayed for a certain interval of time. This delay in communication is caused due to communication performed among vehicles and the central controller RSU while gathering payoff information from/to every vehicular node in the network. For that, we will also investigate the delay in replicator dynamics by solving the delayed evolutionary game dynamics.

5. At this stage, we are considering a pre assumed number of clusters taken as an input from our upper layer, but later on, we will modify this upper layer game for the selections of number of clusters by using a liner state differential game [71].
6. To analyse the efficiency of the proposed game on overall protocol stack of the system, we will also run our proposed clustering strategy on different routing protocols in VANETs.

Appendix A

Acronyms

MANETs	Mobile Ad hoc Networks
VANETs	Vehicular Ad hoc Networks
EGT	Evolutionary Game Theory
EPGT	Evolutionary Potential Game Theoretic Framework
RSUs	Road Side Units
ITS	Intelligent Transportation System
VC	Vehicular Communication
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
I2V	Infrastructure to Vehicle
IVC	Inter Vehicle communication
VCI	Vehicular Communication Infrastructure
RVC	Roadside Vehicle Communication
GPS	Global Positioning System
DGPS	Differential Global Positioning system
SRVC	Sparse Roadside Vehicle Communication
URVC	Ubiquitous Roadside Vehicle Communication
HVC	Hybrid Vehicle Communication
OBUs	On Board Units
DSR	Dynamic Source Routing
AODV	Ad hoc On Demand Distance Vector

GPCR	Greedy Perimeter Coordinator Routing
VADD	Vehicle Assisted Data Delivery
CAR	Connectivity Aware Routing
DIR	Diagonal-Intersection-Based Routing
DRG	Distributed Robust Geocast
IVG	Inter Vehicle Geocast
ZOR	Zone Of Relevance
ZOF	Zone of Forwarding
ROVER	Robust Vehicular Routing
VIN	Vehicle Identification Number
DV-CAST	Distributed Vehicular Broadcast Protocol for Vehicular Ad Hoc Networks
MAC	Medium Access Control
APROVE	Affinity PROpagation for Vehicular Networks
DBC	Density Based Clustering
SNR	Signal to Noise Ratio
DMAC	Distributive and Mobility Adaptive Clustering
TTL	Time To Live
QOS	Quality Of Service
AMACAD	An Adaptive Mobility Aware Clustering Algorithm
CDMA	Code Division Multiple Access
ALM	Aggregate Local Mobility
WLANs	Wireless Local area Networks
ESS	Evolutionary Stable Strategies

Table A.1: List of acronyms

Appendix B

Algorithms

Algorithm 1 Cluster Formation

function ATTACH –HEADS –MEMBERS
    input :$Node, init_H, NumOfNodes, init_M$
    for $index_{mem} \leftarrow init_H + 1 : numOfNodes$ **do**
        for $index_H \leftarrow 1 : init_H$ **do**
            Calculate the distance from each head by using eq.3.4
        end for
        Pick up the nearest head and attach members with that cluster head.
    end for
    for $index_H \leftarrow 1 : init_H$ **do**
        return $HM, TotalClusterNodesCount$
    end for
end function

Algorithm 2 Cluster Formation

```
function ATTACH –HEADS –MEMBERS
    input :Node, init_H, NumOfNodes, init_M
    for index_mem ← init_H + 1 : numOfNodes do
        for index_H ← 1 : init_H do
            Calculate the distance from each head by using eq.3.4
        end for
        Pick up the nearest head and attach members with that cluster head.
    end for
    for index_H ← 1 : init_H do
        return HM, TotalClusterNodesCount
    end for
end function
```

Algorithm 3 Main Program

function CAPTOTAL

  RSU Placement in the Middle of Roads and drawing its range

  $x, y, r \leftarrow$

  $ang \leftarrow 0 : 0.01 : 2 * pi$

  $xp \leftarrow r * cos(ang)$

  $yp \leftarrow r * sin(ang)$

  $plot(x + xp, y + yp)$

  $plot(x, y,' -ob')$

  $NumOfNodes \leftarrow$

  for $nodeindex \leftarrow 1 : NumOfNodes$ **do**

    Get x and y coordinates of nodes

  end for

  $Heads_{I}nitialization \leftarrow$

  $totalHeadsLimit \leftarrow$

  $DifferenceBetweenHeads \leftarrow$

  $expectedOutputs \leftarrow totalHeadsLimit/DifferenceBetweenHeads$

  $IndexResultsOfTotalCapacity \leftarrow 1$

  while $(HeadsInitialization \leq totalHeadsLimit)$ **do**

    $totalToDisplay \leftarrow 0$

    $Headsno \leftarrow HeadsInitialization$

    $initpop \leftarrow NumOfNodes$

    $initH \leftarrow Headsno$

    $initM \leftarrow initpop - initH$

for $k \leftarrow 1 : NumOfNodes$ **do**

if $k \leq initH$ **then**

Uniquely Identify Each Head

else

Uniquely Identify Each Member

end if

end for

$[HM, Current_Index] \leftarrow$ AttachHeadsMembers$(Node, initH, NumOfNodes, initM)$

$[HM, Cluster_Throughput] \leftarrow$ CalculateClustersThroughput$(HM, RSULocation, TotalHMCount, initH)$

$Iterations \leftarrow$

for $nitindex \leftarrow 1 : Iterations$ **do**

$[PickedCluster, TotalMembers, IndexToStartReCheck, IndexToEndReCheck] \leftarrow$ MinimumThroughputCluster$(ClusterThroughput, HM, initH, NumOfNodes)$

$[HNewCluster, NewMembers, HeadCode] \leftarrow$ MakeEachMemberAsHead$(PickedCluster, TotalMembers)$

Calculate Throughput for each Member as a Cluster Head

$[HMX, CurrentIndex] \leftarrow$ AttachHeadsMembers$(HMNew, initH, NumOfNodes, initM)$

$[HMX, ClusterThroughput] \leftarrow$ CalculateClustersThroughput$(HMX, RSULocation, XTotalHMCount, initH)$

Get the member with maximum throughput and replace it with new cluster head and do cluster reformation on the whole network.

$[HM, ClusterThroughput] \leftarrow$ CalculateClustersThroughput$(HM, RSULocation, TotalHMCount, initH)$

$[HM, totalToDisplay, h2] \leftarrow$ DisplayNodes$(HM, NumOfNodes, initH)$

Display current status of VANET Clustering topology

end for

Calculate Results Of Total Capacity

end while

plot Results

end function

Algorithm 4 Cluster Throughput of Clusters

function CALCULATECLUSTERTHROUGHPUT
    input :$HM, RSULocation, TotalHMCount, init_H$
    while $(index_{TH} \leq TotalHMCount)$ **do**
        for $iTemp = 1 : TempMembers$ **do**
            $TempCluster \leftarrow HM$
        end for
        $xTH = ThroughputCluster(RSULocation, TempCluster)$
    end while
    return $HMNode, ClusterTH$
end function

Algorithm 5 Throughput Cluster

part 1

function THROUGHPUTCLUSTER

  input :$RSU, Cluster$

  $bw \leftarrow$ ▷ Capacity Calculation parameters

  $ptx \leftarrow$

  $noise \leftarrow$

  $lambda \leftarrow$

  $NumOfNodes \leftarrow Cluster$

  $NumOfMembers \leftarrow NumOfNodes - init_H$

  $locRSU \leftarrow Cluster$

  $locHead \leftarrow Cluster$

  ▷ Calculate the distance of each mem with respect to H

  for $indexMem = 1 : NumOfMembers$ **do**

    $locMemx \leftarrow Cluster$

    $locMemy \leftarrow Cluster$

    $locHeadx \leftarrow locHead$

    $locHeady \leftarrow locHead$

    $d_{mem} = sqrt((locHeadx - locMemx)^2 + (locHeady - locMemy)^2)$

    $BW \leftarrow bw$

    $pTX \leftarrow ptx$

    $pRX \leftarrow pTX * ((lambda/(4 * pi * d_{mem}))^2)$

    $SNR \leftarrow pRX/noise$

    $Ci(indexMem) \leftarrow log(1 + SNR)$

  end for

  ▷ Calculate the distance of each H with respect to RSU

  $locHeadx \leftarrow locHead$

  $locHeady \leftarrow locHead$

  $RSUx \leftarrow locRSU$

  $RSUy \leftarrow locRSU$

  $d_H = sqrt((locHeadx - RSUx)^2 + (locHeady - RSUy)^2)$

  $BW \leftarrow bw$

  $pTX \leftarrow ptx$

$pRX \leftarrow pTX * ((lambda/(4 * pi * d_H))^2)$

$SNR \leftarrow pRX/noise$

$C1 \leftarrow BW * log(1 + SNR)$

▷ Calculate the Total Throughput of a cluster

$n \leftarrow NumOfNodes$

$C1_H \leftarrow C1$

$sum1 \leftarrow C1_H/n$

for $sum_M \leftarrow 2 : n$ **do**

  $Ci_M \leftarrow Ci(sum_M - 1, 1)$

  $sum1 \leftarrow sum1 + ((1/n)/((1/Ci_M) + (1/C1_H)))$

end for

if $n \leq 5$ **then**

  return $TH \leftarrow sum1 - (.5 * sum1)$

else

  return $TH \leftarrow sum1$

end if

end function

Algorithm 6 Minimum Throughput Cluster

function MinimumThroughputCluster ▷ This functions takes the Throughput of every cluster and sends the cluster with minimum throughput to function $MakeEachMemberAsHead$ for cluster head re-election

  input :$ClusterThroughput, HM, init_H, NumOfNodes$

  for $m \leftarrow 1 : init_H$ **do**

    for $k \leftarrow 1 : init_H - 1$ **do**

      Sort $ClusterThroughput$ and get cluster with minimum throughput

      $ClusterThroughput \leftarrow node$

    end for

  end for

  return $ClusterToRecheck \leftarrow ClusterThroughput$

  return $P_Cluster \leftarrow PickedCluster$

  return $TotalM, IndexToS, IndexToE$

end function

Algorithm 7 Cluster Head Re-election

function MAKEEACHMEMBERASHEAD ▷ This functions gets the *PickedCluster* as minimum throughput cluster and checks the throughput of every member of that cluster by considering it as a head and returns the best suitable member as a head

  input :$PickedCluster, TotalMembers$

  for $i \leftarrow 1 : TotalMembers$ **do**

    check every member throughput by considering it as a head and returns the best suitable member as a head

  end for

  return $NewCluster \leftarrow HNewCluster$

  return $NMemebers \leftarrow NewMembers$

  return $Headcode \leftarrow PickedCluster$

end function

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