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Cognitive Radio Enabled VANET for Multi-agent Based Intelligent Traffic Management System

S. M. Nadim Uddin[1], Nafees Mansoor[2], Sazzad Hossain[3]
[1] Department of Electronics and Telecommunication Engineering, University of Liberal Arts Bangladesh
[2,3] Department of Computer Science and Engineering, University of Liberal Arts Bangladesh
E-mail: [1]sm.uddin.ete@ulab.edu.bd, [2]nafees.mansoor@ulab.edu.bd, [3]sazzad.hossain@ulab.edu.bd

***Abstract*—With the mounting interest on cognitive radio (CR) technology in wireless communication systems, it is anticipated that CR-enabled vehicular networks will play a vigorous role in the enrichment of communication efficiency in vehicular network. This paper presents a Cognitive Radio enabled VANET for multi-agent based intelligent traffic management system. A skeleton for intelligent learning and decision mechanism for Central Traffic Management is also proposed and discussed in the model. The proposed model has two distinct information exchange system layouts. One is dynamic (vehicle to vehicle) and another is semi-dynamic (vehicle to Road-Side-Unit). For the vehicle-2-vehicle communication, the proposed model assumes that vehicles can communicate with each other using available wireless resources with the help cognitive radio mechanism. This paper also introduces a cluster formation scheme for better accuracy in data transmission among vehicles. The dynamic module of the proposed model is later simulated and validated for some important performance communication metrics.**

***Keywords*—Cognitive Radio; VANET; Traffic Management System; CR-VANET; MANET**

I. INTRODUCTION

With the advancement of microelectronics and communication modules, a rapid surge of interest is observed in the research community for Mobile Ad-hoc Network (MANET) and Vehicular Ad-hoc Network (VANET). MANET, a special type of ad-hoc network, is self-organized and is fully operable without the assistance from any fixed infrastructural support or central administration. The mobile nodes are inter-connected by the wireless links and communication is held directly between nodes or through intermediate nodes [1]. Each node in MANET continuously maintains the updated information that is required to properly route the traffic [2]. The Internet Engineering Task Force (IETF) has developed two standard track routing protocols for MANET, namely proactive and reactive MANET protocols [3].

On the other hand, VANET is a distinctive class of MANET where moving vehicles act either as nodes for direct communication or as routers to provide intermediate connectivity. These vehicular nodes can communicate with other vehicles to establish Vehicle-to-Vehicle communication system. These nodes can also communicate with the access point (AP) to establish an Infrastructure-to-Vehicle communication system. A VANET network consists of four major components, namely Vehicles (nodes or mobile hosts), On-Board Unit, Road-Side Unit and Central management system [5].

Thus, VANET follows and applies the same principle of MANET in a highly dynamic environment of surface transportation. However, due to the high mobility of the nodes, VANET needs to consider dynamic information exchange and unreliable channel conditions. These considerations are absent in MANET. As a result, deployment of MANET protocols in VANET show poor performance [6]. Since the vehicles move along the road, movements of the vehicles are predictable in VANET, where network density changes over time and location [4].

According to the IEEE 802.11 independent basic service set (IBSS), no access point is required to communicate in distributed peer-to-peer manner and IBSS operation can occur if two nodes are within the radio range of each other. [5].

However, the radio spectrum scarcity has become more vigorous concern with the amplifying demand in wireless applications. To combat the growing demand of radio spectrum, proper utilization of the radio spectrum is essential. Cognitive radio exercises dynamic spectrum allocation technique to utilize radio spectrum efficiently and reduces the bottleneck on frequency bands. With the recent advances in cognitive radio systems [24-25], cognitive radio enabled vehicular users in VANETs would be able to sense and hop from one frequency to another (or one network to another) in the entire spectrum range based on their needs and operating environment with the help of cognitive radios. While several studies exist in literature on applying CR to wireless mesh networks, ad hoc networks, and cellular net- works, the research on applying CR to VANETs is still in its early stage. The research solutions proposed for general-purpose CR networks cannot be directly applied to CR-VANETs as the unique features of vehicular environment, such as the role of mobility, and the cooperation opportunities need to be taken into account while designing the spectrum management functions for CR-VANETs [26-27].

In this paper, Cognitive Radio Enabled VANET for multi-agent based intelligent traffic management system is proposed. The proposed system ensures data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band (5.85-5.925 GHz). In this model, vehicles can communicate with each other using available wireless resources with the help cognitive radio mechanism. Without the loss of generality, the proposed model is simulated and validated for some important performance communication metrics. In this paper, a cluster formation mechanism is considered for better accuracy in data transmission among vehicles. A skeleton for intelligent learning and decision mechanism for a central traffic management is also proposed and discussed in the scope of the model.

Rest of the paper is organized as follows. In section II, a brief analysis on different lately developed protocols for VANET Communications is discussed. The proposed network model and architecture for "Cognitive Radio Enabled VANET for Multi-agent Based Intelligent Traffic System" are described in section III. In section IV, the simulation results of the proposed model are presented. Conclusion and future works have been discussed in section V.

II. Related Works

Different protocols have been proposed for better performance in wireless networks for vehicular communications. OLSR sends two types of messages namely hello message and Topological control message [7]. This protocol gives better performance among the proactive routing protocols [8]. DSDV uses the shortest path to find the route to the destination and guarantees loop free nodes reduces count to infinity problem and also reduces control message overhead. This protocol is suitable only for smaller number of nodes [9].

Ad-hoc on-demand distance vector (AODV) protocol discovers routes only on demand i.e. it establishes a route only when any node needs to send a message to the destination. It offers low network overhead by avoiding the flooding of messages periodically in the network. It requires less memory size and the routing tables only contain the recent active nodes. AODV is flexible to highly dynamic and large-scale network [10]. Ad-hoc On-demand Multipath Distance Vector Routing (AOMDV) protocol maintains multiple loop free path with minimum overhead. It is suitable for high mobility nodes [11]. Dynamic Source Routing (DSR) protocol mainly consists of two mechanisms, namely route discovery and route maintenance and uses a unique id request in the route request packet [13]. Temporally Ordered Routing Algorithm (TORA) protocol uses multi hop routes. This protocol is based on the link reversal routing algorithm which uses directed acyclic graph to identify the flow of packets TORA's performance is better than DSR in highly dynamic ad-hoc environment [13].

Zone Routing Protocol (ZRP) is the first hybrid routing protocol, which divides the network into overlapping zones. It uses the proactive routing scheme inside the zone and reactive routing scheme outside the zone [14]. Core Extraction Distributed Ad-hoc Routing (CEDAR) is a protocol with integrated QoS support [15]. Distributed Dynamic routing algorithm Protocol (DDR) is a tree based routing protocol that does not require the root node support for data transfer. Greedy Perimeter Stateless Routing (GPSR) selects node closer to the destination-using beacon [17]. Greedy Perimeter Coordinator Routing (GPCR*)* is a position-based overlay routing protocol that uses greedy algorithms to forward packet based on a pre-selected path .It has been designed to meet the challenges of city scenarios. No Global Information System required for GPCR [18]. Connectivity- Aware Routing (CAR) is well suited for city and highway scenarios. It uses AODV for path discovery and PGB for data dissemination. It also uses guard concept for path maintenance. It ensures the shortest connected path and no digital map is required for CAR. It has higher packet delivery ration than GPSR [18]. GSR (Geographic Source Routing) is designed for city environment, uses greedy forwarding approach along pre-selected path using Djkshtra's shortest path algorithm. It combines the features of topological information and position based routing [19]. Recent cognitive radio based wireless mesh network related work either use the channel selection within a network [10] or transmit power or rate adaptation within a given network [11]. These types of solutions are not directly applicable in heterogeneous wireless environment since different networks have different characteristics. All of the aforementioned research works are related to protocol designing for VANET in CR, where routing protocol-integrated intelligent traffic management system is absent.

III. Proposed Model

A. Network Model

In the proposed model, it is assumed that there are two distinct scenarios in terms of nodes' density namely highly dense network and light dense network. A mobile vehicle is noted as node where mobile vehicles can be cars, buses etc. in the network. A sender node is defined as a particular node from where the data packets are coming and destination node is defined as the sink or the desired recipient of the data packets. A grid is defined as a geographical area with at least a Roadside Unit (RSU) and a predefined number of nodes with On-Board Units (OBU) installed into them. Here node density is the number of nodes in a grid and network is considered as the accumulation of all grids. A RSU is a hardwire mounted on top of a pole or tower in a grid, which is capable of maintaining simultaneous wireless duplex connections with nodes and Central Traffic Management Unit (CTMU). RSUs build a neural network with each other and the CMTU.

In a grid, there are two types of networks, which is labeled as Dynamic networks and Semi-dynamic networks. Dynamic network is created among nodes where nodes can move along a predefined manner and semi-dynamic network is created between a node and a RSU.

In a dynamic network, the nodes can communicate with each other using the principle of cognitive radio with the help of OBUs, which follow the IEEE 802.11p protocols. OBUs are connected with each other via wires or wireless networks. CMTU is the central management system, which periodically updates traffic conditions and sends relevant data to RSUs for proper route maintenance and nodal information to be displayed in Dynamic Info Board (DIB). A DIB is an info board from where nodal position and approximate speed and arrival time can be seen. It is mounted on the same pole of a RSU.

Data packet, in the model, follows a basic structure consisting of sender node id, destination id, hop count, timer, sequence number etc. The routing path for source to destination is determined by the greedy forwarding algorithm which means node closest to the destination node among all neighboring nodes in the transmission range of the sender node is selected as the next relaying node or the next hop. It is assumed that MAC protocol is TDMA, in which time is slotted and synchronized and to ensure proper sharing of the wireless resources, an appropriate scheduling algorithm is selected. For simplicity, rerouting mechanism (in case of link failure), packet collision probability (two nodes trying to send data packets to one node at the same time), nodes' mobility (speed) etc. are not considered in the scope of this paper.

B. Architecture:

The proposed model is an intelligent traffic management system mainly focused on city scenarios though it can be implemented in highways as well as rural areas.

In an arbitrary geographical location, it is assumed that there are some grids with some fixed RSUs. When a node enters a grid, it is automatically connected to the wireless network of that grid through its OBU. OBU then sends data packets to its nearby nodes or RSU. In a wireless ad-hoc network, a node can only send data packets if there is another node or the desired node within the transmission range of the sender node.

If the RSU is not in the range of the sender node, the data packets can be sent from the sender node to the destination node or RSU via intermediate nodes, which are labeled as relaying nodes.

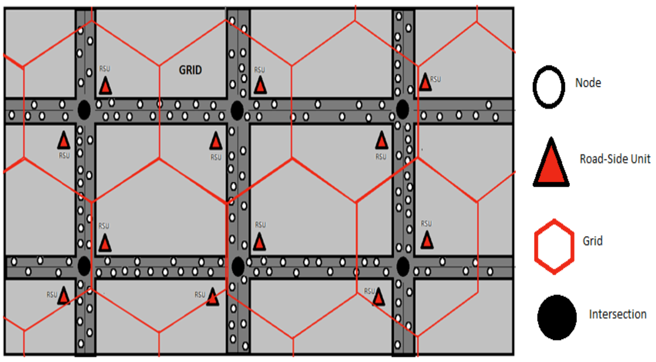

Fig. 1: The proposed traffic management system

A RSU picks up the data packets sent to it and extract the necessary information for traffic conditions in that grid and sends the data to CTMU for further processing. CMTU then processes the received data and sends the updated data to the RSUs. RSUs then display information of selected vehicles (local transports, ambulance etc) such as positions and approximate arrival time in DIB. An overview of advanced traffic system is shown in Fig 1.

Suppose a node "A", which is a local transport, enters a grid namely "XYZ". In XYZ, there are several nodes "B", "C", "D", "E" etc. "A" is then connected to a network label as "GHJ123" in which all other nodes are connected as well. In that grid, there is a RSU, labeled as "RSU1", at an intersection. "A" needs to send data packets to RSU1, but it is not in the range of "A". So, the data packets from A can be sent to RSU1 via B, C and D. RSU1 receives the data packets and sends to the CTMU. CMTU processes data and sends the updated data to the RSU1, RSU2, RSU3 etc. A basic network with links among nodes and RSU is shown in Fig. 2.

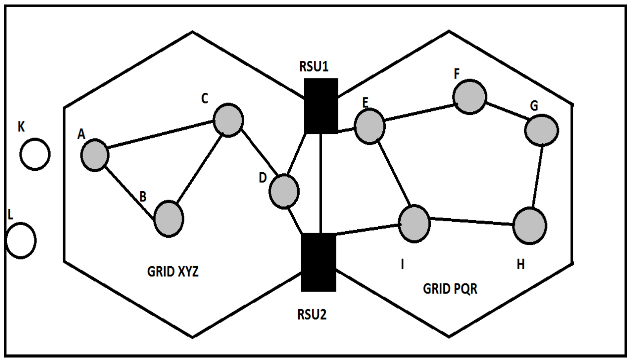

Fig. 2: Node view

According the mechanism discussed in the Network Model subsection, clusters form among the nodes to achieve better accuracy in data packet exchange. In a cluster, all links among the nodes have link-weight, which depend on the possession of available channels in cognitive networks. The node with greater link-weight is selected as the "Cluster head" and other nodes within the transmission range of the CM become members of that particular cluster. Cluster-head becomes responsible of transmitting data packets to the destination or to the next cluster through "Edge Members". Edge members are responsible for maintaining the links among clusters. To avoid data packets loss, a "Secondary Cluster head" is selected in case of unavailability of Cluster head. An example of cluster formation among nodes is illustrated in Fig. 3.

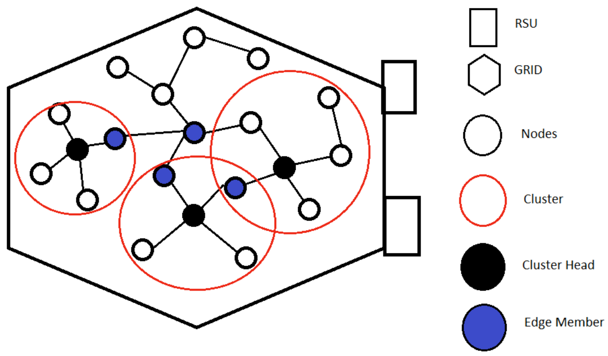

Fig 3: Proposed clustering scheme

On-Board Unit is a hardware implemented on the vehicles, which creates and maintains links with other nodes or RSU. It operates according to IEEE 802.11 protocols and it utilizes the available wireless resources such as bandwidth, channels etc. with the help of cognitive radio network mechanism. Though the OBU continuously consumes energy, as OBU is active while the vehicle is active, it is assumed that the node has sufficient power supply for it. The main task of the OBU is to sense spectrums and maximize the possibility to be online by using or sharing available bandwidth so that it can broadcast its data packets to the destination node.

A DIB is a board, which displays some basic real time information about the partial grid traffic and local transports. It is connected to the RSU on which it is mounted. Whenever the RSU is updated from the CMTU, updated information about some specific vehicles shows up on the DIB. It shows approximate location, time of arrival, accidents etc.

CMTU is the main server or the accumulation of several main servers, which controls the whole traffic system. It is connected with the RSUs via wire or wireless connections and builds a neural network. CMTU has an intelligent learning and decision-making algorithm, which extracts necessary data from the data, received from the RSUs and updates its database for future decision-making. CMTU then updates the RSUs and the specific updated data for specific route is shown in the DIB of specific RSU. CMTU allocates time intervals in intersections based comparison in previous data and the updated data in its database.

C. Cluster formation

With the mounting interest on cognitive radio (CR) technology in wireless communication systems, it is anticipated that CR-enabled vehicular networks may improve the vehicular communication efficiency. Thus, considering cognitive radio technology, the dynamic module of the proposed network model is designed to be functional on cognitive radio environment. As discussed earlier in the network model section, the dynamic vehicular network in each grid is divided into some sub-groups or clusters. Clustering concept is introduced in the dynamic module as cluster-based ad-hoc network aims to achieve better accuracy in data packet exchange.

The proposed clustering mechanism is inspired from author's previous spectrum aware clustering scheme for cognitive radio ad-hoc network [20-22]. In the existing clustering mechanism, cluster-head selection is based upon a weight, where to calculate the weight number of common channels and number of neighboring nodes is taken into consideration. However, in this paper another parameter has been taken into account called node's speed along with the previous two to calculate weight for each node.

Once the weight calculation for each node is completed, the node with higher weight is selected as the "Cluster head" and other nodes within the transmission range of the Cluster-head (CH) become cluster members of that particular cluster. Cluster-head becomes responsible of transmitting data packets to the destination or to the next cluster through "Edge Members". Edge members are responsible for maintaining the links among clusters. To avoid data packets loss, a "Secondary Cluster head" is selected in case of unavailability of Cluster head. An example of cluster formation among nodes is illustrated in Fig. 3.

In the clustering scheme, CH defines and upholds operating channels for the cluster. To find the existence of any other clusters in the neighborhood, CMs check their neighbor list for other cluster heads. CM becomes the Edge Member (EM) and connects two clusters once it finds other CH in the neighbor list. In the proposed clustering scheme, cluster consists of one CH, one SCH and CMs. All cluster members are 1-hop apart from the CH. EM connects two neighboring clusters, where there can be maximum two intermediate EMs between two CHs. Using local common channels, intra-cluster communications are performed.

IV. Simulation Results

A. Simulation Environment

To evaluate the clustering performance of the dynamic module (vehicle-2-vehicle) of the proposed model, simulation is conducted. Though several network simulators are available, whose output depicts as close as possible to real time implementation, to simulate and analyze performances of the proposed model, discrete-event simulator NS2 has been used and the performance analysis are conducted using PERL scripts.

Two parameters, namely energy consumption and overhead are considered as the performance metrics to evaluate the performance of the network. Moreover, two distinct dynamic scenarios in terms of nodes' density are considered for the comparative study in the simulation environment. Thus, in one scenario the radio transmission range of a node is considered to be 100 meters and in the other scenario, the transmission range is set to 500 meters. For both scenarios, number of nodes is considered to be 100 where distributed sources and sinks are altered randomly.

A simulation area of 4000 m^2 is considered for the simulation purpose. The Two-Ray Ground model is used as the propagation model and Drop-tail method is used for the queuing purpose. MAC/802.11p is considered as the MAC type and maximum packet queuing delay is considered as 50ms. In the simulation, data traffic is generated with Constant Bit Rate (CBR) with packet size is set to 512 bytes. Varied packet rate ranging from 100 packets/sec to 800 packets/sec is considered to evaluate the performance of the network for different traffic load. Initial energy for all the nodes is considered to be 10 Joules. Maximum speed for the nodes is considered to be 10 m/s. The simulations are run for 150s each and the results are calculated as mean of several observations in light dense dynamic environment and heavily dense dynamic environment.

B. Performance Evaluation

This section of the paper discusses the simulation results of the proposed model in terms of energy consumption and overhead.

1. Performance based on Energy consumption

In this paper, energy consumption is defined as the cumulative sum of consumed energy by all the nodes of the network during the entire transmission period, where consumed energy of a node is calculated by subtracting remaining energy from initial energy. The unit for energy consumption has been considered as Joule. Minimum energy consumption is desirable while designing the routing protocol for the proposed dynamic network. In the simulation environment, consumed energy of a node mainly depends on the functional period of a node to transmit the data packets to its next hop. Moreover, network energy consumption also depends on the number of relying nodes while transmitting packets. In Fig. 4, the horizontal axis indicates the traffic load and the vertical axis indicates the consumed energy.

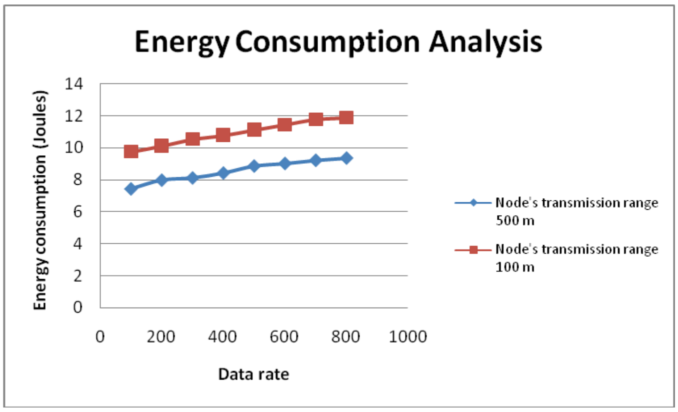

Fig. 4: Performance Evaluation in Terms of Consumed Energy

From the figure, it is seen that the energy consumption increases with increasing data flow rate in both scenarios. The reason is that when traffic load is increased, more data packets need to be transmitted over the network from the source node to the destination node, where the intermediate nodes are required to be at the active state for longer period of time. As consumed energy of a node is considered to be dependent on the functional period, therefore with increasing traffic load, energy consumption is also increased in both networks.

Moreover, it can also be seen from Fig. 5 that the energy consumption is lesser in a network with radio transmission range of 500 meters compared to the network with radio transmission range of 100 meters for all different traffic loads. This is because, when radio transmission range in a network is longer, number of hops from the source to the destination tends to be lesser than that of a network of shorter transmission ranged radios. Thus, a network with long ranged transmission results lesser number of intermediate nodes between a source and the destination than the network with short ranged transmission. Therefore, energy consumption remains lesser in a network with longer transmission ranged radios as lesser number of intermediate nodes is engaged to forward the data packet from the source node to the destination.

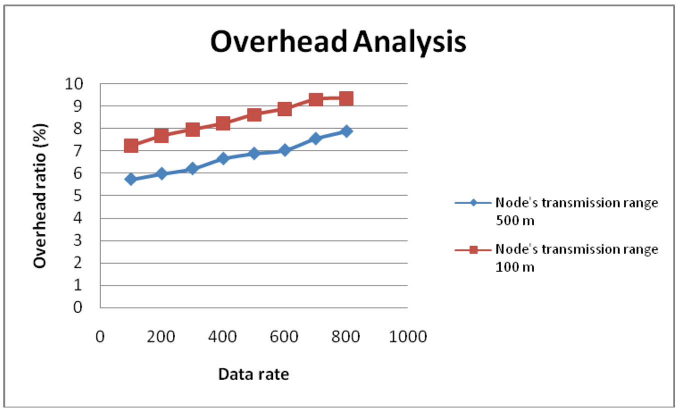

Fig. 5: Performance Evaluation in Terms of Overhead Ratio

2. Performance based on Overhead Ratio

The network overhead is considered as the sum of transmitted control packets during the transmission sessions. Thus, network overhead ratio is defined as the total transmitted control packets over total received data packet at the destination node. In Fig. 5, the network overhead ratio is presented in terms of percentage, where network overhead ratio is desirable to be minimum while designing the routing protocol for the proposed dynamic network. In the figure, the horizontal axis indicates the traffic load and the vertical axis indicates the network overhead ratio.

From the figure, it is seen that the overhead ratio increases with increasing data flow rate in both scenarios. The reason is that when traffic load is increased, more data packets need to be transmitted over the network from the source node to the destination node. In a wireless ad-hoc network, each node has a defined data packet queuing delay. Increase in data rate means nodes need to process more data packets individually which eventually results in reduction of a node's efficiency for packet forwarding. As a result, with the increase of traffic load, retransmission of data packets from source node to destination node increases and therefore, acknowledgement control messages for retransmission to source node and from destination node increase, network overhead increases. Thus, with the increase in traffic load, the network overhead ratio increases.

Moreover, it is also observed from Fig. 5 that the overhead ratio is lesser in a network with radio transmission range of 500 meters compared to the network with radio transmission range of 100 meters for all different traffic loads. That is because, nodes in a network with shorter radio transmission range will need more number of relaying nodes for transmitting data packets to the destination node from the source node than that of with longer radio transmission range. As the number of the nodes is comparatively more, more nodes will have to process increased traffic load and as a result, retransmission of data packets due to exceeding node's capacity to process data packets will increase which eventually increases number of transmitted control packet. Thus, a network with radio transmission range of 100 meter will have more network overhead ratio than that of a network with radio transmission range of 500 meters.

V. CONCLUSION AND FUTURE WORKS

This paper presents a Cognitive Radio enabled VANET for multi-agent based intelligent traffic management system. The proposed model has two distinct information exchange system layouts, namely dynamic module (vehicle to vehicle communication using cognitive radio) and semi-dynamic module (vehicle to Road-Side-Unit). For the dynamic module, a cluster formation scheme is introduced and later simulation is conducted to validate the performance. Our next research steps are to develop the prototype of the model and to develop an intelligent algorithm that can give optimal decision to manage the traffic.

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