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Link stability based multipath routing and effective mobility prediction in cognitive radio enabled vehicular ad hoc network

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ABSTRACT

Vehicular ad hoc networks (VANETs) provide a robust infrastructure for intelligent transportation system (ITS) applications. VANET communication involves vehicle-to-vehicle and vehicle-to-infrastructure connections, primarily with roadside units (RSUs). Analyzing cognitive radio (CR)-VANET studies revealed two key performance issues: high energy consumption and latency. To address these challenges, we propose a novel approach: link stability and mobility prediction-based clustered CR-VANETs, known as LMCCR-VANET. LMCCR-VANET consists of four main components: CR-VANET construction, clustering model, speed-based mobility prediction, and link-based multipath routing. Initially, we establish cluster-based CR-VANETs to analyze and mitigate spectrum scarcity and power utilization problems in VANETs. Mobility prediction evaluates vehicle speed variations and predictions. Finally, employing link stability-based multipath routing (LSMR) in conjunction with the fuzzy interference model and ad hoc on-demand multipath distance vector (AOMDV) routing protocol ensures stable and efficient routing. Experimental results showcase the superiority of LMCCR-VANET. It exhibits enhanced energy efficiency, delivery rates, reduced energy consumption, end-to-end latency, and routing overhead when compared to recent works such as SCCR-VANET, CFCR-VANET, and MMCR-VANET.

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1. INTRODUCTION

Nowadays vehicular ad hoc networks (VANETs) become an important part of the intelligent transportation system (ITS) based application. The communication is performed in VANETs through a dedicated short-range communication with the IEEE 802.11 and IEEE 1609.4 as well as it helps to carry out the basic communication modules of VANETs such as vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication [1]. The usage of vehicles is enormously increased which provides the way to the creation of new technologies and algorithms as well as spectrum utilization and allocation in VANETs has become a complicated task. For that reason, a key enabling technology called cognitive radio (CR) is introduced in VANETs that allows devices to sense and use the spectrum and the licensed channels. CR-VANETs help to reduce the complicity which is created due to spectrum scarcity and they can able to provide safe road traffic and low congestion during the usage of next-generation autonomous-driving vehicles [2]–[4]. CR technology is an effective solution to overcome the spectrum-related issues in the network because in general in CR the users are split into two separate categories which are licensed part of the system called primary users (PUs) and unlicensed part of the system called secondary users (SUs). In CR, to find the PUs, the SUs initially perform the spectrum sensing process and it works in the inactive spectrum band without disturbing the PUs. To make the vehicles more intelligent CR enabled VANETs (CR-VANETs) are introduced where the data transmission is performed in the idle spectrum band [5]. Clustered CR-VANETs perform reliable broadcast so that they can able to increase the coverage area of the vehicles and perform communication with lower energy consumption [6]. In terms of the real-time issues such as higher routing overhead and high latency reflects in the creation of complexity in the system [7]. So, it is very essential to develop a model which concentrates on the effectiveness of the system. For that purpose, in this paper, extended link stability and mobility pattern-based clustered CR-VANETs are proposed and as well the research contributions are elaborated.

To enhance the communication quality of the CR-VANETs a new model is introduced in the proposed research namely the link stability and mobility prediction-based clustered CR-VANETs (LMCCR-VANET) approach and it mainly concentrates on the drawbacks such as high energy consumption, end-to-end connection latency, and overhead occurrences during data transfer. To overcome these drawbacks clustered CR-VANETs initiated two segments, they are mobility prediction and extended link stability-based routing. Through mobility prediction, the vehicle speed is analyzed in real road traffic environment and it helps to find an effective neighbor to perform communication. Through an extended link stability creation model multipath routing is performed. It is the combination of fuzzy interferences model which uses the Kalman filter to perform linear filtering to understand about the connection stability with ad hoc on-demand multipath distance vector (AOMDV) routing protocol. The remaining sections of the article are arranged as follows, the earlier research about CR-VANETs and their characteristics are analyzed in section 2. In section 3 LMCCR-VANET approach is elaborated. In section 4, the proposed work experiments in network simulator 2 (NS2) and the results are discussed. Finally, section 6 concludes the effectiveness of the proposed approach with suggested future direction.

2. RELATED WORKS

Several earlier studies are developed in cluster-based VANETs and CR-VANETs as well some of them are discussed in this section. They are, clustering of the VANETs in a highway environment [8], clustering oriented rouing model and in gets enhanced with the help of modified K-means method [9], efficient cluster head selection (ECHS) [10], fuzzy logic-based clustering control technique [11], in recent works clustering concept is combined with the medium access control (MAC) layer protocols to improve its efficiency [12], to reduce the power utilization and control the vehicle speed the connectivity prediction based clustering model with dynamic connectivity is developed [13], dual-slot transmission with mobile edge computing (MEC) [14], cluster-based resource management system [15], to minimize the broadcast overhead during communication the novel scheme is developed in VANETs called emergency message dissemination [16], to improve vehicles reliability during data transmission in real roads anovel idea id developed namely diverted path approach [17], destination-aware context-centered routing architecture [18], to optimize the power utilization in VANETs the concept of multi-hop clustering is developed [19], clustering particle swarm optimization (PSO)-based V2V routing method [20], clustering approach based on self-adaptive multi-kernel clustering [21], to develop a noise free and adaptive network structure in VANETs both novel clustering and adapted ordering points are built [22], effective channel selection in CR-VANETs [23], fuzzy cluster head (CH) selection scheme in CR-VANETs [24], and later multiple user based several inputs and outputs are collaborated with clustering model with the novel idea of cooperative spectrum sensing in CR-VANETs [25]. Once after analyzing the earlier research, it is understood that the CR-VANETs suffer from communication link failure, high energy consumption, and packet loss. To overcome this drawback in this research, extended link stability and mobility pattern based clustered CR-VANETs and it is elaborated on in the section.

3. LMCCR-VEHICULAR AD HOC NETWORKS APPROACH

The proposed LMCCR-VANET is developed to achieve effective communication in dynamically moving CR-VANETs. For that reason, mobility prediction and extended link stability calculation is performed in it. The flowchart of the proposed LMCCR-VANET approach is shown in Figure 1.

In general, clustering is defined as the grouping activity where the network is grouped into a certain region and one among the node in that region is chosen as the CH and others are declared as its child. This idea is incorporated with CR-VANETs to improve network control in terms of dynamic speed. Once the SUs enters the network with the dynamic speed that time cluster mechanism is introduced in CR-VANETs to control the communication in the system. The parameters mainly used in the process of CH election in CR-VANETs are vehicle connectivity (C_v), vehicle velocity (V_v), vehicle acceleration (A_v), and vehicle distance (D_v). The mathematical expressions which are considered for these parameters are described in Table 1.

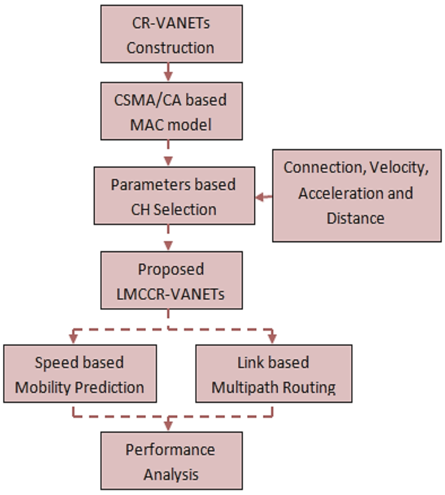


Figure 1. Proposed LMCCR-VANET approach

Table 1. Equations for the parameters

S. No	Parameters	Mathematical expressions
1	C_v	$C_v = Deg_v$
2	V_v	$V_v = \frac{1}{Deg_v}\sum_{n=1}^{Deg_v} \lvert v_1 - v_2 \rvert$
3	A_v	$A_v = {V_v}/{t_0}$
4	D_v	$D_v = \frac{1}{Deg_v}\sqrt{(A_{v_1} - A_{v_2})^2 + (B_{v_1} - B_{v_2})^2}$

In Table 1, the terms Deg_v imply the degree of the vehicles and the attributes used for the calculation of the distance are (A_{v_1}, B_{v_1}) and (A_{v_2}, B_{v_2}). According to the values of these parameters, the mobility rate of the vehicles is analyzed and the CH is chosen. The CH tries to cover the maximum of the roadside unit (RSU) and it acts as an intermediate between the RSU and the base stations (BS).

3.1. Mobility prediction in cluster cognitive radio vehicular ad hoc networks
3.1.1. Mobility speed variation

In this section, the variable speed of the CR-VANETs is analyzed by considering two speed range values (50–100 and 100–150 km/h) of large mobility-based SUs. The difference in speed variation among the SUs is 10 to 50 km/h which are fixed based on their speed characteristic in real traffic environments. In CR-VANETs, SUs aremainly utilized to travel in fixed transmission range $FT_{range} = 300\,m$, using this parameter any two vehicle connectivity (SU_1 and SU_2) is calculated in (1). The speed of the SUs, SU_1 and SU_2 is declared as 105 and 99 km/h respectively. Using those parameters, the total connectivity between the SUs SU_1 and SU_2 calculated in (1):

$$TC_{(SU_1,SU_2)} = \left(\frac{FT_{range}}{SU_1 - SU_2}\right) \times 2 = \left(\frac{300}{105-99}\right) \times 2 = 50 \times 2 = 100secs \quad (1)$$

According to the speed calculation the simulation is performed in the CR-VANETs with the consideration of a 20 km real road traffic scenario. In the simulation experimentation, 1,000 vehicles are used for the 10 km segment the vehicles are densely connected and the communication range of each vehicle is declared as 300 m. At the initial stage of data transmission, each SU periodically transmits the beacon packets to find its respective PU or RSU as well as its positioning coordinates. Once receiving the IDs, the respective PU or RSU establish the link to perform active communication among them. In case no PU or RSU is present in the coverage area of the SU then it performs one hop communication to reach it by selecting its best neighbor which is present in the line of sight to the PU or RSU to forward the data.

3.1.2. Speed-based mobility prediction

The mobility of the SUs is predicted using its signal strength of it. During the process of initial routing using AOMDV routing protocol, beacon packets are transmitted to get the signal strength. As per the simulation, the two-ray ground reflection model is used as a radio propagation model when the distance is measured and it is mathematically expressed in (2):

$$SP_{(PU,RSU)} = \left(\frac{SP_{SU} \times G_{SU} \times G_{(PU,RSU)}}{d^2}\right) \quad (2)$$

In (2) the terms $SP_{(PU,RSU)}$ *and* SP_{SU} imply the destination and sender signal power, G_{SU} and $G_{(PU,RSU)}$ implies the antenna gain of the receiver and transmitter respectively and d implies the transmitter and receiver distance. Using (2) the for distance is calculated (3):

$$d = \sqrt[2]{(G_{(PU,RSU)} \times G_{SU})\frac{SP_{(PU,RSU)}}{SP_{SU}}} \quad (3)$$

Using (3) the SU can able to predict the suitable path to reach the PU or RSU. The routing is performed using the AOMDV protocol and the transfer details are get stored in the routing table for future decision-making purposes.

3.2. Link stability based multipath routing routing model

Link stability based multipath routing (LSMR) is the combination of the fuzzy interference model and the AOMDV protocol. Routing in extended link stability and mobility prediction-based clustered CR-VANETs (ELSMR) is performed in terms of the motion parameters such as vehicle speed, vehicle angle, vehicle connectivity as well as path and data control. The link stability of the vehicle to indirectly proportional to the movement of the vehicle and it is highly influenced by it. Hence the vehicles in the CR-VANETs network consist of highly dynamic vehicles the speed calculation becomes difficult due to the interference of the noise factor. For that purpose, fuzzy logic has been combined with the AOMDV protocol.

The major parameter which is considered in the ELSMR routing is speed prediction which is carried out using the help of the Kalman filter (linear filtering-based prediction method). To validate the input and the output of the system the linear equations (state and measurement) are utilized. The speed prediction using the Kalman filter is illustrated in the pseudo code.

Algorithms 1: pseudo-code of Kalman filter-based speed prediction

START

Input Terms: X(t)→state of time, C(t)→control amount for state of time, M_1 *and* M_2 →system parameters, Y(t)→measured value of time, H→Parameter of the system measurement, N_1 *and* N_2 →noise and C_1 *and* C_2 →convergence values;

Output Term: $P(t|t) \rightarrow$ Updated Convergence filter equation for prediction

- State equation $= X(t) = \{M_1 * X(t-1)\} + \{M_2 * C(t)\} + N_1(t)$
- Measurement equation $= Y(t) = \{H * X(t)\} + N_2(t)$
- Initial prediction equation $= X(t|t-1) = \{M_1 * X(t-1|t-1)\} + \{M_2 * C(t|t-1)\}$
- Convergence equation (Prediction) $= P(t|t-1) = \{M_1 * P(t-1|t-1)\}M_1 + C_1$
- Convergence filter equation $= X(t|t) = X(t|t-1) + \{G_{KF}(t) * Y(t)\} - \{H * X(t|t-1)\}$
- Kalman filter gain $= G_{KF}(t) = {\{P(t|t-1) * H'\}} / {\{H * P(t|t-1) * H'\} + C_2}$
- Updated Convergence filter equation $= P(t|t) = \{1 - G_{KF}(t) * H\} \times P(t|t-1)$

STOP

In the ELSMR routing protocol, according to the current speed of the vehicle, the velocity is measured. To minimize the difficulty in the calculation of speed and velocity the Kalman filter is used. According to the fuzzy interference model, the connectivity strength of the vehicles is predicted and the optimal path gets selected with a minimum number of intermediate vehicles using the AOMDV routing protocol. During the time of data transmission among the vehicles (sender and receiver), the routing table is empty. Then the source broadcast a route request (RREQ) to its neighbor vehicles (n) which are in the line of sight to the destination. The process gets continued when RREQ reaches its corresponding destination. The intermediate vehicle (n) is chosen according to the fuzzy interference model and the Kalman filter-based speed prediction approach. Through this process, the connectivity strength among the links is predicted and the weaker links get discarded. Once the RREQ reaches its destination then the vehicles transmit the route reply (RREP) in the same path to reach the source.

4. RESULTS AND DISCUSSION

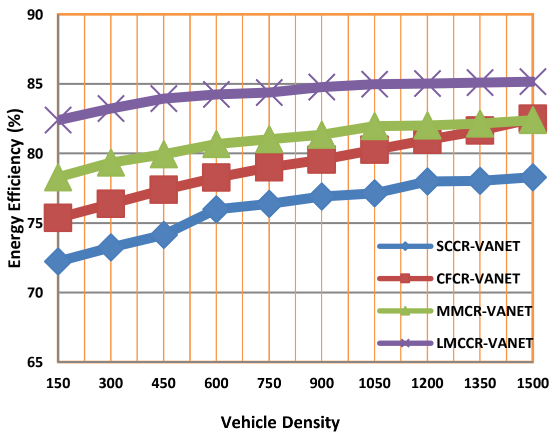
The experimentation of the proposed LMCCR-VANET approach has been implemented in the simulation using the software environment called NS2. During the process of simulation, many observations are performed and the average results among them are considered for the performance evaluation as well as the comparative analysis. Consequently, the performances of the LMCCR-VANET approach are compared with the earlier research such as super cluster based optimum channel selection for CR-VANET (SCCR-VANET) [23], cluster head stability using fuzzy in CR-VANET (CFCR-VANET) [24], and multi-user multiple-input and multiple-output based CR-VANET (MMCR-VANET) [25] in this section. Furthermore, the parameters which are considered for the performance assessments of these protocols are energy efficiency and packet delivery ratio.

4.1. Energy efficiency calculation

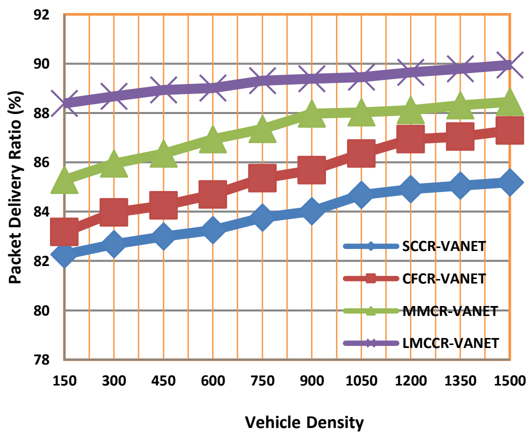
It is defined as the measure of the residual energy which is present at the end of the simulation for all the vehicles which are involved in the process of data transmission. Figure 2(a) demonstrates the performance of the LMCCR-VANET approach with the other approaches. An increase in vehicles density reduces the network efficiency however the LMCCR-VANET achieves stable energy efficiency during data transmission. The energy efficiency completed with the aid of using the proposed LMCCR-VANET method is 85.16% whilst in comparison with the previous strategies such as SCCR-VANET, CFCR-VANET, and MMCR-VANET it reaches as much as 78.29%, 82.49%, and 83.39% respectively. So, the efficiency of LMCCR-VANET method is 2% better than MMCR-VANET and 3% better than CFCR-VANET, and 7% better than SCCR-VANET.

4.2. Packet delivery ratio calculation

It refers to that total number of received information (packets) at the destination to the total number of transmitted information at the source during the process of communication. It is the primary metric that directly increases the effectiveness so the LMCCR-VANET exclusively concentrates on the increment of the delivery ratio and of course from Figure 2(b) it is proven that the LMCCR-VANET approach achieves high data delivery when compared with the earlier approaches. The delivery ratio of LMCCR-VANET method is 89.95% whilst in comparison with the previous strategies such as SCCR-VANET, CFCR-VANET, and MMCR-VANET reach as much as 85.19%, 87.29%, and 88.45% respectively. So, the delivery ratio of the LMCCR-VANET method is 1% better than MMCR-VANET, 2% better than CFCR-VANET, and 4% better than SCCR-VANET.



(a)



(b)

Figure 2. Comparing simulation results of earlier methods with proposed LMCCR-VANET concerned with vehicle density for the parameters (a) energy efficiency and (b) packet delivery ratio calculation

5. CONCLUSION

To enhance the efficiency of CR-VANETs, clustering is incorporated into it. To minimize the power utilization, delay, and communication overhead of CR-VANETs a novel approach is introduced namely extended link stability and mobility prediction based clustered CR-VANETs are proposed. This model is mainly designed to concentrate on vehicle mobility and connectivity. For that purpose, mobility prediction and link stability detection are performed. Effective routing is achieved using the fuzzy interference model with the AOMDV routing protocol. The simulation is carried out in NS2 with a simulation of urban mobility (SUMO) environment. The parameters which are considered for the performance analysis are energy efficiency and packet delivery ratio, and as well it is compared with the others such as SCCR-VANET, CFCR-VANET, and MMCR-VANET. From the comparative analysis, it is understood that LMCCR-VANET approach achieves 7% better energy efficiency and 4% better packet delivery ratio when compared with the earlier approaches. In the future direction to improve the network security, cryptography model will get concentrated.

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