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Cognitive Radio Assisted OLSR routing for Vehicular Sensor Networks

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Abstract

Vehicular Sensor Network (VSN) emerged due to recent developments in Wireless Sensor Network (WSN) and functioning as a way for observing metropolitan environments and enabling vehicles to share relevant sensor data to assist safety, convenience and commercial applications. Data dissemination is an important aspect of these networks and requires timely delivery of important sensor information. In VSNs, rapid mobility of the vehicles causes recurrent topography modifications. The possibility of on-demand protocols that makes routing decisions reactively in Vehicular Networks are restricted owing to its structural instability and current routing protocols, operating in a table-driven fashion like OLSR are unable to cope up with the high demands imposed by vehicular applications. Furthermore, sensor data transmissions are accompanied by rapid fluctuations in the convention of licensed spectrum and acquire more number of channels to transmit huge bandwidth data and result in spectrum scarcity. Existing works on OLSR protocol failed to examine spectrum conditions and calculate utilization of channel. Cognitive Radio (CR) is a possible solution for guiding OLSR to discover unused frequency bands and utilize them opportunistically. This paper presents an optimal OLSR routing for efficient data communication using Cognitive Radio enabled Vehicular Sensor Networks (CR-VSNs). The proposed model was tested under simulated traffic of Chennai urban road map. Delay is observed to be minimal for data communications in CR-VSN.

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Keywords: Channel Assignment; Cognitive Radio; Link Stability; Optimized Link State Routing; Vehicular Sensor Networks.

1. Introduction

In recent years, Vehicular Sensor network (VSN) has drawn people's interest with its ability to provide inter-vehicular communications, and communication between roadside sensors and the vehicles. Sensors are installed along the roadside to gather environmental data such as urban road conditions (e.g. vehicular traffic, crowd density), air quality monitoring and transmit the observed data to the vehicles which fall inside the data transmission range of the sensor node or route the information to appropriate sink nodes. During such data transmissions, massive channel utilization tends to amplify the data traffic load to higher numbers. Cognitive Radio (CR) alleviates the issue of channel scarcity and provide as a backbone for high bandwidth communication in VSNs. The CR enabled vehicles are used as data forwarders to forward sensed information to their corresponding neighbor vehicles by accessing the spectrum holes that constitute unused channels. Major issue arises due to high mobile nature of the vehicles in VSNs

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which heavily affects the Packet Delivery Ratio (PDR) by dropping huge number of packets due to constant topology change of the network. Due to recurrent topology change and frequent detachment of neighbor links makes it hard to model a capable routing protocol for forwarding data to neighboring vehicles. The majority of the routing solutions proposed in the literature for WSNs are not suitable for VSNs because of rapidly varying wireless links between nodes and faces challenges in maintaining routing path due to vehicle mobility. However, energy is not a primary concern for VSNs since vehicles carry large capacity batteries unlike conventional WSNs that constitute low-cost devices. Therefore, maximizing the utilization of VSNs[12] and[13] can be accomplished by searching good routing algorithm among those proposed for VANETs. The classification of routing protocols in Vehicular networks fall into two categories, namely topology based and position based. This research attempt targets the dynamic nature of VSN topology and hence will focus on topology based routing protocol which are divided into proactive and reactive. Reactive routing protocols have failed to cope up with highly dynamic nature of vehicular network because the delay in finding appropriate route is very high because of its reactive nature and thus unfit for VSNs. The majority of routing mechanisms in Vehicular networks most likely rely on table-driven proactive protocols instead of on-demand reactive protocols since proactive routing could cope with the rapid mobility which leads to frequent network partitions and reduces delay in finding the next best link in case of link failure. Optimized Link State Routing protocol (OLSR) which is a traditional ad hoc routing protocol comes as the first choice proactive routing protocol because of its capability to display low latency and enhance delivery ratio of packets in frequently changing topology. Though, the current optimizations of OLSR does not consider channel load as a metric in calculating routing paths because of its inability to detect spectrum conditions and has suffered from frequent path breaks. Bandwidth utilization has tremendously increased in recent years due to high vehicle mass and resulted in intense competition for channel access. OLSR is still finding ways to conquer the channel insufficiency problems and the quickly varying spectrum conditions comes as an additional overhead in finding alternate paths. CR is a promising solution to handle channel scarcity problems and efficiently manage spectrum utilization in vehicular transmissions. CR senses the wireless spectrum licenses to primary users (PUs) and identifies unused channels which we refer to as spectrum holes. During data communication, secondary users (SUs) are allowed to acquire the unused portion of spectrum for transmission without causing any interference to PU activities. The vehicles enabled with CR could utilize the idle channels to forward data among its neighbor vehicles for sensor data communication. This would enable high bandwidth communication, which further reduces the delay of sensor information to reach the sink node and thus allows them to respond quickly. Thus, OLSR assisted CR-VSN is allowed with legal spectrum access and the difficulty of OLSR to calculate dynamic routing paths considering varying spectrum conditions are resolved. The channels allotted for IEEE 802.11p standard that supports inter-vehicle data transmission in VSN are inadequate to satisfy the growing demands of VSN applications. Hence to reduce channel contention, there is requirement to increase channel availability to improve high speed dependable data communication.

The cognition ability to OLSR is given by CR for dynamic optimal channel selection and allocation among available idle channels. Rapid mobility of nodes results in repeated spectrum fluctuations that further increase the complexity of allocating the best channel among available multiple channels from PUs to SUs. Hence, the challenge is to model OLSR routing protocol to efficiently manage spectrum allocation that helps reduce the routing delay. The following issues related to vehicular routing are addressed by this research paper:

- Frequent routing path breakages due to highly dynamic topology have resulted in minimal connectivity time of the vehicular links and lead to unstable paths from source vehicle to destination vehicle. Importantly, vehicles travelling in opposite directions will have very less connectivity time and hence appropriate mechanisms must be in place to enhance the transmission time of two communicating vehicles.
- OLSR suffers from channel scarcity problem caused by inadequate channels due to vehicle mass and high mobility of vehicles and results in frequent link disconnections. Suitable channel allocation techniques must be deployed in OLSR routing to find next best hop with improved link transmission time.

2. Related Works

To efficiently propagate multi-hop information in VSNs, literature survey explores both OLSR routing and CR assisted routing mechanisms in vehicular networks. Although certain routing techniques having different forwarding characteristics are rising for deployment in Vehicular topology, only limited studies have presently reassessed the idea of using OLSR in such high mobile scenarios. Wahab *et al.*[2] proposed a method that maintained the stability during communications and link failures by forming stable clusters and thus addressed the problem of clustering in VANETs while satisfying the Quality of Service requirements. The authors[3] evaluated the cost of spectrum occupation caused by the OLSR routing protocol as a method of various parameters such as the propagation range and occurrence rate of the control messages, vehicle density and the carrier sense area in a linear VANET. Toutouh *et al.*[4] used a parallel evolutionary algorithm to search for energy-efficient OLSR configurations to tackle the issue of minimizing the consumption of power of the OLSR routing protocol in vehicular networks. Belhassen *et al.*[5] sustained the stability of selected routes in the context of an urban VANET with obstructing obstacles by utilizing the awareness about location of nodes. Certain Nature-inspired algorithms[6] were studied for solving an optimization problem to construct a more capable OLSR in ad hoc network. The authors[7] reduced the searching complexity of optimal channel selection and improved the transmission performance over each hop by exploiting the geographic location information and discovering the local spectrum access opportunities. Pan *et al.*[8] maximized the capacity of the link on the chosen spectrum portion by allowing each CR to adjust their transmission power and build real-time decisions on channel and power allocation on the basis of locally gathered information. The authors[9] proposed a protocol that adapts to any changes of the network scalability by dynamically changing the paths and the channels that are used for transmission and developed an accurate channel model to evaluate the signal strength in different areas of the environment. An efficient channel allocation method[10] was used to reduce co-channel interference, routing overhead and achieving lesser energy consumption during multi-hop routing between CR sensor nodes. Shah *et al.*[11] provided energy efficient multimedia delivery with the preferred QoS support and exploited clustering to manage dynamic spectrum access. The major issues in the existing optimization schemes applicable to OLSR protocol are the reactive protocols failing to cope up with the frequent topology changes in Vehicular networks. Existing OLSR suffers from drastically varying spectrum conditions and workload, hence experiences wider delay distributions. OLSR failed to utilize channel conditions to dynamically calculate alternate paths and failed to account both high mobility and link lifetime in making routing decisions. The above issues have been overcome in the proposed system by enabling sufficient cognitive ability for self optimization.

3. Proposed Model

Typical VSN structure is formed by source sensor nodes, data sinks, source and destination vehicles, non-participating vehicles and a group of Multi-Point Relay (MPR) nodes which form a subset of prechosen vehicles used to execute topological advertisements and to perform forwarding and broadcasting control messages comprising routing information thus reducing overhead. The roadside access points of the residential 802.11 a/b/g are the licensed users and vehicles constitute the unlicensed users. Using MPRs, the source sensor node or the vehicle functions as a source and broadcast the control information. To transmit the data packets from the source to destination, the MPR vehicles, which is the subset of the chosen neighbor vehicles by each source to access all the two-hop neighbors act as forwarders. The functional architecture of C-OLSR routing protocol is shown in Fig. 1. To transmit the data packets from the source to destination, the MPR vehicles, which is the subset of the chosen neighbor vehicles by each source to access all the two-hop neighbors act as forwarders. The functional architecture of C-OLSR routing protocol is shown in Fig. 1. The network topology is refreshed by every node in the network using OLSR as a function of the routing procedure. MPR vehicles are used to minimize the control message overhead in VSN. Each vehicle maintains an MPR-selector list, which keeps track of the vehicles for which it functions as MPR and every MPR distributes its MPR-selector list for building routing table. HELLO packets, which are broadcasted periodically among neighbor nodes, are used to construct this list.

4. Best Channel Allocation

The segment introduces the Best Channel Allocation (BCA) technique for selection and allocation of the optimal channel for the SU. The co-channel impedance, the attribute of the link, the conduct of PUs and the rapid mobility of vehicles are the significant elements in guaranteeing the efficiency of the channel. Let us consider that the co-channel

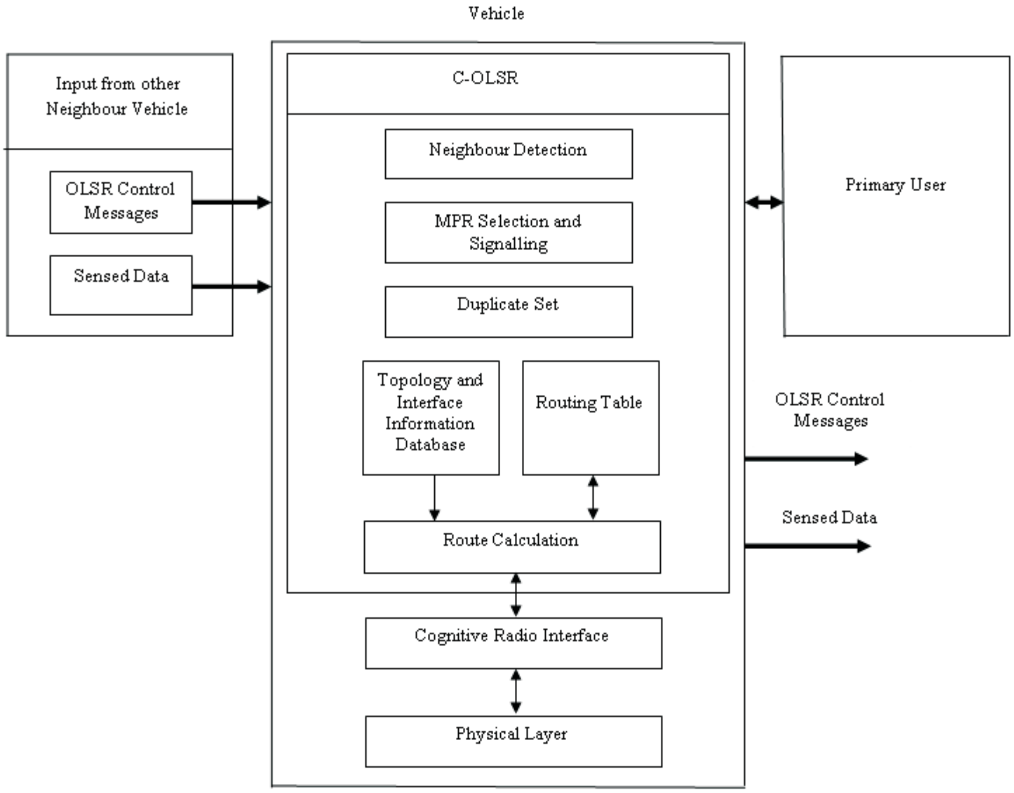

Fig. 1. C-OLSR with CR Interface.

interference is eliminated by utilizing each SU's transceivers having multiple interfaces and all neighbor links are accessible. Hence, topology of the network is vastly controlled by the mobility of vehicle and the number of channels accessible. To select the best possible route, CR functions as an interface for supplying the needed cognition to OLSR. The BCA algorithm utilizes specific routing measures, such as Predicted Transmission Count (PTC) and Predicted Transmission Time (PTT) and channel load are evaluated for appropriately selecting the channel.

The VSN communication depicts the graph walk mobility model in which the probability of unlicensed users to acquire the PU channel is calculated by identifying the channel condition of the PU. The channel load of SU's own channels is estimated periodically, while CR channel detection encourages every SU to obtain and assign the desired communication channel. Hence, the model proposed, enables the mobile nodes to exploit the opportunities to acquire the PU spectrum and assists the routing mechanism to handle spectrum assignment effectively. For appropriate channel allocation among multiple PU channels, Fig. 2 sequences the steps associated with the BCA algorithm in performing a cross-layer communication between the routing layer and physical layer.

4.1 Channel sensing

The sequence of communication for best channel allocation is represented in Fig. 3. The intelligence for determining the minimum PTT among the accessible channels is added to the existing functionality of OLSR. SU uses periodic sensing of its accessible licensed frequencies and further utilizes the detected spectrum occupancy knowledge like predicted ON duration, P_{on}, and predicted OFF duration, P_{off} of the channel to estimate the channel load. In this section, we design an ON-OFF process for every SU channel. In Fig. 4, the transmission of SU data packet over a channel is represented by each rectangle and denotes the ON period and the idle time of the SU channel are represented

Algorithm 1: Best Channel Allocation Algorithm

Input: Secondary User channel state information
Output: Channel substitution for minimum PTT Channel
Sequence involved in channel access:
1. Determine Channel state information, $P_{on} \& P_{off}$
2. Estimate Channel Utilization, $CH_u = \frac{P_{on}}{P_{on} + P_{off}}$
3. Estimate Bandwidth Utilization, $B_u = D_r * (1 - CH_u)$
4. Calculate Packet Error Ratio, $PK_m = 1 - (1 - BR_p)^m$
5. Estimate $PTC = \frac{1}{1 - PK_m}$
6. Estimate $PTT = PTC * \frac{P_r}{B_u}$
7. If PTT < Minimum Transmission Time of the Channel,
7.1: Channel accessibility is checked within SU allotted channels, then choose a channel from the licensed frequency band of SU
SU: Check within SU, If (Channel$_n$ = OFF), then allot Channel$_n$ to SU
7.2: If channel scarcity found within allotted frequency band of SU, then request and borrow Channel$_m$ from PU
PU: If (Channel$_m$ = OFF), then time stamped Channel$_m$ is allotted to requesting SU.
SU: Channel$_m$ is released after timer expiry

Fig. 2. BCA Algorithm.

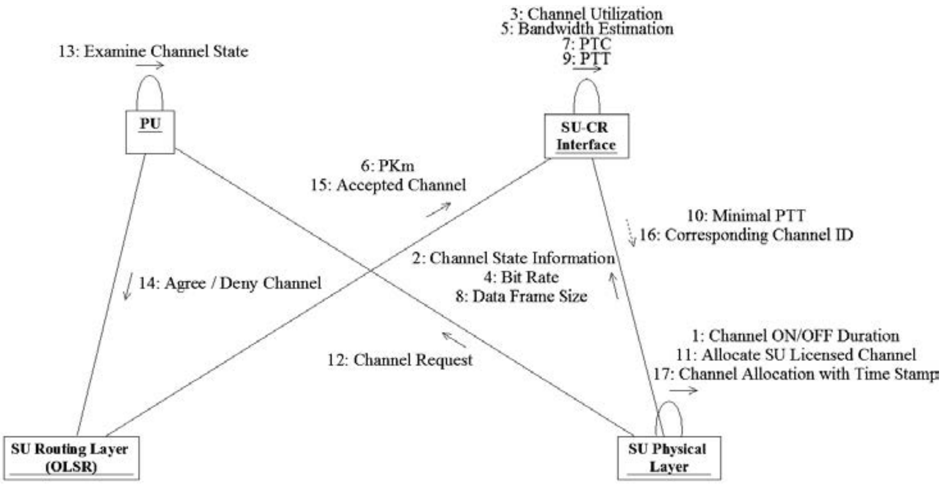

Fig. 3. Collaboration among different modules for Optimal Channel Allocation.

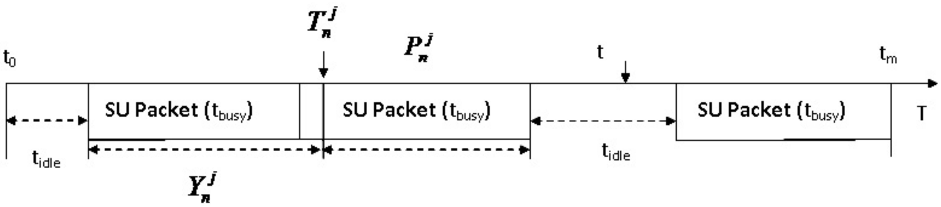

Fig. 4. SU Channel is monitored between time slots t_0 to t_m.

by other white spaces and denotes the OFF period. The rectangle length represents the SU packet size. In Fig. 4, t_0 indicates the time an SU starts predicting channel occupancy duration. Thus, at $t(t > t_0)$, which denotes the future time for the nth channel, the status of the SU channel is indicated by $S_n(t)$. $S_n(t)$ represents a stochastic binary values 1 and 0 to indicate the respective busy and idle condition and we consider, an M/G/1 system being used by each SU and therefore, the Poisson process is used to model the SU packet arrival method with the average packet arrival rate λ_n and P_n^j, the SU packet length, follows an random probability density function (pdf).

Figure 4 depicts the traffic activity of SU on channel n, where X_n^j, which indicates the inter-arrival time and follows exponential distribution and T_n^j indicates the arrival time of the jth packet, respectively. According to Fig. 4, the probability that the state of nth channel is ON or OFF for any future time t can be represented as in eqn. (1):

$$\begin{aligned}&\text{If} \quad T_n^j < t \quad \text{and} \quad T_n^j + P_n^j \geq t, \quad j \geq 1 \quad \text{then } Pt(S_n(t) = 1), P_{\text{ON}}\\ &\text{If} \quad T_n^j + P_n^j < t \quad \text{and} \quad T_n^{j+1} \geq t, \quad j \geq 1 \quad \text{then } Pt(S_n(t) = 0), P_{\text{OFF}}\end{aligned} \tag{1}$$

Exponential distribution is used to represent the P_{on} and P_{off} of the channels with arrival rates as λ and μ and their respective Cumulative Distribution Functions (CDFs) are represented as in eqn. (2) and (3):

$$\begin{aligned}Pt(P_{\text{on}} < y) &= \int_0^{p+y} \lambda_n e^{-\lambda_n t} dt\\ &= 1 - e^{-\lambda_n (p+y)}\end{aligned} \tag{2}$$

$$\begin{aligned}Pt(P_{\text{off}} < y) &= \int_0^{p+y} \mu_n e^{-\mu_n t} dt\\ &= 1 - e^{-\mu_n (p+y)}\end{aligned} \tag{3}$$

4.2 Predicted transmission count

The association between the packet error ratio (PER) and bit error ratio (BER) is invalid for correlated noise channels and acceptable for a typical data transmission system that communicates messages with uncorrelated noise across a binary symmetric channel. The packet length measured in bits is m and the BER for the channel is BR_p. The BER represents the division of a number of errors in bits to the entire amount of bits sent over a time interval. Every data packet containing one or more bits in error is rejected and PER, which is the probability of receiving a data packet in error and represented as PK_m is calculated as in eqn. (4):

$$PK_m = 1 - (1 - BR_p)^m \tag{4}$$

The number of bits available in the data payload of the packet and BR_p solely defines PK_m and is not reliant on what occurs throughout the transmit-receive process or how the message is encoded. It is usually acceptable to convert between Predicted Transmission Count (PTC) and PK_m as in eqn. (5)

$$PTC = \frac{1}{1 - PK_m} \tag{5}$$

4.3 Predicted transmission time

Though, PTC is not preferred to estimate the transmission rate of the link. All the broadcasts are done at the feasible network rate and the probes utilized are lower than the normal data packets. PTC neither examines the size of packet nor identifies links with different bandwidths and thus, specifies a minimal value. To overcome this issue, Predicted Transmission Time (PTT) was proposed, which modifies PTC to accommodate fluctuating physical bandwidth and varying length of packets. PTT is termed as the total duration required for a packet to be transmitted to each neighbor

Algorithm: Link Stable Time Algorithm

Input: Position coordinates: (a1,b1), (a2,b2)
Velocity: (v_x, v_y)
Transmission Range: T_r
Output: Choose most stable link from the forwarding subset

Sequence for finding most stable link:
1. For each symmetric neighbour node
2. begin
   if (a1 = a2) then
      begin
      if (b2 > b1) then $\theta = 0.5 * \Pi$
      else $\theta = 1.5 * \Pi$;
      exit;
      end;
   $\theta = \arctan((b2 - b1)/(a2 - a1))$;
   if $a2 < a1$ then $\theta = \theta + \Pi$;
   if $\theta < 0$ then $\theta = \theta + 2 * \Pi$;
   $\theta = \theta * 180/\Pi$;
   end;
3. If $\theta < 90$ then,
      Orientation of neighbour Vehicle = approach
   else Orientation of neighbour Vehicle = depart
4. Add neighbouring nodes with (orientation = approach) to forwarding subset
5. Estimate proximity, $P_{xy} = \sqrt{(a2 - a1)^2 + (b2 - b1)^2}$
6. Calculate Link Stability,

$$LS = \frac{\sqrt{T_r{}^2 - (P_{xy}\cos\theta)^2} + \sqrt{P_{xy} - (P_{xy}\cos\theta)^2}}{|v_{x-}v_y|}$$

7. Terminate iteration
8. Based on forwarding subset, the forwarder with the most stable link is found

Fig. 5. LST Algorithm.

and is calculated in terms of PTC and the usual data packet time taken for transmission. The PTT of the channel is determined in eqn. (6), where B_u and P_r denotes the channel's data capacity in bps and the probing packet size in bits respectively

$$PTT = PTC * \frac{P_r}{B_u} \tag{6}$$

4.4 Channel allocation

The PTT of the accessible SU channels is defined by the CR interface, which is further used as an interface to request and borrow channel from PU if PTT is lower than the threshold and no licensed access is available within the allocated frequency band of SU. The PU decides the availability of its channel by analyzing the condition of its channel and allocates if it is found idle. PU transmits the information of the chosen channel along with the time limit for expiry to the CR interface. CR instructs SU to return the channel to the licensed user following the expiry time and thus, allowing PU to shift between independent SUs within its transmission region.

5. Link Stability

To discover neighbors and the nature of the links between them, HELLO messages are broadcasted periodically. C-OLSR uses the services of Link Stable Time (LST), depicted in Fig. 5, to perform optimal neighbor selection, which

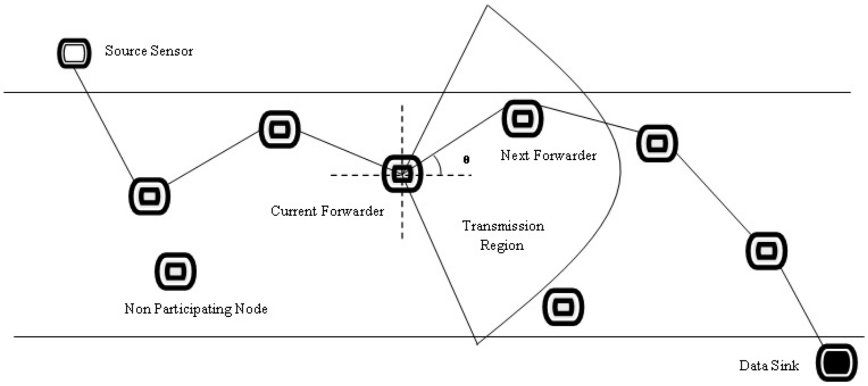

Fig. 6. Estimating Vehicle Proximity.

Fig. 7. Anna Salai urban roadmap for VSN Scenario.

accounts distance as well as velocity in prediction of link existence. Moreover, the forwarding vehicle uses LST to calculate the separation angle of the vehicles in its vicinity for the suitable choice of next hop and helps enhance the routing efficiency. The neighbor vehicle proximity, calculated for the vehicles that fall inside the accessible region of the current forwarder, considering the node at origin is shown in Fig. 6. For the purpose of providing a route when required, every vehicle in the VSN topology utilizes OLSR and refreshes the VSN topology by Topology Control (TC) message broadcasting. The vehicle's neighbor set information is contained in the TC messages and each vehicle will distribute its neighbor set information with every other vehicle in the VSN topology via TC messages. Furthermore, every vehicle uses the obtained neighbor set information to compute its routing table, which is further referred for route selection to choose the appropriate neighbor vehicle.

6. Simulation Setup

NS2 version 2.35 is used for Network Simulation and VANETMobisim tool within space of 3000×3000 form the simulation setup.

Figure 7 shows a segment of an urban road map of Anna Salai, an arterial road of Chennai, a metro city in India. VanetMobiSim is used to generate the mobility traces for the Anna Salai road map as shown in Fig. 8.

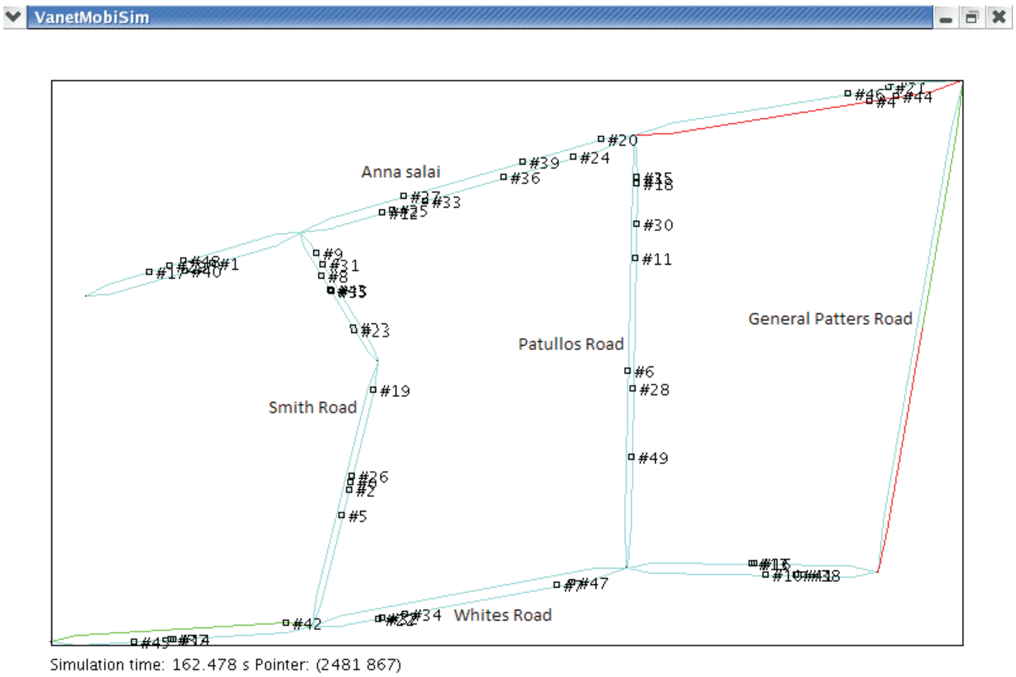

Fig. 8. VanetMobiSim Representation of Anna Salai Urban Roadmap.

Table 1. Simulation Parameters.

Parameter	Value
Simulation Time	50s to 500s
No. of wireless nodes	50 to 250
Speed	50 kmph to 100 kmph
Routing Algorithm	C-OLSR
Simulated Area	3000 × 3000
Packet size	512 bytes
Packet Rate	3 packets/sec
Mobility model	Graph Walk
Propagation model	Two Ray Ground

In this representation, each node strictly follows its lane bound and alters the direction randomly at road junctions. The experimental factors for establishing the vehicular structure in Network Simulator are tabulated in Table 1. The mobile vehicles act as SUs and fixed nodes act as PUs in the VSN topology. The graph walk mobility model is used to enable communication between vehicles.

7. Result Analysis

Performance analysis measures such as end to end delay and packet delivery ratio (PDR) are used for the comparison of C-OLSR and OLSR in the urban road map of Anna Salai. C-OLSR performs local optimization by cognitively choosing most fitting local channels of the SU as well as that of the PU and also selects the route accounting both hop count and LST routing metric and thus attains global path optimization. The LST value is refreshed periodically to adapt to the dynamic change in spectrum environment. Table 2 depicts a sample

Table 2. Sample Topology showing the Routing Table of Node 21.

Destination	Selected Forwarder	Number of Hops	Current Forwarder	Expected LST (Seconds)	Actual Lifetime (Seconds)
42	42	1	21	6.57	7.43
6	6	1	21	2.11	4.06
27	27	1	21	5.52	6.37
18	18	1	21	4.35	5.01
16	16	1	21	3.73	6.18
11	42	3	21	6.32	9.35
32	32	1	21	4.31	5.11

routing table. The routing entries for typical OLSR are depicted in the first four columns and the predicted LST metric is shown in the fifth column. The real simulated link connectivity time is displayed in the last column. Usually, Anna Salai urban road is distinguished by larger density of vehicles, which increases the chances of forwarding due to the high vehicle mass. Therefore, the predicted output for the above scenario is higher PDR with low end to end delay. Figure 9 depicts the graph showing the properties of end to end delay against number of vehicles. During the complete set of experiments, the pair of source-destination is randomly selected. The experiment shows that an increase in node density causes the delay to decrease for both OLSR and C-OLSR and with lower node density, the scattered network leads to lesser connectivity among nodes. C-OLSR delivers lesser end to end delay than OLSR since density of vehicles improves chances of spectrum exploitation for transmitting data by BCA algorithm and also enhances the estimation of the optimal route through the use of LST metric. Figure 10 shows an aggregated PDR of C-OLSR and OLSR against number of nodes ranging from 50 to 250. An increase in the density of vehicles increases the chances of forwarders, which further results in higher PDR.

C-OLSR is less vulnerable to path breakages than OLSR with LST assistance and improves the forwarding set and thus functions well with expanding number of vehicles than OLSR. Therefore, C-OLSR outperforms OLSR strongly stabilizing its control in crowded and fluctuating spectrum environments. Figure 11 depicts the performance of PDR against speed for 50 vehicles. The experiments show that the delivery rate decreases due to link failures and frequent path breakages caused by the high mobile nodes. Figure 12 shows the time difference of predicted and the real simulated lifetime of the links. The graphs constructed from the simulations depicts the capability of the proposed LST and BCA techniques to predict the link existence with the neighbor vehicle and nearly matching the predicted time with the real link existence time obtained from simulations.

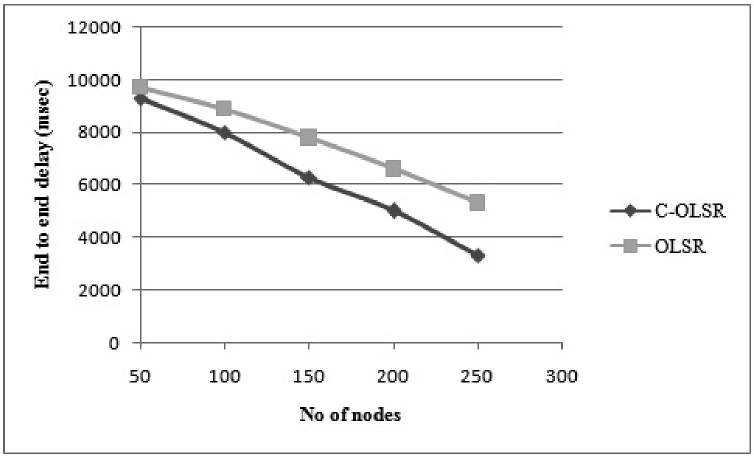

Fig. 9. Number of Nodes vs End to End Delay.

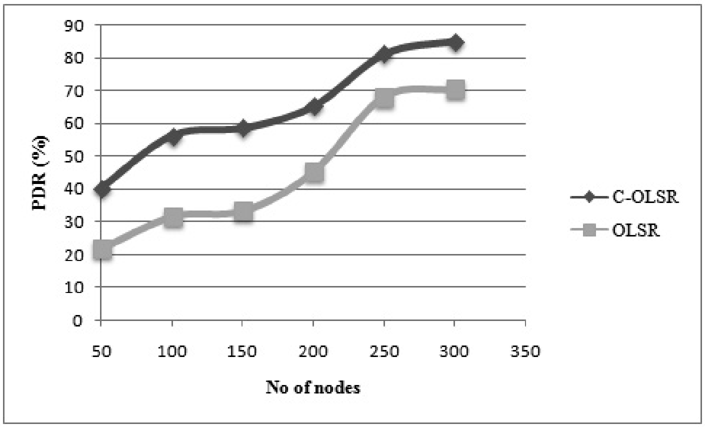

Fig. 10. Number of Nodes vs PDR.

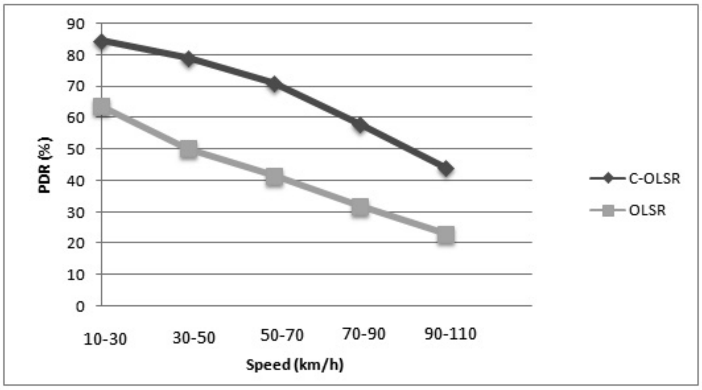

Fig. 11. Speed vs PDR.

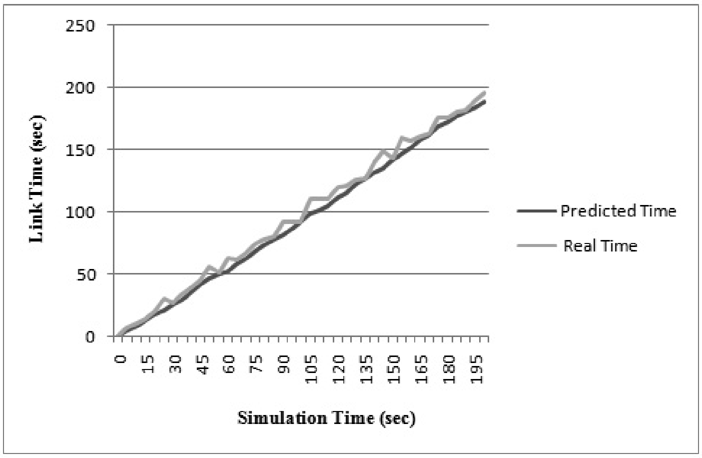

Fig. 12. Predicted LST vs Real Lifetime of the Link.

8. Conclusions

The research paper has focused on enhancing the throughput of the network against high vehicle mobility, which is a major difficulty faced by VSN. This paper introduced Best Channel Allocation (BCA) and Link Stable Time (LST) algorithms to choose the best available channel from PU and SU applying cross-layer communication. BCA allows OLSR to use link state information dynamically for predicting the most suitable path on the basis of lifetime of the next hop link. Maximizing the network throughput with drastically varying bit rate in divergent VSN structure will be considered for the future work. Furthermore, according to the necessity of bandwidth for different sensor applications, an additional number of channels will be determined and allocated to the SUs.

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