Connectivity Provisioning Using Cognitive Channel Selection in Vehicular Networks

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Abstract. High mobility of vehicles, limited transmission range of roadside units (RSUs), and channel status (busy or idle) cause dynamic topological changes in Vehicular Networks (VNs). Due to these dynamic topological changes, maintaining full connectivity arises as a main communication challenge in VNs. Moreover, the high number of channel switching also effects the quality of network connectivity causing an another significant problem in VNs. In order to overcome these challenges, we analyze the full connectivity provisioning in VNs by proposing four cognitive channel selection algorithms, parameterizing the vehicle satisfaction ratio and the number of channel switching. Specifically, the proposed channel selection algorithms provide minimal channel switching ratio while conserving full network connectivity. We also compare the results of multi-channel selection and single channel selection and simulation results show that network connectivity can be enhanced while optimizing the channel switching with our proposed cognitive channel selection algorithms.

Keywords: Vehicular networks · Network connectivity · Channel switching · Dynamic channel allocation

1 Introduction

With recent advances in online embedded mobile applications, traffic safety and efficiency have gained major importance in vehicular networks. Among them, online safety, monitoring, tracking and infotainment applications can be listed as leading examples. To support these applications and to enhance network performance, RSUs are deployed for vehicle to infrastructure (V2I) communication pattern. However, one of the main distinct characterization of vehicular networks is high mobility of vehicles. In addition to the high mobility of vehicles, limited transmission range of RSUs and channel status (busy or idle) cause dramatic changes behaviours of the network topology influencing network performance negatively. In such a dynamic network topology, maintaining continuous and robust connectivity will be significantly difficult in vehicular networks.

Specifically, after The U.S. Federal Communications Commission (FCC) has allocated bandwidth of 75 MHz in the 5.9 GHz frequency band for dedicated short range communication in 1999, many attractive applications have become

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more popular in transportation system. However, although new applications and innovations emerged in transportation system, increasing bandwidth requirement in these online applications cause new problem; spectrum scarcity. To utilize unused spectrum bands, dynamic spectrum access (DSA) has been proposed in many researches to supply growing demand [1–3]. However, due to changing channel availability status, network connectivity is more challenging in vehicular networks.

Moreover, the number of channel switching effects the quality of network connectivity in vehicular networks. Each channel switching results with intermittent connectivity and communication duration continuously changes depending on network topology. Vehicles need to exploit the channel status to check availability of channels at all times. Therefore, when the number of channel switching increases, the quality of network connectivity will effect by causing communication disruptions. Therefore, the quality of communication is related to determine best available channels dynamically.

These aforementioned challenges, maintaining full network connectivity, channel switching and dynamic channel allocation, is investigated in many researches with different approaches in vehicular networks.

[4] presents a knowledge-based learning to service vehicular communications and proposes the use of Vehicular Dynamic Spectrum Access (VDSA). The authors investigate channel selection problem and calculate channel switching and channel access rate in a realistic simulation environment. [5] researches dynamic channel selection schemes and focus on channel switching in multi-hop vehicular ad hoc networking and evaluate the total time of transmission and the amount of transmitted data in DSA inter-vehicle networks. In [6], the authors study on the learning techniques to use in many applications in VDSA and determine channel availability status to analyze channel prediction and selection process. [7] presents channel allocation algorithm using game theory in Vehicular Ad hoc NETworks (VANETs).

Moreover, there exist many works related to connectivity in vehicular networks. [8] proposes an analytical model to improve connectivity in vehicular networks. The effect of road traffic parameters (traffic flow, speed), transmission range of vehicle on the connectivity is described with the proposed model. [9] investigates the relationship between mobility and network connectivity with different mobility models for realistic VANET by proposing an analytical framework. In [10], authors combine two concepts, cooperative communications and analog network coding (ANC), to improve network connectivity and capacity in vehicular networks.

Even though the connectivity challenge has been analyzed in these aforementioned studies, a full connectivity maintenance has not been investigated while optimizing continuous connectivity, channel switching and channel allocation simultaneously in vehicular networks.

Therefore, in this paper, we propose cognitive channel selection algorithms to evaluate the relationship between network connectivity and channel switching in vehicular networks. We analyze the connectivity problem with different traffic density in terms of satisfaction ratio and the number of channel switching. These two performance parameters are defined as follows.

- Satisfaction ratio: Total usage ratio of channels with respect to proposed dynamic channel selection algorithms in different traffic densities.
- The number of channel switching: The total number of channel switching throughout entire communication period in different traffic densities.

In our work, our main objective is to enhance network connectivity between vehicles and RSUs in vehicular networks. With this purpose, we maximize satisfaction ratio while minimizing the number of channel switching with the proposed cognitive channel selection algorithms. In the proposed algorithms, we define best available channels with two different approaches, multi-channel selection and single channel selection. Therefore, at first we propose a channel utilization map and then implement different cognitive channel selection algorithms, finally we compare the results with different approaches including single channel switching and multi-channel switching.

Specifically, this paper makes the following main contributions.

- We develop a channel utilization map using temporal usage characteristics of vehicles.
- Using this map, we derive analytics for channel utilization ratio, vehicle satisfaction ratio and channel switching.
- We propose four different cognitive channel selection algorithm by maximizing connectivity, maximizing channel utilization ratio, checking channel utilization table by selecting maximum channel utilization ratio and optimizing between satisfaction ratio and channel switching.

The results show the relationship between network connectivity and channel switching with the proposed algorithms to provide effective communication between vehicles and RSUs.

The rest of the paper is organized as follows. Section 2 gives the details of proposed system architecture. Section 3 describes the proposed cognitive channel algorithms for vehicular networks, Section 4 gives simulation results and evaluate the performance and finally Section 5 concludes the paper.

2 System Architecture

In this paper, we proposed a vehicular network architecture for the communication between vehicles and RSUs. In this architecture, RSUs units are deployed specific location with a limited transmission range, α, in order to communicate with vehicles.

We assume that there are c channels that are divided into fixed time slots, t, and m vehicles that can opportunistically access to channels depending on communication requests. Vehicles move at variable velocity, v', which are between v_1 and v_2 depending on traffic density. The movement of vehicles is considered normally distributed zero mean and unit variance.

Each vehicle registers to RSU when they come into the transmission range of a RSU. Moreover, vehicles sense multiple channels at a time in order to obtain the information of channel availability within the transmission range of a RSU and they can dynamically switch to another suitable channel when the channel is detected as unavailable. However, vehicles access only one channel in each time slot.

In the proposed architecture, network connectivity is required to establish communication and disseminate online information between vehicles and RSUs. RSU collects all network information by including channel availability status and communication requests of vehicles within the geographical area of itself. To maintain full connectivity, Fig. 1 is proposed which is implemented in RSU and each module is modelled as follows.

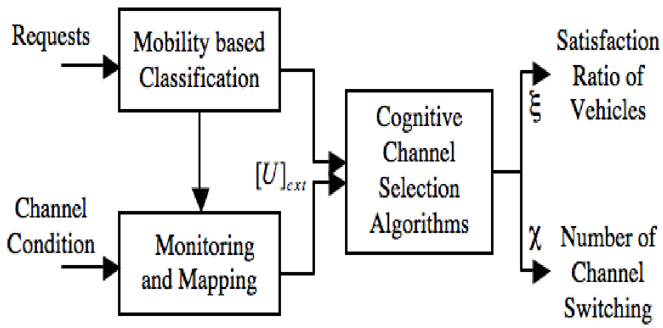


Fig. 1. Proposed System Model

2.1 Mobility Based Classification Module

This module characterizes communication requests of vehicles within the transmission range of RSU. Requests, R(t), are represented with binary variables and distributed according to Poisson process with the arrival rate λ_R in time interval $[1, t]$. Vehicles move at variable velocities, v', which are between v_1 and v_2 depending on traffic density and RSUs determine the time interval of vehicles, how long will remain in its transmission range, assuming that $\frac{\alpha}{v'}$. The movement of vehicles is considered normally distributed zero mean and unit variance.

2.2 Monitoring and Mapping Module

In this module, each channel is modelled as idle or busy in each time slot which is represented with binary variables, C(t), and distributed according to Poisson process with the arrival rate λ_C in time interval $[1, t]$.

In this module, after storing communication requests and monitoring channel condition in RSU, channel utilization map is derived and utilization ratio of channels are calculated for each vehicle. When a new vehicle moves into the transmission range of a RSU, it characterizes which time slots are idle and calculates channel utilization map as shown in Fig. 2.

Time

Communication Request, R(t)	no request	requested	no request	requested
Channel Availability, C(t)	idle	idle	busy	busy
Utilization Map, $[U]_{cxt}$	**N/A**	**occupied**	**N/A**	**N/A**

Fig. 2. Channel Utilization Map

When channel is idle and vehicle has a communication request in this specified time slot, then the channel can be occupied by a vehicle. It can be formulated by eq.1 as follows:

$$[U_{cxt}] = \begin{cases} 1, & R(t) = 1,\ C(t) = 0 \\ 0, & otherwise \end{cases} \tag{1}$$

where $[U_{cxt}]$ is utilization matrix for each vehicle, R(t) and C(t) represent communication request and channel availability, respectively.

Then, utilization ratio of each channel is calculated for each vehicle in eq.2 as follows:

$$U_{c_i}^m = \frac{\sum_{j=1}^{t} [U]_{c_i}^m}{t} \qquad \forall i \in [1, 2, ..., c], \forall j \in [1, 2, ..., t] \tag{2}$$

where $U_{c_i}^m$ is utilization ratio of channel i for vehicle m, $c_i \in c$ and $[U]_{c_i}^m$ is the utilization matrix of i^{th} channel for vehicle m.

After obtaining the utilization map for each vehicle, vehicle determines available channels and decides a channel selection algorithm to maintain full connectivity with minimal channel switching.

3 Cognitive Channel Selection Algorithms

In this section, we defined four novel cognitive channel selection algorithms in order to maintain full network connectivity with two approaches, multi-channel selection and single channel selection. In single channel selection, vehicles can access only one channel throughout entire communication period and whenever channel is detected as unavailable, vehicles quit the channel and wait until channel is available. Due to the usage of only one channel, channel selection is the more significant when compared with multi channel operations. To evaluate the results with these approaches, we specified two main communication performance parameters described in the previous section and then elaborated them under different traffic density.

– Satisfaction ratio, ξ: Total usage ratio of channels with respect to proposed channel selection algorithms.
– The number of channel switching, χ: The total number of channel switching throughout entire communication period.

With the proposed algorithms, our aim is to maximize satisfaction ratio while minimizing the number of channel switching by defining best available channels. With these motivations, the following algorithms are derived.

3.1 Algorithm 1 (Connectivity Maximization)

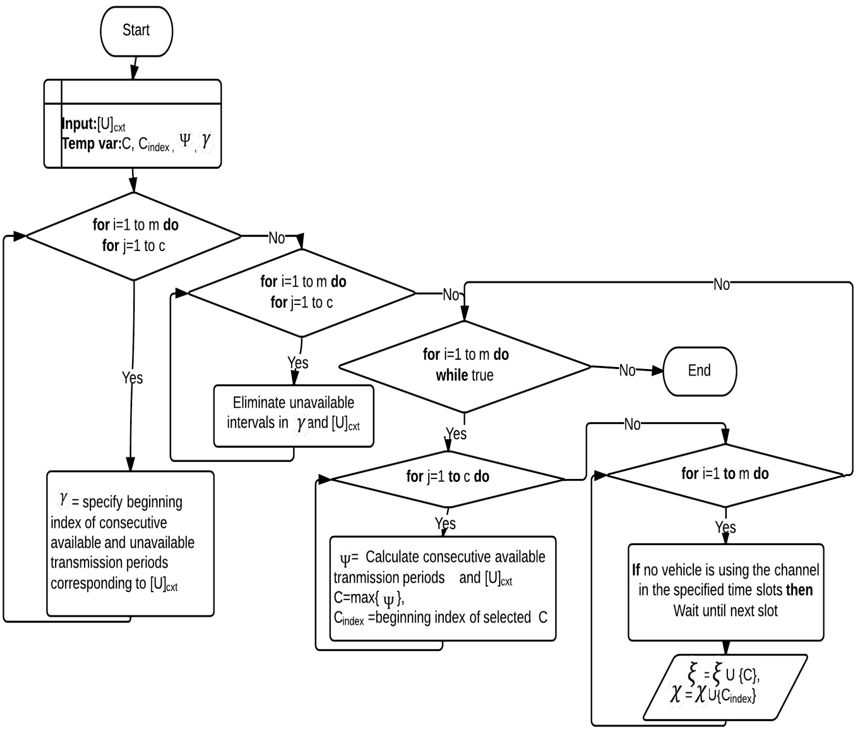
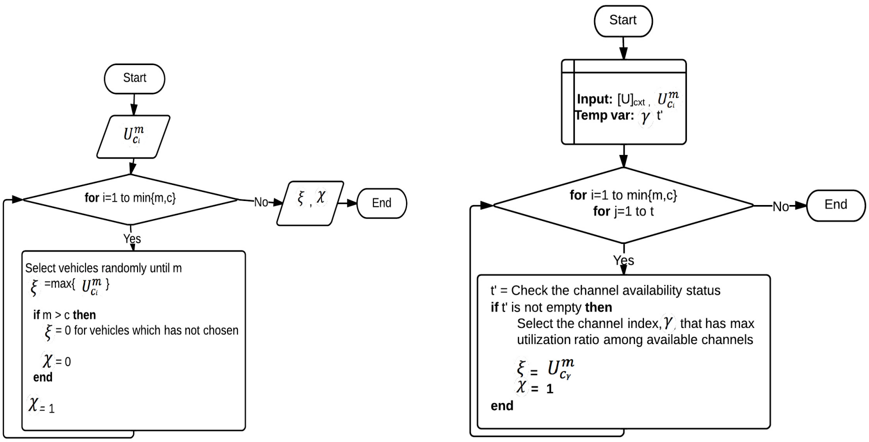


Fig. 3. Flowchart of algorithm 1

Algorithm 1 is based on multiple channel selection by maintaining maximum connectivity with maximum channel switching as flow diagram given in Fig. 3. In algorithm 1, each vehicle determines available and unavailable transmission periods in its utilization map and calculates consecutive available transmission intervals. At the end of the each transmission period, available channels are determined and then a large amount of transmission interval is selected for the next channel switching. Every selection is based on higher utilization in order to minimize channel switching. In this algorithm, vehicles dynamically switch to another suitable channel whenever channel is detected as unavailable and all idle time slots are used to obtain maximum satisfaction ratio resulting frequent channel switching.

3.2 Algorithm 2 (Maximum Channel Utilization Ratio)

Algorithm 2 is based on single channel selection approach. Channel utilization ratios, $U_{c_i}^{m}$, are calculated for each vehicle as given in eq.2 and each vehicle selects a channel that has maximum utilization ratio throughout entire transmission period in order to utilize the channel as long as possible. However, if the number of vehicle is higher than the number of channels, all vehicles cannot be access the channels. The flow diagram is given in Fig. 4(a).



(a) Algorithm 2 (b) Algorithm 3

Fig. 4. Flowcharts of Algorithm 2 and 3

3.3 Algorithm 3 (Checking Channel Utilization Table by Selecting Maximum Channel Utilization Ratio)

Algorithm 3 uses only one channel selection approach. In this algorithm, channel utilization ratios, $U_{c_i}^{m}$, are calculated for each vehicle similar to algorithm 2 and each vehicle checks its utilization map by starting from initial time slot. When one or more channel is detected as available at a time, vehicle selects a channel that has maximum utilization ratio among available channels in this specific time as flow diagram given in Fig. 4(b).

3.4 Algorithm 4 (Optimization Between Satisfaction Ratio and Channel Switching)

This algorithm is proposed to avoid frequent channel switching in algorithm 1 with multiple channel selection approach.

To decrease the number of channel switching in algorithm 1, at first algorithm 1 is run in order to obtain performance parameters, satisfaction matrix and the number of channel switching, and then total amount of transmission periods in satisfaction matrix is calculated in each channel switching. With the help of obtaining these transmission intervals in each channel switching, the mean of all periods is calculated to compare with each transmission period. Then transmission periods that smaller than the mean value are eliminated to decrease the number of channel switching in algorithm 1. The flow diagram is given in Fig. 5.

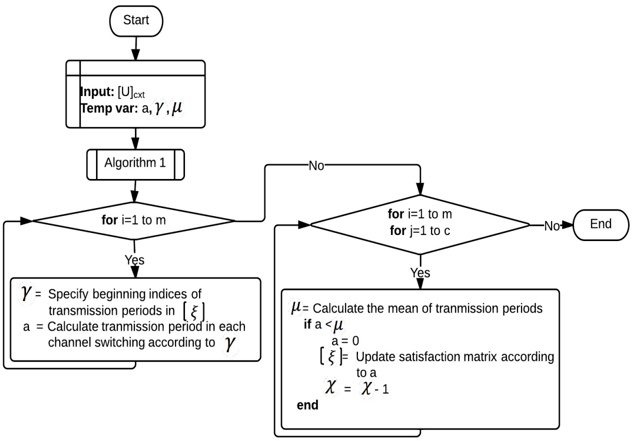


Fig. 5. Flowchart of algorithm 4

However, we can expect that while decreasing number of channel switching, satisfaction ratio is also decreased in algorithm 4. However, we observe that satisfaction ratio and number of channel switching are optimized by conserving full network connectivity.

4 Performance Evaluation

In this section, we evaluate the performance of the proposed system model and show the relationship between connectivity and channel switching with the proposed four cognitive channel selection algorithms. The results of proposed algorithms and all system modules are implemented in MATLAB environment. We look into the connectivity problem with two different approaches, multi channel selection and single channel selection. Moreover, we obtain the results with different traffic densities, low, medium and high. The number of vehicles varies between 1 to 10, 10 to 15 and 15 to 20 in low, medium and high traffic densities, respectively. The parameters used in the simulation are shown in Table.1.

Table 1. Simulation Parameters

Parameter	Value
Transmission Range of a RSU	5000 m
Velocity of Vehicles	10 to 20 m/s
Number of Channels	10
Number of Vehicles	1 to 20
Total Number of Time Slot	1000

We use a vehicular network architecture with one RSU and between 1 and 20 vehicles with variable velocity between 10 and 20 m/s. We assume that all vehicles are registered and connected to RSU when they come into its transmission range.

A total number of 10 channels are divided into 1000 time slots and vehicles opportunistically access to channels depending on channel status (busy or idle).

We compare the proposed algorithms in terms of satisfaction ratio and the number of channel switching according to different traffic densities with the following approaches.

- Multi-channel selection: Vehicles can sense multiple channels and access one channel at a time when the channel is detected as available and can switch to another suitable channel dynamically when channel is detected as unavailable.
- Single-channel selection: Vehicles can access only one channel throughout entire communication period depending on availability of channel.

In this respect, Fig. 6 shows the relationship between satisfaction ratio and number of channel switching depending on traffic density for each proposed algorithm. Algorithm 1 enables to maximum connectivity resulting frequent channel switching in each traffic density. However, the results of algorithm 4 is acceptable due to the decreasing the number of channel switching with a 47% rate by conserving network connectivity. Moreover, the satisfaction ratios of algorithm 2 and 3 is less than due to the usage of only one channel. We observe that maintaining connectivity is more challenging in high traffic density for all proposed algorithms.

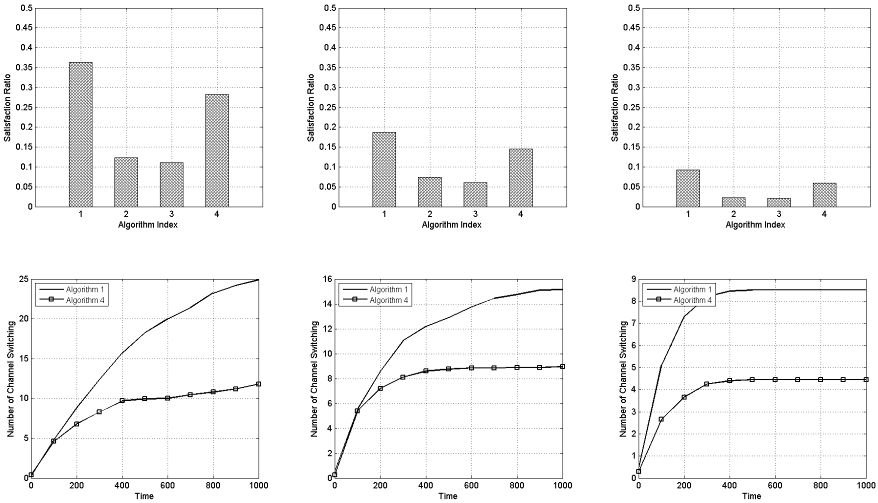


Fig. 6. Satisfaction ratio and the number of channel switching w.r.t. low, medium and high traffic density, respectively

5 Conclusion

In this paper, we propose four cognitive channel selection algorithms in order to maintain full connectivity between vehicles and RSUs in terms of satisfaction ratio and number of channel switching. The proposed multi-channel selection and single channel selection algorithms are evaluated in simulation environment separately. We observe in the proposed algorithms that multi-channel selection can significantly improve the network performance when compared with single-channel selection and simulation results show that there is a significant relationship between satisfaction ratio and the number of channel switching to maintain connectivity and connectivity can be enhanced the proposed cognitive multi channel selection algorithms.

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