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Robust and continuous connectivity maintenance for vehicular dynamic spectrum access networks

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ABSTRACT

In vehicular networks (VNs), limited transmission range of roadside units (RSUs), the high mobility of vehicles and channel status (busy or idle) cause dramatic changes in spatial and temporal behaviors of the network topology. These dynamic topological changes bring a crucial problem in terms of network connectivity maintenance. Moreover, the high number of channel switching becomes also a problem due to dynamic topology changes in VNs. These aforementioned two challenges cause expressive degradations both in the user satisfaction and wireless communication quality in the VNs. To overcome these challenges, in this paper, we propose a novel queuing theory based framework for Vehicular Dynamic Spectrum Access Networks (VDSANs). Specifically, our proposed framework uses queuing theory analytics to model the dynamic behaviors of vehicles and obtain high satisfaction ratio of vehicles. Moreover, we propose six novel dynamic channel selection algorithms to provide minimal channel switching ratio while conserving the network connectivity. The thorough evaluations show that the network connectivity can be enhanced while optimizing the channel switching with our proposed queuing theoretic VDSANs paradigm.

1. Introduction

Vehicular networks are of paramount importance to drivers due to the improving traffic safety and efficiency with the help of diverse online applications such as traffic information system, emergency management, and warning messages. To support these different types of applications, continuous transmission and network connectivity are needed. Moreover, limited transmission range of RSUs, the high mobility of vehicles and channel status (busy or idle) cause dynamic network topology in vehicular networks. For example, in United States, an average commuter drives approximately 26 km per day and spectrum occupancy characteristics vary while traveling on the road [1]. In such a case, establishing continuous communication and disseminating online information can be achieved with robust network connectivity.

However, due to the dynamic topological changes in the vehicular networks, connectivity cannot be achieved at all times. Therefore, robust and continuous network connectivity maintenance will be main communication challenge in vehicular networks. In particular, thanks to facilitating vehicular communication on the move toward the access technologies such as WiMAX, 3G, various applications, specially infotainment online applications have become more popular in transportation systems. In addition to being offered many opportunities with these applications, this increasing bandwidth requirement causes crucial problem; spectrum scarcity. To obtain additional spectrum allocations, DSA has been proposed in many researches as a solution to support growing demand in vehicular networks [2–4]. In this respect, vehicles have an opportunity to

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obtain unused spectrum bands in VDSANs. However, the network connectivity maintenance is more challenging in VDSANs due to the dynamic vehicular network topology.

An another performance metric related to connectivity in vehicular networks is the number of channel switching. The communication duration varies according to both spatial temporal behaviors of the network topology, and the movement of vehicles. In particular, due to the changing of channel availability status, vehicles need to exploit available channels and switch to another suitable channel frequently. Since high channel switching affects the connectivity quality causing communication disruptions, to determine best channels based on dynamic channel allocation emphasize the importance of the quality of communication.

In this respect, the analysis of vehicular network connectivity, channel allocation and spectrum management have been studied in many researches with different approaches.

Jin et al. [5] give a theoretical analysis of vehicular network connectivity and shows the relationship among connectivity, vehicle density and transmission area by calculating the minimum transmission area according to vehicle density. Sou and Tonguz [6] analyze the enhancement of vehicular network connectivity depending on deploying a limited number of roadside units and research the routing performance for safety applications. In [7], authors propose a cognitive channel hopping protocol to maintain connectivity in vehicular networks and observe that the selection of multiple channels improve network performance when compared with the selection of single channel with the proposed approach.

Moreover, there exist many works related to VDSANs. Rocke et al. [8] propose a knowledge-based learning to service vehicular communications in different types of applications and suggest the use of Vehicular Dynamic Spectrum Access (VDSA) to support non-safety applications. They discuss the use of CBR (case-based reasoning) for channel selection problem and calculate channel switching and channel access rate in a realistic simulation environment. In [9], the authors discuss how learning techniques can be used in many applications in VDSA. Channel prediction and selection process analyze in terms of time and location to determine channel availability.

Tsukamoto et al. [10] investigate dynamic channel selection schemes and authors 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. Borota et al. [11] investigate cooperative spectrum sensing performance in a vehicular networks to detect available channels, to utilize more spectrum usage and an efficient congestion control mechanism. Moreover, Canberk and Oktug [12] analyze spectrum decision challenges in CRAHNs (Cognitive Radio Ad-Hoc Networks) and propose a spectrum decision mechanism to make a decision about channel usage. With the help of the proposed cooperative and distributed spectrum decision mechanism, more accurate spectrum decision is obtained by utilizing SNR observations and local decisions of users. In [13], best transmission channel is described for multiple IEEE 802.11 network environment and cognitive dynamic channel assignment is designed in order to improve network performance.

In addition to these researches, the studies related to queuing model in VDSANs have been investigated in many researches. In [14], the authors examine the VDSA system by using queuing theory via multi server multi priority approaches and calculate transmission latency and the probability of all channels is busy over TV white space. Moreover, more researches over TV white spaces [15] have been intensively studied. Pagadarail et al. [16] describe a geo-location database to determine TV channel availability by showing vacant UHF TV channels and the total available bandwidth at different locations.

Moreover, most researches have been focused on enhancing connectivity and channel utilization in vehicular networks. However, same results cannot be obtained VDSANs due to the changing channel status. Due to the highly dynamic network topology, connectivity of VDSANs is more challenging.

In spite of the aforementioned researches, a comprehensive performance evaluation has not been investigated yet in terms of satisfaction ratio and number of channel switching with a queuing theory approach in VDSANs. In particular, we give a deep understanding to show the relationship between connectivity and channel switching with the proposed dynamic channel selection algorithms.

In this paper, we analyze the connectivity problem under different traffic density in VDSANs. Moreover, we observed that when the number of vehicles is high, network performance is decreased due to the limited number of channel and channel availability. We modeled the vehicular communication using queuing analytics and scheduled the communication requests accordingly. Here, the following communication performance parameters are considered.

- *Satisfaction ratio:* Total usage ratio of channels with respect to proposed channel selection algorithms.
- *The number of channel switching:* The total number of channel switching throughout entire communication period.
- *Waiting time:* The total time spent waiting in the queue with respect to different traffic density.
- *Queue length:* The number of vehicles waiting in the queue with respect to different traffic density.

Our objective is to maximize satisfaction ratio while minimizing the number of channel switching. We can expect that while increasing satisfaction ratios, number of channel switching will also increase resulting more delay and also affecting network performance negatively. To enhance connectivity, we define best available channels with respect to dynamic channel selection algorithms.

In our work, selection of a channel is related to the quality of connectivity and the number of channel switching. Our approach is to solve connectivity problem by proposing novel channel selection algorithms in terms of satisfaction ratio and the number of channel switching. Therefore, at first we proposed a channel utilization table and then implemented different channel selection algorithms, finally we compared the results with different approaches