Mitigating WiFi Interference to Improve Throughput for In-Vehicular Infotainment Networks

Woongsoo Na, Nhu-Ngoc Dao, and Sungrae Cho

**Abstract — ***In recent years, in-vehicular infotainment networks (IVIN) have rapidly become one of the most valuable features with which auto makers have used to promote their flagship models as an advanced competitive marketing weapon. IVINs can provide passengers with multimedia services locally as well as with Internet connectivity through a gateway known as a mobile hotspot. The in-vehicle mobile hotspot is embedded in the car and supports cellular connection. Utilizing this system, mobile devices can access the in-vehicle unified infotainment framework to comfortably enjoy streaming services, online games, online commerce, and social network services, etc. However, because of wireless access characteristics, if a significant number of Wi-Fi mobile hotspots are densely located, the throughput of the mobile devices will be tremendously diminished due to the interference among the mobile hotspots of IVINs, as well as with existing fixed office or residential APs along the road. In this article, we discuss the interference problems of Wi-Fi access in IVIN, provide effective solutions to these problems, and present the performance of each proposed approach within typical case studies.*

I. Introduction

Today, Internet of Things (IoT) technology turns vehicles into a hub for an entire ecosystem of connected services that offer users a wealth of benefits, including enhanced safety and security, a richer user experience, and a new suite of product offerings. Cars have been enabling us to connect our devices via Bluetooth to make calls and navigate; however, it is not currently possible for streaming apps to provide the content we love without the need to fiddle with our phones while driving and consume valuable data plans. By leveraging the always-on connectivity that IoT provides, today's connected car manufacturers are providing an entirely new interface for delivering and interacting with streaming content services. In-vehicular infotainment technology is the perfect answer for all of our mobile requirements [1].

The in-vehicular infotainment network (IVIN) changes the opinions of people that are thinking about travelling by car. Instead of a boring trip without anything to do, passengers can now enjoy various entertainment services as a personal relaxation experience, including streaming services, online games, online commerce, social network services, etc. Moreover, the convergence of all services, content, and connections into one unified infotainment framework creates a significantly convenient environment for passengers, as well as the driver [2]. The IVIN interconnects with various services, content, and application providers through mobile data networks such as LTE (Fig. 1).

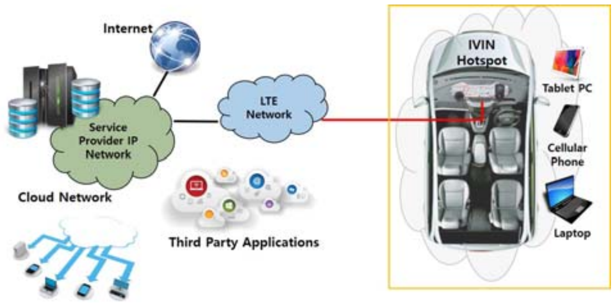


Fig. 1. An overview of an IVIN in a connected car.

Although application services offered by the IVIN are interesting to consider, in the scope of this article, we would like to consider the IVIN in terms of its connectivity, which is an important component for a successful system. Due to the mobility behavior, keeping the IVIN connected with the outside world while retaining high user experience is still a question for researchers and manufacturers. Recently, *connected car* services have been researched and developed by a large number of companies and research organizations [3]. In fact, this technology has been commercialized by a large amount of companies in recent years. For instance, the Ford Motor Company introduced Sync3, based on the Blackberry QNX platform, in order to provide a stable and connected ecosystem [4]. Of course, there are a lot of proposed technologies that can be utilized to provide inside and outside connectivity for the IVIN, such as inter-vehicular communication architecture [5], cognitive radio enabled vehicles [6], dynamic bandwidth distributions [7], as well as various other technologies. However, none of them have been commercialized yet. The popularity of Wi-Fi supported devices directs connected car inventions toward using Wi-Fi as a default acceptable technology. The *fully connected car* is assumed to be equipped with ubiquitous high speed mobile packet data such as LTE, along with the global positioning system (GPS) [8]. This vehicle might use a gateway that transparently distributes the LTE data to users in order to augment the mobile services through in-vehicle wireless local area networks (WLANs) such as IEEE 802.11.

The advantages are quite appealing. However, there are some technical challenges that the network faces: 1) *Security*, 2) *Positioning,* and *3) Interference*. For instance, if a significant number of vehicles are densely located, the throughput of the mobile devices will be tremendously diminished due to the interference among the Wi-Fi enabled networks. Because of the mobility behavior, the mobile hotspot might also interfere with existing fixed office or residential APs installed along the road. These interference phenomena could cause contention among the existing fixed APs and impose serious performance degradation.

In this article, we focus on discussing the interference problems when the IVIN uses Wi-Fi as an in-vehicle access technology. We also assume that the vehicles are embedded with an LTE antenna which distributes LTE traffic to Wi-Fi enabled devices to form an in-vehicle basic service set (BSS). Based on our investigation, we classify the technical challenges of Wi-Fi access services in IVINs into three categories: (1) *interference among mobile hotspots*, (2) *interference between a mobile hotspot and fixed APs*, and (3) *mobility problems.* We then provide appropriate solutions to these issues. In the first part of the article, we present the technical challenges of interference problems. In the second part, relevant interference avoidance techniques are discussed and we show examples of solutions to resolve the interference in Wi-Fi IVINs. The performance of each approach is evaluated with case studies. Finally, we draw conclusions and suggest future directions.

II. TECHNICAL CHALLENGES

In this section, we present the technical challenges of the Wi-Fi IVIN. Although Wi-Fi service in vehicles can provide a variety of useful applications, it also causes potential problems, including interference among mobile hotspots, mobility problems, and interference between mobile hotspots and fixed APs. In particular, we consider the vehicle's mobility and backward compatibility with existing fixed APs in order to provide appropriate solutions for mobile hotspots in the IVIN design.

A. Interference among mobile hotspots

As mentioned in the previous section, the emergence of mobile hotspots can cause a variety of problems. One of the problems is interference among mobile hotspots. If a huge number of mobile hotspots are densely located, the throughput of the user devices in the vehicle can be tremendously reduced, or even drop internet service altogether. For example, on the road or highway, if there are a lot of cars equipped with a mobile hotspot, they may not have much of a chance to occupy the available channel to access the Internet because of a traffic jam (Fig. 2). In particular, this problem can be exacerbated when the passengers are served with time critical services such as video streaming or real time traffic notification. In the Wi-Fi IVIN, both the mobile device and the mobile hotspot move very quickly. This means that vehicles which suffer from interference can potentially move out of the interference zone.

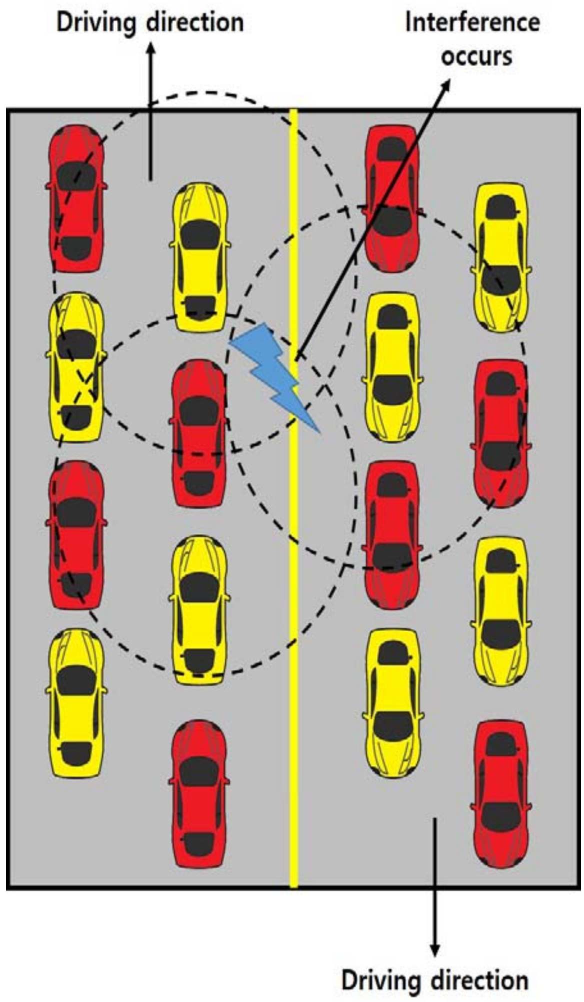
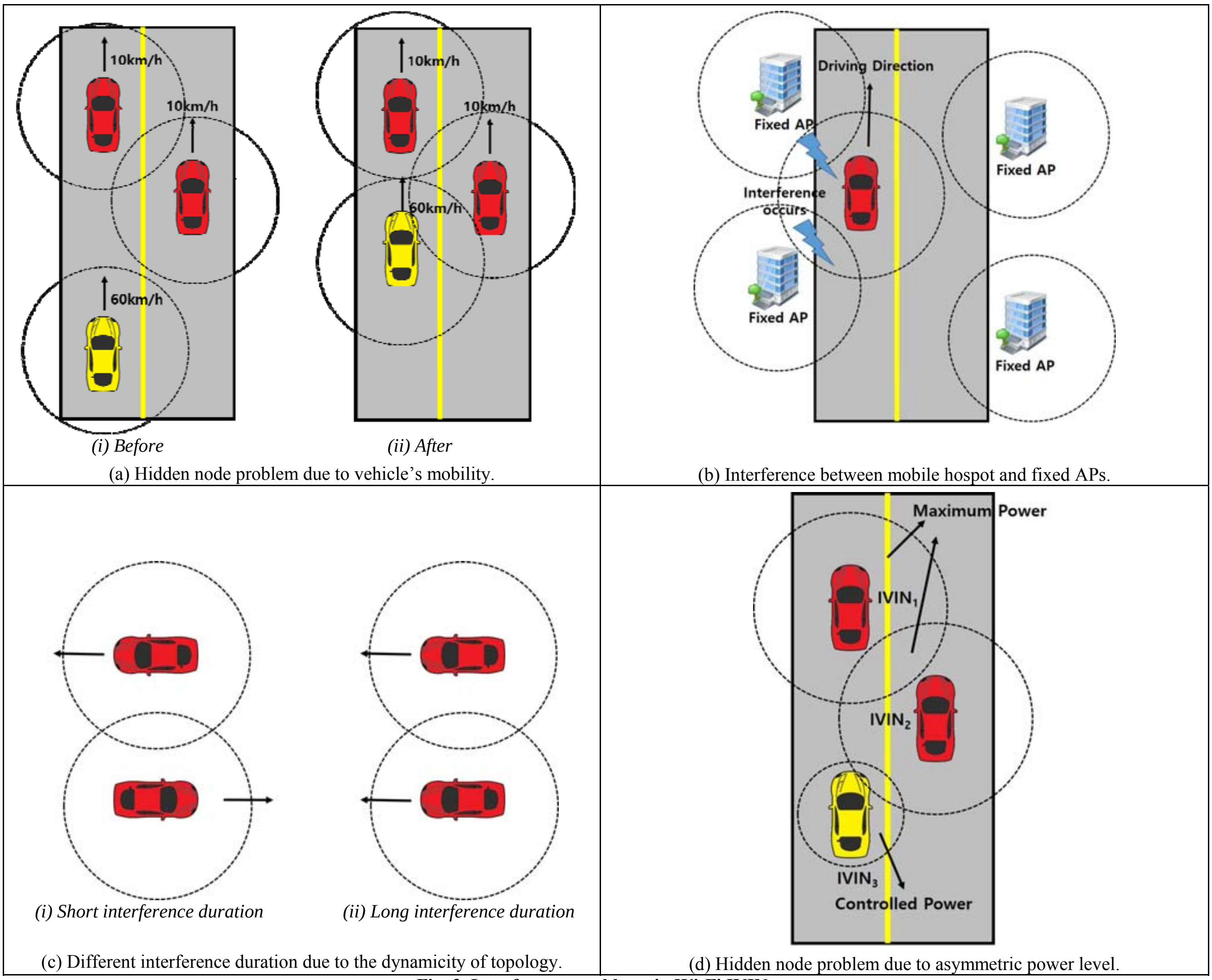


Fig. 2. Interference among mobile hotspots.

Traditionally, these kinds of problems have been challenged by a number of studies [9]. Interference avoidance techniques have been taken into account as a major research issued in wireless networks from physical to data link layers. The existing interference avoidance techniques have used multi-channel, power control, or cooperative scheduling schemes [10, 11]. Unfortunately, not only have there been few proposals aimed at resolving the interference, but they also do not consider the mobility of mobile devices or access points (mobile hotspots) in the Wi-Fi WLANs; further, since they assume that mobile devices and mobile hotspots have less mobility or no mobility (fixed), the existing techniques are not suitable for Wi-Fi IVINs.

B. Mobility problem

Since the mobile hotspot has mobility characteristics along with vehicle movement, it will appear and disappear on other specific networks repeatedly. This phenomenon will disrupt the existing competition among mobile hotspots and create a hidden node problem. Fig. 3.(a) shows the vehicle's mobility problem. As described in the figure, two vehicles are driving



(i) Before *(ii) After*

(a) Hidden node problem due to vehicle's mobility.

(b) Interference between mobile hospot and fixed APs.

(i) Short interference duration *(ii) Long interference duration*

(c) Different interference duration due to the dynamicity of topology.

(d) Hidden node problem due to asymmetric power level.

Fig. 3. Interference problems in Wi-Fi IVINs.

at 10 km/h and one vehicle is driving at 60 km/h. These two groups of vehicles do not interfere with each other. Moreover, they are not aware of each other because of their sensing range. After a while, the latter vehicle overtakes the other two vehicles and invades their communication range. As a result, the communications of the above group and latter vehicles collapse.

C. *Interference between mobile hotspot and fixed APs*

The emergence of the mobile hotspot will cause serious interference problems with existing fixed APs installed in public areas or buildings along the road. Fixed APs are installed after considering the transmission range, set of available channels, and/or number of neighboring APs. Therefore, users who exploit fixed AP networks are provided with stable throughput. However, it cannot provide reliable services anymore due to the appearance of mobile hotspots. Mobile hotspots frequently cause changes in the network topologies and environment. Moreover, some vehicles can stay on a particular network for an extended time, while other vehicles can go through the network instantaneously.

Fig. 3.(b) shows the interference between a mobile hotspot and fixed APs. The fixed APs are installed without any interference from each other. However, if a mobile hotspot moves along the road, interference can occur and the communication of the fixed APs might be disturbed. This problem will become even more serious when there are lots of APs densely located in a downtown area or public area. To resolve this problem, a mobile hotspot has to actively avoid interfering with the fixed APs communication range.

III. Interference Mitigation Techniques

In this section, we present techniques to resolve the above problems. To avoid interference among mobile hotspots and/or other fixed APs, there has been a significant amount of research which uses channel switching, power control, and cooperation with neighbor nodes. We discuss each approach in terms of how to avoid interference in detail and what its limitations are in the Wi-Fi IVIN. After that, we propose some solutions which are suitable for Wi-Fi IVIN networks.

A. *Channel hopping technique*

To resolve the aforementioned problems, we have surveyed a large variety of schemes in the literature. As a result, we have found that one of the most effective solutions for interference avoidance is the channel hopping technique. We classify prior channel hopping techniques among APs[1] into two categories: *proactive* [12, 13] and *reactive* [14]. The former is an interference avoidance technique that presumably changes the frequency of channels to statistically reduce the chances of having the same channel among APs. With the proactive scheme, the probability of having the same channel will be relatively small in the next period, even if the APs currently have the same channel. However, the proactive scheme involves synchronization among the APs, and also causes unexpected overhead since the APs need to change the frequency channel unnecessarily, even if the APs currently have different channels. The latter is a reactive scheme (avoidance technique) which tries to resolve the interference once it occurs. Unlike the former, this strategy can reduce unnecessary overhead since channel hopping occurs only when needed.

The aforementioned mechanisms try to resolve interference by selecting a channel reactively or proactively. However, they do not take the mobility of the APs into consideration, where mobile hotspots can randomly or dynamically move in any direction. This shortcoming makes the result less effective in the case of Wi-Fi IVINs.

To cope with the dynamicity of this topology, our approach exploits the mobility vector and location information of neighboring mobile hotspots provided by the global positioning system (GPS). Based on the location information, the proposed scheme computes the interference duration with neighboring mobile hotspots. If the interference duration of the current channel is negligible, as in Fig. 3(c.i), it continues to use the channel. However, if the interference duration is considerably long, as in Fig. 3.(c.ii), the mobile hotspots will search for another available channel to avoid interference. The rationale behind this approach is that the general channel hopping technique will impose unnecessary overhead when the mobile hotspot interferes with the others in a very short period of time. In case the interference duration is relatively long, the mobile hotspots are required to search and move to another channel. While searching, mobile hotspots contend periodically with themselves to acquire a channel. For the contention, we provide a notion of priority based on the definition of traffic volume levels in the Wi-Fi IVINs. The mobile hotspot with higher traffic volume will gain higher priority in terms of the channel occupation to increase the overall networks throughput.

B. *Power control technique*

In the vehicle, the distance between a mobile hotspot and mobile devices used by passengers is relatively small and limited. With the help of existing power control techniques, adjusting the transmit power optimizes the whole vehicle coverage to be minimal, reducing the risk of interference among mobile hotspots. Unfortunately, most of the previous studies adopted power control approaches that were focused on the energy saving aspect [15]. Few studies have tried to resolve the interference problem by using power control for in-vehicle communications. Moreover, these approaches cause another potential problem - a hidden node resulting from asymmetric links, due to the variable transmit power (Fig. 3.(d)). As shown in Fig. 3.(d), mobile hotspots in $IVIN_1$ and $IVIN_2$ use the maximum power level, whereas the mobile hotspot in $IVIN_3$ uses a controlled power level. Although the mobile hotspot in $IVIN_3$ can detect the mobile hotspots in $IVIN_1$ and $IVIN_2$, the contrary case is not true; that is, $IVIN_1$ and $IVIN_2$ cannot sense the existence of a mobile hotspot in $IVIN_3$. Therefore, the communication of the mobile hotspots in $IVIN_1$ and $IVIN_2$ will interfere with the mobile hotspot in $IVIN_3$. Even if the transmit power level is limited to covering just a vehicle, the mobile devices located near the vehicle's surface interfere with other IVINs. Moreover, although the mobile device limits its power level, its coverage might be extended to neighboring vehicles. To resolve the above problem, the mobile hotspots or devices notify that they are engaged in communication with their neighboring nodes, where neighboring nodes can interfere with the originator's communication. For this reason, the transmit power level must be the same as the power level of the others. One of the ways to adapt the same power level is for the sender to transmit RTS/CTS, including its communication information, using the maximum power level. Since the RTS/CTS frame size is relatively small compared to the data frame size, the interference duration caused by the maximum power level is not a serious problem. However, if this scheme is adapted for Wi-Fi IVINs, the vehicles which did not receive RTS can interfere with the sender. These vehicles might be located outside of the range of the sender's maximum power level and must be gradually getting closer to the sender. Therefore, the maximum power level is not enough to cover all of the neighboring nodes, and the mobility of the vehicles must also be considered in the case of mobile hotspot design.

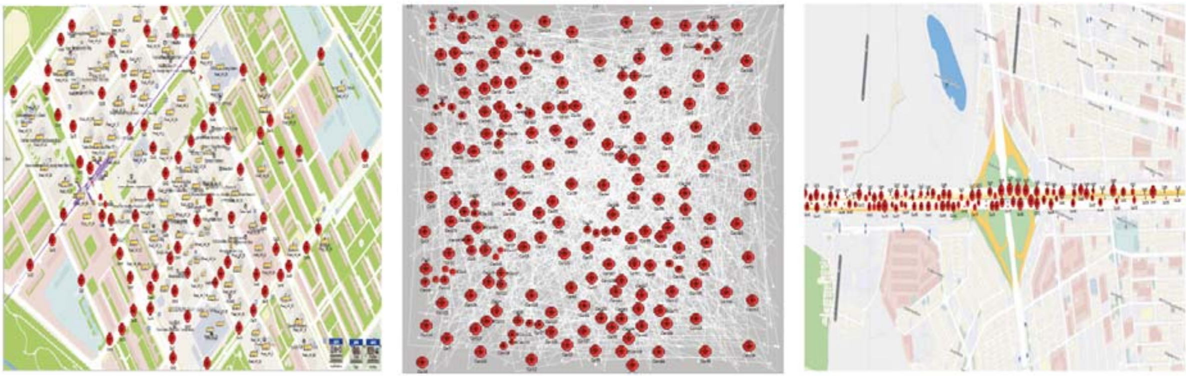
C. *Cooperation with infrastructures and neighboring vehicles*

Another solution to avoid interference among mobile hotspots is to have the mobile hotspots cooperate with infrastructures or neighboring vehicles. For example, some vehicles can configure small networks where the vehicles have similar mobility. Therefore, they can negotiate and communicate with each other according to the time schedule or control the transmit power for simultaneous communication. The merit of this approach is that it is less sensitive to network changes, but it spends additional network infrastructure configuration cost.

IV. PERFORMANCE EVALUATION

Since the existing techniques for interference avoidance in Wi-Fi access networks do not consider vehicular mobility, we conclude that those techniques are not suitable for Wi-Fi

[1] In this subsection, the term AP covers mobile hotspot as well.



(a) (b) (c)

Fig. 4. Simulation topologies: (a) Manhattan model (1 km x 1 km; 10~60 km/h speed), (b) Random Walk model (1 km x 1 km; 10~120 km/h speed) (c) Highway model (10 m x 400 km; 70~110 km/h speed).

IVINs. In this section, we evaluate two interference avoidance techniques. The first technique uses a vehicle's mobility vector and calculates the interference duration among vehicles. If the interference duration is long, one of the vehicles must switch the channel. The second technique uses a power control mechanism where the mobile hotspot limits the power in order to cover only the vehicle, reducing the interference. This technique also transmits the RTS frame using the maximum power level. It can reduce the probability of the hidden node problem in Wi-Fi IVINs.

The performance is evaluated using the OPNET modeler. The maximum transmission power is 100 mW. The traffic type is set to VBR with a packet size of between 1000 and 5000 bytes, and a packet inter-arrival time of 25 ms, operating in three channels (1, 6, and 11). We applied the Random Walk, Manhattan, and Highway scenarios to the given topology. The topology sizes are 2 km x 2 km (Random Walk, Manhattan) and 10 m x 400 km (Highway) along with a car density of between 0 and 320 cars/km^2. Vehicles move at speeds of around 80-120 km/h, 10-60 km/h, and 60-140 km/h in Random Walk, Manhattan, and Highway, respectively. Moreover, we deployed fixed APs in the Manhattan scenario in order to evaluate the performance under a real environment.

A. *Case study 1*

To evaluate interference avoidance techniques in Wi-Fi IVINs, we compare the performance of the proposed scheme with the IEEE 802.11g standard, the distributed dynamic channel selection (DDCS) scheme [14], and the SNR based channel hopping scheme in densely located Wi-Fi IVINs. In the DDCS scheme, each vehicle exploits the MAC delay by observing the channel continuously, where channel switching occurs if the MAC delay exceeds a certain threshold. In the SNR based channel hopping scheme, each vehicle monitors the channel status and randomly switches the channel if the SNR drops lower than a specific threshold. To simulate as a more realistic scenario, we apply the Random Walk, Manhattan, and Highway scenarios to a given topology. The initial node positions in the topology are randomly selected (Fig. 4).

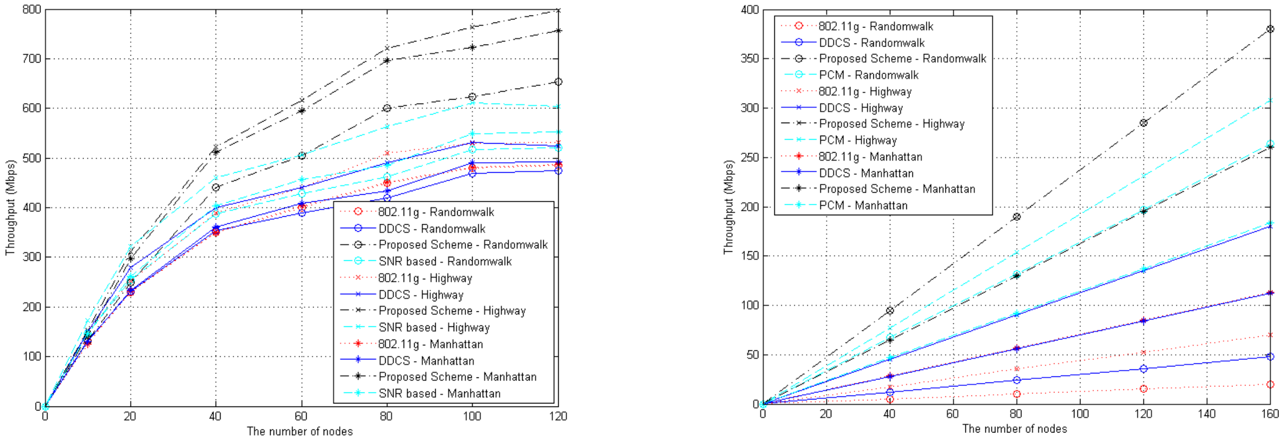
Figure 5.(a) shows that the throughput is directly proportional to the number of nodes. This result was measured under a fixed traffic load of 40 frames/sec. As shown in the figure, the average of the aggregated throughput increases as the number of nodes increases for all four schemes and mobility models. In the range of 0-40 nodes, the throughput increases rapidly and the number of collisions from each mobile hotspot will not be significant because the node density and the probability of interference are relatively small. However, in the range of 40-120 nodes, the aggregated throughput grows more slowly since the increase in node density causes more collisions.

Our proposed scheme outperforms the other three schemes. This is because, in the DDCS and SNR based schemes, the channel switching is triggered after suffering from interference. On the other hand, in the proposed scheme, the vehicle proactively predicts the interference duration based off of the mobility vectors and location information of the neighboring vehicles and takes an appropriate action in advance.

B. *Case study 2*

Another proposed technique uses power control in order to avoid interference among mobile hotspots. In this technique, each mobile hotspot computes the optimum transmit power and limits the power to cover the vehicle only; this enables the maximization of the spatial reuse of a given frequency channel. Further, the RTS frame with increased power can resolve the hidden node problem, where the RTS frame can be relayed by a neighboring vehicle. Since the vehicle has mobility, the RTS frame has to be delivered outside of the transmission range. Therefore, we expect that our approach can reduce not only the probability of the hidden node problem, but also the interference between mobile hotspots and fixed APs.

This simulation has been conducted in the same network topology as in the first case study. However, we limited the number of channels to be to two. To evaluate our technique, we compared our method with the IEEE 802.11g standard, DDCS scheme, and PCM scheme. The PCM scheme controls the transmit power and continuously transmits with maximum power, in order to prevent the hidden node problem. Figure



(a) Channel hopping technique

(b) Power control technique

Fig. 5. The throughput vs. the number of nodes in Wi-Fi IVINs

5.(b) shows that the aggregated throughput is directly proportional to the number of nodes in the three simulation topologies with three mobility models. The increase in the number of nodes generates a greater traffic load for all schemes in the figure. We observe that our proposed interference avoidance scheme has relatively better performance in the Highway model and Random Walk model as compared with the Manhattan model, as well as with other schemes. The reason for this is that the fixed APs are not used by our scheme for the Manhattan model. Therefore, fixed APs transmit a frame with normal power which causes more interference and a hidden node problem. On the other hand, all of the APs transmit a frame with normal power in IEEE 802.11g, and thus the hidden node problem does not occur. Therefore, IEEE 802.11g outperforms the Manhattan model as compared to the other topology models.

C. Discussion

The throughput gain of the proposed scheme in IV-A and IV-B is achieved at the expense of extra signaling traffic. To reduce signaling overheads, we can consider other schemes such as SNR [10] and DDCS [14]. However, as mentioned previously, their approaches blindly react after interference (see Fig. 5.(a)), and thus these types of schemes are not suitable for IVINs.

Additionally, when the relative velocity of the vehicles is very high (as in the Highway model), the update time for the mobility vector and location information may be insufficient. However, the interference duration would be very short in that case, and thus it does not cause significant performance degradation. We can observe this phenomenon in the results of the Highway model in Fig. 5. In the case studies (IV-A and IV-B), we show two approaches separately to evaluate and compare the effectiveness and performance between them. The combined solution of the two approaches might be useful to provide better performance of IVINs.

V. Conclusions and Future Work

The in-vehicular infotainment network plays an important role in human life, while the personal and public transportation means have raised rapidly. This article introduces the Wi-Fi IVIN and its technical challenges of interference. To resolve this problem, there has been a great deal of research aimed at avoiding the interference by using channel hopping, power control, and cooperation with neighboring nodes. However, most of the research does not consider the vehicular mobility problem. Due to the vehicle’s mobility, the topology of the network is frequently changed. We proposed two types of interference avoidance techniques for Wi-Fi IVIN in this article. Our simulation results show that when considering the mobility of the vehicles, the proposed techniques outperform the existing schemes significantly in terms of throughput.

There are still technical challenges needed to fully exploit the potential of the IVINs. For example, the proposed techniques have signaling overheads and processing time delay. Therefore, the proposed schemes need to be further refined in order to take advantage of the opportunities in the IVINs.

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