Spectrum Sharing of Wi-Fi and DSRC In The 5.9 GHz Band

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ABSTRACT

Given the likely government mandate, every new vehicle in the near future is expected to have the capability of "talking" to each other. DSRC is the primary technology that has been developed to implement this capability. Via DSRC technology, vehicles are able to periodically share their status information with other nearby traffic participants, thereby improving situational awareness among all traffic participants.

Although much prior work has demonstrated that DSRC technology is adequate to support safety message exchanges, several challenges remain, among which the coexistence of legacy wireless technologies, such as Wi-Fi, and DSRC in the 5.9 GHz band is actively discussed in both the U.S. and Europe. Compared to conventional spectrum sharing scenarios, such as unlicensed devices sharing TV whitespaces, the safety-critical nature of DSRC transmissions places stricter requirements on the effectiveness of spectrum sharing mechanisms. As part of my thesis, I conduct such an analysis by identifying fundamental challenges of sharing the 5.9 GHz band between DSRC and Wi-Fi, providing guidance on challenging scenarios where Wi-Fi devices are not able to provide adequate protection to DSRC devices, and evaluating the performance of two recently proposed spectrum sharing mechanisms, Detect & Vacate and Detect & Mitigate, under these challenging scenarios.

1. INTRODUCTION

Dedicated Short Range Communications (DSRC) is an Intelligent Transportation System (ITS) technology which enables direct vehicle-to-vehicle and vehicle-to/from-infrastructure communications. It allows a vehicle to share trajectory, driving status as well prevailing road and traffic conditions with other vehicles. With this shared information, significant improvements in road safety and efficiency are expected.

Given the potential impact of DSRC, the U.S. Federal Communications Commission (FCC) has exclusively allocated 5.850-5.925 GHz band (5.9 GHz band) for DSRC-based applications in 1999 [1]. However, with the rapid growth of Wi-Fi devices popularity, the 2.4 GHz and 5.8 GHz Industrial, Scientific and Medical (ISM) bands have become increasingly congested. Driven by the bandwidth demands, strong interest from the Wi-Fi industry exists in exploiting the adjacent 5.9 GHz band [5], which would allow usage of several new Wi-Fi channels. Compared to other spectrum sharing scenarios (e.g., [3]), which have primarily focused on non-safety critical and non-latency critical applications, the safety-critical nature of DSRC places stricter requirements on the spectrum sharing performance—as the primary user of the band, the DSRC systems should experience no or negligible performance degradation.

Two spectrum sharing mechanisms, Detect & Vacate (D&V) and Detect & Mitigate (D&M), have been recently proposed in TR 103 319 [2]. These protocols are currently under further investigation in the Broadband Radio Access Networks (BRAN) working group within the European Telecommunications Standards Institute (ETSI). However, our analysis identifies the delayed detection problem due to self-interference and the unilateral hidden terminal problem as the key issues of the two protocols. Delayed detection arises because conventional primary user detection mechanisms on secondary user devices are only effective during idle periods, i.e. when the Wi-Fi device is not transmitting. While not unique to this scenario, the detection delay is more critical due to fast moving vehicles and the safety-related nature. The unilateral hidden terminal problem arises due to different channel bandwidths, which means that DSRC devices can not effectively detect and defer to a Wi-Fi transmission. This leads to collision losses that affect DSRC transmissions. With insights learned from the analysis, two scenarios, where the Wi-Fi devices are not able to provide adequate protection to DSRC devices, are identified. The performance of the proposed mechanisms is then evaluated in these scenarios via carefully calibrated ns-3 simulations.

2. PRELIMINARY RESULTS

2.1 Systematic Analysis

The investigation of D&V and D&M falls into two phases, i.e., the pre-detection phase and the post-detection phase. The former starts from the moment at which DSRC transmissions appear on the channel and ends when the interfering Wi-Fi devices apply mitigation procedures. In this phase, the primary concern is how well a Wi-Fi device can detect the presence of DSRC transmissions. It has been observed that due to strong self-interference, a Wi-Fi device

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can detect the presence of DSRC transmissions only when the Wi-Fi device itself is not transmitting. This process can be approximated as a Bernoulli experiment and the probability of a successful detection decreases as the Wi-Fi traffic load increases.

The analysis for the post-detection phase focuses on studying how well a Wi-Fi device can protect DSRC transmissions after it detects one. Due to lack of mutual carrier sensing, a unilateral hidden terminal problem can arise, causing undesired packet collision between DSRC and Wi-Fi. The higher the Wi-Fi traffic load is, the larger the probability of packet collision is.

2.2 Preliminary Simulation Results

A four-leg urban intersection with large buildings at corners is selected as the primary simulation scenario for following reasons: 1) Wi-Fi deployment is commonly seen in an urban intersection, e.g., in the buildings near the intersection; 2) communications between DSRC devices in two perpendicular roads are mostly blocked by the buildings, resulting in non-line-of-sight (NLOS) communications. Comparing to line-of-sight (LOS) communications, NLOS communications are normally more vulnerable to interference due to much lower signal strength. Specifically, in the studied intersection, each DSRC device is mounted on one car and two cars are placed in two perpendicular roads of the intersection. Our simulation models are calibrated via the data collected in a vehicular network experiment with 400 DSRC transmitters. The calibration primarily focused on the propagation model and the receiver model of the simulator. The details of the simulator calibration have been reported in [4].

2.2.1 Pre-detection Performance

Fig. 1 shows that the average number of DSRC transmissions to their first detection by Wi-Fi devices for D&V and D&M is the same since the two mechanisms share the same detection phase. However, both mechanisms require about 20 DSRC transmissions before a Wi-Fi device can detect the presence of DSRC transmissions. For a typical DSRC transmission interval, i.e., 100 ms, it may take up to 2 seconds. Such delayed detection could further degrade the effectiveness of DSRC-based safety applications.

2.2.2 Post-detection Performance

The packet error rate (PER) of DSRC transmissions between two devices for different Wi-Fi Access Categories [1] is depicted in Fig. 2. It is observed that without Wi-Fi traffic, the packet loss of DSRC transmission is about 0.2% only. However, 11.52% extra packet loss is introduced by the Wi-Fi transmissions when AC_BE is used. This extra packet loss is increased to 25.98% and 28.22% for AC_VI and AC_VO, respectively. The greater packet loss rate for AC_VI and AC_VO is because higher Wi-Fi traffic load is allowed on the channel when these AC are used.

3. FUTURE WORK

As the future work, I plan to extend my work in the following directions.

Improving DSRC detection performance: A Wi-Fi device can detect the presence of DSRC transmissions only when it is not transmitting. Therefore, increasing the length of Wi-Fi idle periods is expected to significantly improve the detection performance. One practical proposal is to adjust the parameters of the inter-frame spacing configuration. However, longer Wi-Fi idle periods would naturally increase the overhead of Wi-Fi transmissions and thus decrease the benefit of Wi-Fi sharing the band with DSRC. To balance this trade-off, an adaptive mechanism, which can adjust the parameters of the inter-frame spacing based on the length of Wi-Fi transmission duration and the recent DSRC detection history, would be the desired choice.

Studying the impact of coexisting Wi-Fi traffic on the performance of DSRC-based safety applications: The current work primarily focuses on studying the impact of coexisted Wi-Fi traffic on the communications between DSRC devices. However, how the effectiveness of these safety applications built upon DSRC technology is affected remains unknown (e.g., the warning timing of a DSRC-based crash warning system may be changed due to increased packet loss).

Studying other spectrum sharing proposals: Besides the two currently studied spectrum sharing mechanisms, other proposals are actively discussed as well. One good candidate is to re-organize the channel allocation of DSRC bands (i.e., moving safety-critical transmissions to the upper 30 MHz ITS band and sharing the lower 45 MHz ITS band with Wi-Fi). Given this different design from D&V and D&M, it is also interesting to understand its advantages and limitations.

[1]Wi-Fi employs Enhanced Distributed Channel Access (EDCA) approach to provide prioritized channel access for different access categories (ACs).

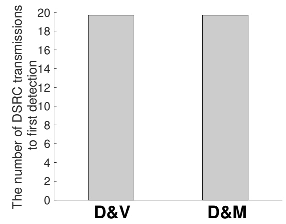

Figure 1: The average number of DSRC transmissions to the first detection: D&V v.s. D&M

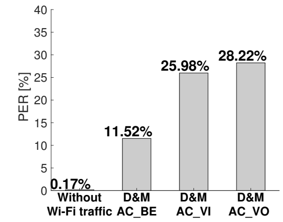

Figure 2: The post-detection PER of DSRC device with different EDCA categories

4. REFERENCES

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