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Self and static interference mitigation scheme for coexisting wireless networks ☆

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ABSTRACT

High density of coexisting networks in the Industrial, Scientific and Medical (ISM) band leads to static and self interferences among different communication entities. The inevitability of these interferences demands for interference avoidance schemes to ensure reliability of network operations. This paper proposes a novel Diversified Adaptive Frequency Rolling (DAFR) technique for frequency hopping in Bluetooth piconets. DAFR employs intelligent hopping procedures in order to mitigate self interferences, weeds out the static interferer efficiently and ensures sufficient frequency diversity. We compare the performance of our proposed technique with the widely used existing frequency hopping techniques, namely, Adaptive Frequency Hopping (AFH) and Adaptive Frequency Rolling (AFR). Simulation studies validate the significant improvement in goodput and hopping diversity of our scheme compared to other schemes and demonstrate its potential benefit in real world deployment.

1. Introduction

Coexistence of multiple networks operating in the Industrial, Scientific and Medical (ISM) band causes unwanted interference among competing wireless technologies and devices such as Wireless Local Area Network (WLAN), Bluetooth, Personal Area Network (PAN), Cordless, etc. Among these existing standards, Bluetooth is one of the standards for low cost, simple and low power consumption devices, which provides promising features for the next generation network technologies, e.g., industrial automation networks. Also WLAN (IEEE 802.11) employs very well standardized protocols with higher coverage area and enjoys mass deployment of WiFi-compliant devices in industrial premises, offices, homes and public hotspots, to a point that every laptop, PDA, smart phone and many other devices are preinstalled with WiFi network card. Many of such devices now-a-days support both WiFi and Bluetooth. Both networks are self configuring which makes their deployment very easy. Since no or little fixed infrastructure is required, their operation and maintenance is also very cheap and easy. All these advantages will witness more and more networks deploying WiFi and Bluetooth in future. This has led to tremendous attention from both industry and researchers on the issue of co-existence of WiFi and Bluetooth networks.

Particularly in the case of Bluetooth based hopping networks, Federal Communications Commission (FCC) has imposed constraints for frequency hopping networks in the ISM band (containing 79 channels in total) to ensure fair utilization of the available frequency resources. According to the FCC regulation statement (FCC-RS) for a hopping network [1]: "Frequency hopping systems in the 2400–2483.5 MHz band shall use at least 15 channels. The average time of occupancy on any channel shall not be greater than 0.4 s within a period of 0.4 s multiplied by the number of hopping channels employed."

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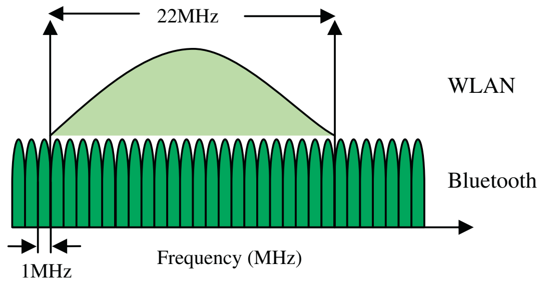

Fig. 1. Coexistence issue between WLAN and Bluetooth.

In case of WLAN, there are 14 WLAN channels in the ISM band, with each channel occupying a bandwidth of 22 MHz. Fig. 1 gives the orientation of a WLAN channels along with 79 Bluetooth channels each of 1 MHz bandwidth [2]. The coexistence of Bluetooth based hopping networks and WLAN results in the extensive interference. These networks experience two types of interferences, i.e., static interference and self interference [3]. In static interference, duration of the interference is more than the packet duration, e.g., interference between WLAN with direct sequence spread spectrum (DSSS) and Bluetooth. While in self-interference, duration of the interference is of the order of packet duration. It is the interference caused by the coexisting hopping networks, e.g. Bluetooth piconets.

Extensive studies have been carried out that analyze the performance of coexisting networks and propose solutions for different networks to coexist in ISM Band without interfering [4–16]. Much research is being conducted to explore and enhance the reliability of Bluetooth. Coexistence between 802.11g WLAN and Bluetooth was analyzed in [17], where the authors concluded that both Bluetooth and WLAN networks should employ intelligent, non-interdependent interference mitigation techniques. Sydanheimo et al. [18] demonstrated interferences in ISM band by the spectrum measurements for Bluetooth, WLAN and microwave oven. El-Hoiydi [19] presented upper and lower bounds on the packet error rate when multiple Bluetooth networks coexist together. Such interferences result in the '*goodput*' degradation of the overall network. Goodput is a quantification metric which characterizes the fraction of successful transmissions.

In Bluetooth hopping networks, a master is connected to seven slaves in a star topology [20]. In Bluetooth Interference Aware Scheduling (BIAS) [21], the master transmits the data only if it finds '*good*' frequencies for itself as well as for the slave, otherwise waits and causes considerable delays. '*Good*' and '*bad*' frequencies are decided on the basis of past transmission experiences, either successful or unsuccessful. One of the simplest metric to classify the channels as '*good*' or '*bad*' is Packet Error Rate (PER) analysis [19]. If for a particular channel, PER exceeds a certain predefined threshold, that channel may be marked as '*bad*'. Adaptive Frequency Hopping (AFH) [22] is currently being used extensively for Bluetooth piconets. In AFH, all the coexisting piconets pick any of the '79' channels pseudo-randomly, causing self interference whenever two piconets hop on the same frequency at the same time. AFH does not differentiate between static and self interferers and neither contains any method to avoid self interferences. In dual channel transmission (DCT) [23], data is transmitted on two channels maintaining the frequency offset of 22 MHz, i.e., bandwidth of WLAN. If one of the channels collides with WLAN, the other may survive.

Yomo et al., proposed a new technique, called adaptive frequency rolling (AFR) which avoids self-interference [24]. In AFR, coexisting piconets hop on a small set of frequencies for a specific time interval, rather than using the whole range of frequencies as in AFH. The author uses the term '*hopset*' for these small ranges of frequencies. In AFR, self interference is avoided by assigning non-overlapping hopsets to the coexisting piconets, and jumping to another random channel when hopsets of two piconets overlap. Static interference is avoided by adaptive frequency rolling with probing (AFR-P) mechanism. In AFR-P, piconets hop on the entire range of frequencies and mark '*good*' and '*bad*' frequencies based on their transmission experiences. Removal of the channels overlapped by the static interferer is not only time consuming but also results in degradation of the goodput because coexisting piconets suffer from self interferences during probing state [25]. Popovski et al. [26] also presented a new technique, called Dynamic Adaptive Frequency Hopping (DAFH). In this technique, coexisting piconets suffering from interference and having unsuccessful transmission experiences readjust their channels utilization by splitting the frequencies into halves. Since the number of channels is halved after each splitting instance, this technique has the potential to violate FCC-RS [1] for frequency hopping in ISM band if number of piconets is increased, i.e., the constraint that the coexisting piconets should use at least 15 channels may be violated. Chiasserini and Rao [27] proposed two different techniques (overlap avoidance scheme) for Bluetooth voice and data traffic to avoid interference between WLAN and Bluetooth, but these techniques cause significant processing delays.

This study enhances the performance of the Bluetooth based hopping networks by diversifying channel selection in AFR [25]. AFR which is one of the most intelligent and established techniques for interference mitigation in case of Bluetooth based hopping networks, suffers from two problems: 1) frequency diversity which is a measure of the frequency offset between two consecutive channels selected, is significantly reduced if number of piconets is high enough and 2) goodput is decreased in the presence of WLAN, because large part of throughput is wasted in a bid to avoid static interference using AFR-P that requires traversal of all channels and self interferences also comes into play. Additionally, shifting to transient