A Fast Adaptive Frequency Hopping Algorithm Mitigating the Effect of Interference in Bluetooth Low Energy Networks

Yongtak Yoon, Kijun Han*

Abstract— The speed and the efficiency of short range communication has increased with the evolution of wireless technologies i.e. Wireless Local Area Network (WLAN), ZigBee, and Bluetooth Low Energy (BLE). Especially, the BLE shows promising results in different fields such as Internet of Things (IoT), health-care, body area networks, etc. As a result of dramatic increase in the wireless device, the frequency interference in 2.4 GHz Industrial Scientific Medical (ISM) band has raised, resulting a higher packet loss. In this paper, we propose Fast Adaptive Frequency Hopping Algorithm (FAFH) to mitigate the effects of interference in BLE. The proposed FAFH algorithm immediately hops to a new channel without waiting for completion of the current connection event. The simulation results show that the FAFH performs better in dense wireless networks as well as improved performances comparing to AFH algorithm.

Index Terms— BLE, Bluetooth, Frequency hopping, Interference, Packet loss, 2.4 GHz.

I. INTRODUCTION

Recently, the mobile user requirements i.e. data, speed, the Internet, energy consumption, etc. has given the opportunity to introduce novel technologies. BLE is one of the prominent candidates to provide low power and low-cost communication. It was first introduced in version 4.0 of the Bluetooth Standard [1]. Since then it has become the leading wireless technology for a broad range of devices.

As already stated, BLE operates in the unlicensed 2.4 GHz ISM band, which increase the chances of interference, congestion, and packet loss. The coexistence of other short-range communication technologies such as WIFI, ZigBee, etc. in the same environment overcrowd the 2.4 GHz ISM band. Consequently, several research studies have been published concerning the co-existence issue of the BLE with other technologies [2]. This paper proposes FAFH Algorithm to mitigate the effects of interference, thereby enhances the performance of coexisting BLE networks in the crowded 2.4 GHz band.

II. STANDARD AFH OVERVIEW

The AFH is one of well-known hopping mechanisms that provide environmental adapting properties by identifying and eliminating the fixed source of interference [3]. The AFH create connection event between the master and slave, the channel is further divided into non-overlapping time units called connection events. However, each connection event always utilizes only a single data channel. The master always initiates the connection event, as it transmits a data packet to the slave. Consequently, the slave must send a response packet to the master, once it received the packet from the master. However, the master is not bound to respond to the slave after receiving a packet. The master always waits for at least $T_{IFS}$ of 150 µs until the end of transmitting a packet and the start of the next packet transmission.

Once the master and slave device created a connection, the AFH algorithm selects a data channel to use throughout a connection event. A data channel for a connection event is selected by an example of the algorithm is shown in Fig 1.

III. PROPOSED ALGORITHM

In this section, we provide a detailed description of the proposed FAFH. As previously stated, the AFH algorithm helps in avoiding interference. As a result, it cannot transmit the data packets at the occurrence of interference. The transmission of data packet fails due to two reasons, 1) when there is interference during transmission of a data packet from the master to the slave or 2) when there is interference during transmission of an acknowledgment from the slave to the master. In either situation, the transferred packet is garbled. Consequently, the master retransmits the same data packet, which can be garbled again. The master continues data transmission until the end of current connection. Thus, it causes a severe wastage of channel capacity and takes a longer transmission time, since the master uses same channel when no
more data packets are available. In AFH, the master continues data transmission until the completion of current connection event, even though it experiences interference during data transmission.

In order to overcome the drawback of AFH, we propose FAFH algorithm. The FAFH algorithm is enabled when the interference occurrence is exceeding the predefined threshold.

![Fig. 3. Workflow of FAFH](image)

Fig. 2 shows the workflow of FAFH. FAFH closes the current connection event and start next connection event when INB reaches the threshold. Thus, FAFH algorithm is capable of transmitting more data packets than AFH algorithm within the same duration. In order to perform channel hopping, the current connection event requires to close the more data (MD) bit, which is included in data header. The MD bit is used to indicate that the master has more packets to send. The master sends a one-bit signal, MD bit, to the slave. If the MD bit received by the slave is 1, it indicates that master has more data packets to send, hence the connection event should be continued. Moreover, the slave should listen after sending an acknowledgement. On the other hand, if the master sends “0” as the MD bit, it indicates that the master does not have more packets to send, thus the connection event can be ceased.

The proposed FAFH algorithm uses 3 bits in the reserved field of data packet header to represent the interference as the Interference Notification Bit (INB).

![Table 1. Simulation parameters](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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<tbody>
<tr>
<td>Used channel set</td>
<td>0-4, 9-13, 17-19, 26, 27, and 32-36</td>
</tr>
<tr>
<td>Unused channel set</td>
<td>5-8, 14-16, 20-25, and 28-31</td>
</tr>
<tr>
<td>Number of used channels (N)</td>
<td>20</td>
</tr>
<tr>
<td>Packer error probability (α)</td>
<td>5 to 50%</td>
</tr>
<tr>
<td>Inter frame space (Tpps)</td>
<td>150 μs</td>
</tr>
<tr>
<td>INB threshold (θ)</td>
<td>3</td>
</tr>
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Fig. 3 shows retransmission rate in FAFH and AFH. The retransmission rate directly depends on the interference. The result depicts a higher retransmission rate as the interference increases up to a certain level. The graph reveals that the AFH performance is deteriorated from high packet loss due to its single connection event when the transmission is failed between the master and slave. On the contrary, the proposed algorithm has ensured less retransmission rate by closing current connection event and shifting to next connection event when transmission is failed between the master and a slave.

V. CONCLUSION

This paper presented FAFH algorithm for coexistence of BLE networks in heterogeneous environments. The simulation results have shown that the proposed FAFH offers a much shorter retransmission rate, average transmission time as well as higher channel utilization.

REFERENCES

