

# Modeling, Simulation & Performance Analysis of Bluetooth

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## ABSTRACT

*Mechanisms based on frequency hopping have been widely used to enable short range wireless networks to use resources from the unlicensed spectrum without frequency planning. As a price for open access, adverse interference may be experienced from other wireless devices that are transmitting in the same unlicensed band. A basic approach to mitigate this interference is the application of AFH and attempts to hop over a set (hopset) of less interfered channels. On the other hand, the regulation of unlicensed operation sets constraints on possible hopset adaptations. In this article we present two novel AFH strategies: EAFH (Enhanced Adaptive Frequency Algorithm) and SAFH (Smooth Adaptive Frequency Algorithm). The strategies are compared and their performance is analyzed based on various parameters.*

**Keywords:** SAFH, EAFH, BER, AFH

## 1. INTRODUCTION

The emerging short-range wireless technologies with ubiquitous usage imply utilization of the unlicensed spectrum. As a price for open access, the unlicensed wireless network may experience adverse interference from collocated wireless devices that are transmitting in the same unlicensed band. A wireless network should exhibit adaptive usage of the unlicensed spectrum so as to attain the best communication performance under the actual interference pattern, while complying with the regulations for unlicensed operation.

Frequency hopping (FH) is a method to enable sharing of the unlicensed spectrum among proximate networks, since it achieves frequency diversity and enables spectrum sharing without frequency planning. FH also decreases interference toward unlicensed devices that operate over a part of the spectrum used by the FH network. This is addressed by defining rules for spectrum usage that limits the radiated power and constrain the occupancy of the channels used in hopping. Bluetooth, [1] a prime example of an FH-based networking technology represents an instance of the wireless personal area network (WPAN), which has been further standardized within the IEEE 802.15 Working Group for WPAN [2]. A hopset is the set of channels used for hopping. Bluetooth uses a hopset of 79 frequencies in the unlicensed industrial, scientific, and medical (ISM) 2.4 GHz band.

Recent work has shown that the performance of a Bluetooth can be heavily degraded by interference from other devices. Interference in the unlicensed band can be mitigated by using either collaborative or non-collaborative techniques. In collaborative techniques, devices avoid one another's activity while easily sharing information, whereas in Non-collaborative Techniques, devices must adjust their behavior to avoid interfering with others [3]. Adaptive FH (AFH) is an important non-collaborative mechanism considered in [4] to mitigate the interference. An AFH attempts to select a hopset that consists of less interfered channels, while the individual channel occupancy conforms to the regulation [5]. From the AFH perspective, there are three different error sources: noise, frequency static (FS) interference, and frequency-dynamic self-interference.

The rest of this paper is organized as follows: Section 2 describes EAFH algorithm. SAFH algorithm is presented in Section 3. Section 4 presents the general System model. The performance of the EAFH and SAFH is analyzed, & compared in Section 5. Finally, concluding remarks are drawn in Section 6.

## 2. ENHANCED ADAPTIVE FREQUENCY HOPPING

An enhanced adaptive frequency hopping (EAFH) mechanism is used for improving the performance of frequency hopping-based wireless personal area networks (WPANs). The algorithm monitors the overall Packet error rate (PER) of the system to determine the right number of channels to be excluded from the hopset. Then based on the PER of individual channel, it decides whether to exclude a certain channel or not.

In order to exclude the bad channels being interfered from the hopset effectively, the paper [6] presented an EAFH scheme based on the feedback mechanism of PER. By monitoring the packet error bit, EAFH can determine the right

number of channels to be removed from the hopset. Then EAFH will decide which channel is to be removed as per packet error rate of individual channel.

The channels are parted into three groups. The group A is used to transmit multiple-slot packets, group B used for single-slot packet, and C is the group of excluded channels. As the channel condition is time-varying, the channel number of each group may change every time. EAFH can balance the usage rate of each channel and the average usage rate of all channels, because EAFH can modify the numbers of three channels based on the PER of every channel. Every user monitors the packet error rate of each channel, and detects all other channels' packet error rate at the same time. Determining the channel which group should be put into, EAFH can mitigate the interference.

The way to eliminate the frequency dynamic interference is that EAFH begin to adjust the channels in the hopset and the length of the packet, when users detect the external interference. In the initialization, the N channels are assigned to the A group, the 2N channels are parted into the group C and the rest of channels belong to the group B. After initialization, EAFH will keep an eye on the packet error rate all the time. While the packet error rate of channel in group A appears higher than the average packet error rate of all channels, EAFH will switch it with a channel which has lower PER in group B or C. In the same way, switching between group B and C may occur in certain conditions. The swap of the three groups can eliminate the unbalance of initial assignment and periodically updates the channels of each group.

While users detect the severe interference in a certain channel for long time, EAFH will recognize that it is the frequency interference in the channels and transitorily excluded the interfered channels from the hopset for duration of T. These channels belong to the subgroup of C, and channels in this subgroup will not join the switching progress.

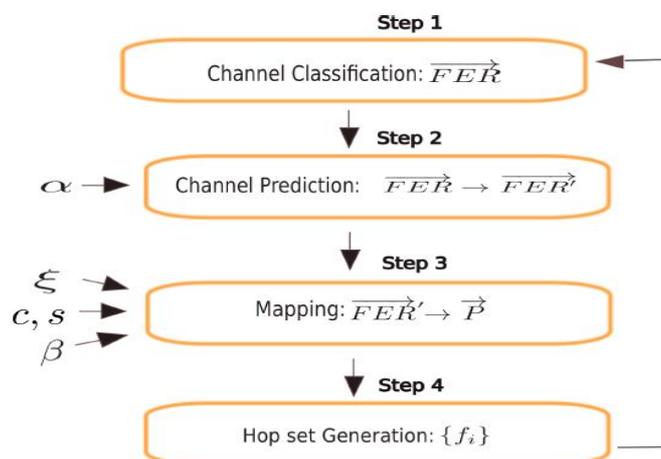
Although the occupancy of each channel does not equal to the average occupancy, it is closer to the average than orthogonal hopset mechanisms in general. This is because a EAFH adjusts its occupancy on any channel according to the interference level.

### 3. SMOOTH ADAPTIVE FREQUENCY HOPPING

Smooth Adaptive Frequency Hopping (SAFH) is based on Probabilistic channel usage [11]. the algorithm uses a kind cross-layer scheme of smooth adaptive frequency hopping, which is based on exponential smoothing filter by assigning usage probabilities to all channels [7]. In this way, SAFH can estimate and predict the channel conditions. Moreover, the upper layers are available to adapt SAFH by changing the parameters in a cross-layer approach. According to simulation, SAFH outperforms conventional frequency hopping and AFH.

There are four main elements of the adaptive hopping procedure SAFH has four major steps as illustrated in Figure 1. First it reads the values of the input parameters  $\alpha$ ,  $\xi$ , c, s and  $\beta$ . Then it assigns equal probability to all the channels and generates an initial hopset based on that. At every interval t, SAFH measures the FER of all the channels  $FER_i(t)$ , and calculates the average FER.

The other steps of SAFH are invoked when the average frame error rate FER exceeds the predefined threshold ( $\xi$ ), and at least one of channels has frame error rate below the threshold; in that case the algorithm uses exponential smoothing to predict  $FER_i(t + 1)$ , updates the hopping probability and generates a new hop-set.

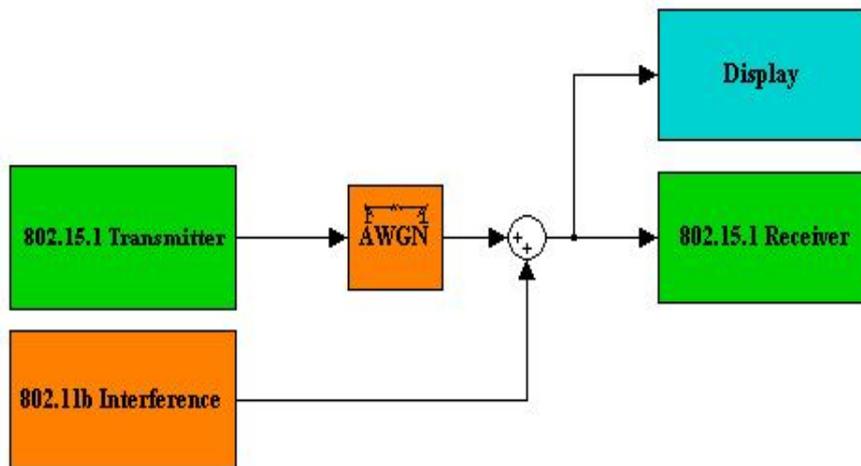


**Figure 1** Block Diagram of SAFH

As is shown in the Figure 1, SAFH has four steps: channel classification, channel prediction, mapping and hopset generation. AFH has only channel classification and hopset generation. In the first step, by analyzing the channel quality and measuring the frame error rate, SAFH can determine the frequencies and the power of interference at the present. SAFH can minimize the risk of incorrect classification. In the second step, SAFH uses exponential smoothing to predict the frame error rate In the third step, we map FER to a discrete probability distribution to satisfy the desired

level of the channel quality. Comparing with conventional adaptive frequency hopping avoiding a bad channel entirely, SAFH assigns a probability which is a function of its distance from the threshold. In the fourth step, SAFH makes the probability distribution map to a hopset.

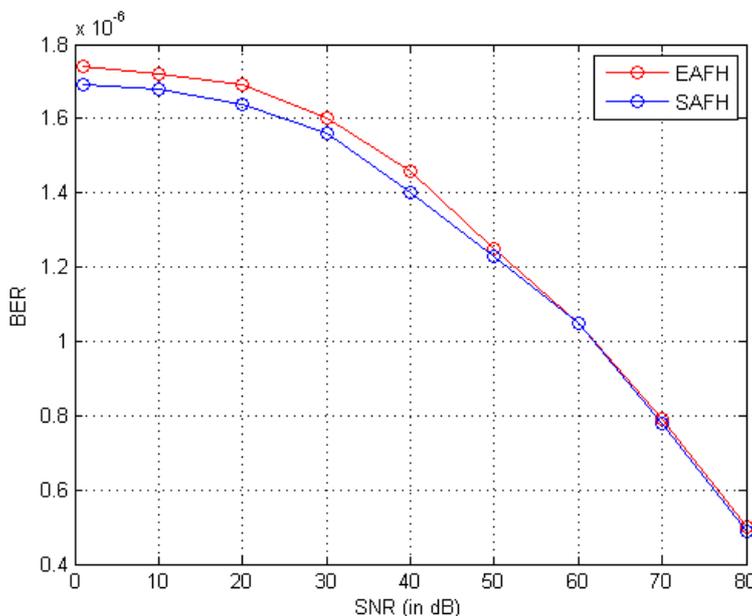
**4. SYSTEM MODEL**



**Figure 2.** System Model [8]

Simulation of wireless system is a crucial step for performance evaluation [9]. It helps in discovery of design flaws early in the development process. SIMULINK®, an extension of MATLAB is selected for simulation [10]. As a result we are able to use all features of the software during the analysis process. The Model consists of various blocks as shown in Figure 2. Opening up these subsystems reveals further levels of details. The 802.11 is generated by a separate independent block which allows us to control precisely the rate of 802.11 transmissions. In simulation, examination of the performance and the way the BER is affected is done.

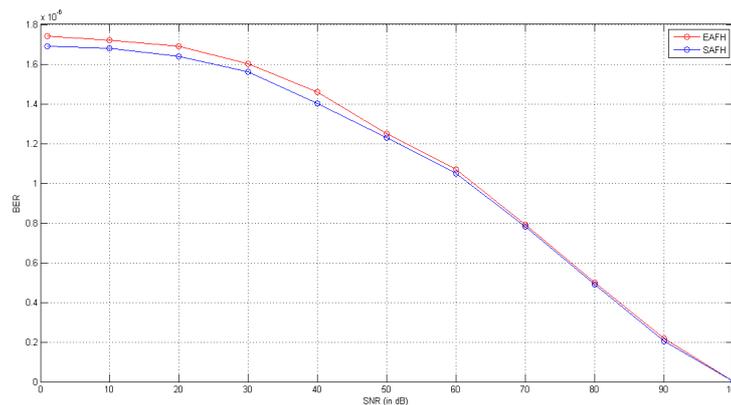
**5. SIMULATION RESULTS**



**Figure 3.** Performance of EAFH versus SAFH

The graph denotes the value of BER as observed from the simulation of 2 different systems, one using EAFH and another using SAFH as the frequency hopping mechanism. The simulation introduced additional interference in the 2.4 GHz band by having a 801.11 transmitter system in vicinity. The primary measurements were done by varying the amount of noise interference in the system by modifying the SNR of the channel.

It can be observed from the graph that for low values of SNRs i.e. high noise values, SAFH has better performance than EAFH in terms of BER.



**Figure 4.** Performance of EAFH versus SAFH with SNR=100

As the SNR increases, the BER drops. It can be noted that at higher SNR, both EAFH and SAFH perform almost equally. This is because as the SNRs improve, noise in channels also decreases. So there is no need of blocking any channel and all channels can perform at their optimum even without any advanced hopping mechanisms. However, achieving such high SNR in practice is not always possible and hence for all practical purposes, SAFH provides better performance than EAFH in terms of BER

## 6. CONCLUSIONS

In this article we have presented two novel strategies for adaptive frequency hopping (AFH) that operate in the unlicensed band: Enhanced adaptive frequency Hopping (EAFH) and Smooth adaptive frequency Hopping (SAFH). Smooth adaptive frequency hopping (SAFH) consists of four steps. First, it performs channel classification, then uses exponential smoothing filter to make channel prediction; based on the forecast status of the channels, SAFH determines the probability mass function, which is later mapped to a hop-set for frequency hopping.

An enhanced adaptive frequency hopping (EAFH) mechanism is used for improving the performance of frequency hopping based wireless personal area networks (WPANs). EAFH could manipulate hopset size and packet length simultaneously to enhance the coexistence ability of BT devices. An analytical model was developed to predict its performance.

SAFH has better performance than EAFH in terms of BER.

## REFERENCES

- [1] Bluetooth Std. Spec., Rev. 1.2, Nov. 2003.
- [2] IEEE 802.15 WG on Wireless Personal Area Networks, Sept. 2004; <http://www.ieee802.org/15/>
- [3] Omer A. Bamahdi, Salam A. Zummo, "An Adaptive Frequency Hopping Technique With Application to Bluetooth-WLAN Coexistence", in Proceedings of the 5th International Conference on Networking (ICN'06), Mauritius, UAE, pp. 131-136, April 2006.
- [4] IEEE Std. 802.15.2, "Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Band," 2003; <http://standards.ieee.org/>
- [5] FCC, "Operation within the Bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz," Pt. 15: Radio Frequency Devices, Oct. 2002.
- [6] Alex Chia-Chun Hsu, David S.L. Wei, C.-C. Jay Kuo, Norio Shiratori, Chung-Ju Chang, "Enhanced Adaptive Frequency Hopping for Wireless Personal Area Networks in a Coexistence Environment", in Proceedings of the Global Telecommunications Conference, GLOBECOM '07, IEEE, pp. 668 – 672, Nov. 2007.
- [7] Sami Ben Cheikh, Tim Esemann, Horst Hellbruck, "SAFH-Smooth Adaptive Frequency Hopping", in Proceedings of Third International Workshop on Cross Layer Design (IWCLD), IEEE, pp. 1-5, Nov. 2011
- [8] Zahir Aalam, S Vhatkar, B. K. Mishra, "IEEE 802.15.1 Simulation and BER Analysis under the Interference", in 2nd International Conference and workshop on Emerging Trends in Technology (ICWET), Proceedings published by International Journal of Computer Applications® (IJCA), pp. 24-28, 2011.
- [9] Principles of Communication Systems Simulation with Wireless applications. Prentice Hall, 2004.
- [10] Mathworks, "Simulink - simulation and model-based design," [<http://www.mathworks.com/products/simulink/>]
- [11] Sejal D'mello, Zahir Aalam, "AFH Techniques – Survey Based on Probabilistic Channel Usage", International Journal of Research in Computer Engineering and Electronics, pp.1-5, vol. 3, April 2014