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Performance Analysis of Smooth Adaptive Frequency Hopping

SejalD'mello, Zahir Aalam, B. K. Mishra
Thakur College of Engineering & Technology, Kandivali (E), Mumbai–101.

ABSTRACT
Due to an increase in the number of operating devices,dealing with the 2.4 GHz ISM band interference has become very important. Bluetooth specification enables the use of adaptive frequency hopping to improveperformance in the presence of interference. This technique avoids thecongested portions of the ISM Band, however; as the number of interferers increases, a greater number of bad channelsare removed from the adapted hopping sequence. This results in degradation of the operation.

In this paper, we present a smooth adaptive frequency hopping (SAFH) Algorithm to improve the performance of frequency hopping in the presence of interference.The model is established and simulated using MATLAB Simulink.

Keywords
Adaptive Frequency Hopping, Probabilistic Channel Usage, Interference Mitigation, WPAN, WLAN, SAFH

1. INTRODUCTION
The 2.4 GHz industrial, scientific, and medical (ISM) band is poised for strong growth. Fuelling this growth are two emerging wireless technologies: wireless personal area networking (WPAN) and wireless local area networking (WLAN). The WPAN category is led by a short range wireless technology called Bluetooth [1]. Bluetooth is a method for data communication that uses short-range radio links to replace cables between computers and their connected units [2].

The WLAN category has several technologies competing for dominance. Wi-Fi products transmit at data rates up to 11Mbps. Wi-Fi devices operate at distances up to 100 meters, however, range varies as a function of transmit power and Environment.[3]

WPAN and WLAN are complementary rather than competing technologies. Moreover, with both of them expecting rapid growth, collocation of Bluetooth and WiFi devices will become increasingly likely, especially in computing devices. While there are certainly many devices where different radio technologies can be built into the same platform (e.g., Bluetooth in a cellular phone), collocation of Wi-Fi and Bluetooth is of special significance because both occupy the 2.4 GHz frequency band. This creates the potential for interference between the two technologies, and hence the need for coexistence [4].

This Paper focuses on variation of AFH technique – SAFH, based on Probabilistic Channel Usage. Section 2describes Bluetooth. Section 3 describes Adaptive Frequency Hopping. In Section 4, we discuss SAFH. Section 5 shows Simulation along with system model. Section 6describes Results& discussion. Section 7 concludes the paper.

2. BLUETOOTH
Bluetoothis a standard for wireless communications based on a radio system designed for short-range, cheap communications devices suitable for substituting cables for printers, faxes, joysticks, mice, keyboards, etc. The devices could also be used for communications between portable computers, act as bridges between other networks, or serve as nodes of ad hoc networks. This range of applications is known as WPAN (Wireless Personal Area Network).

Bluetooth communication is made possible by establishing a piconet. This property makes Bluetooth useful for creating ad-hoc networks. Unlike WLAN, one of the most important features of Bluetooth is that any device can communicate with other device in range by simply establishing one as the master and rest as slaves. There are two different topologies for Bluetooth communication:

1. Piconet
2. Scatternet

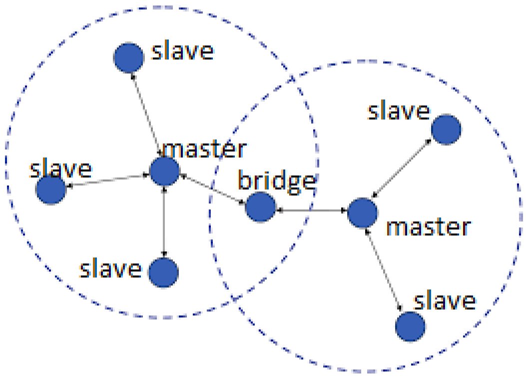

Fig 1. A Scatternet comprising two Piconets

2.1 Interference Issue
The interference between IEEE 802.11 and Bluetooth device does not entirely block each other's transmissions, but they reduce the effective ranges and data throughput. This shows the degradation of technology with respect to users and market perspective.

IEEE 802.11 uses direct spread spectrum techniques while Bluetooth uses Frequency hopping techniques. The important thing to be noted is that due to the differing use of frequency hopping techniques, Bluetooth is more likely to interfere with IEEE 802.11than an IEEE 802.11 interferes with Bluetooth. The main reason is that the Bluetooth hops 1600 times per second, while IEEE 802.11 only hops around 50 times [5].

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The use of relatively long packets and slow rate frequency hopping (50 hops in IEEE 802.11 case) inIEEE 802.11 causes interference with high error rates in IEEE 802.11 than Bluetooth. If Bluetooth and Wi-Fi operate simultaneously in the same place, their channel will overlap and can cause interference.

2.2 Interference Elimination Technique

To eliminate the effect of interference on the network throughput, Special Interest Group (SIG) and IEEE have developed two approaches:

1) Collaborative Techniques, where devices avoid one another's activity while easily sharing information (i.e., manual switching, driver layer switching and MAC layer switching) [10].

2) Non-collaborative Techniques, where devices must adjust their behaviour to avoid interfering with others (i.e. adaptive FH (AFH), adaptive fragmentation, power control, listen-before-talk (LBT) and packet scheduling) [6, 11].

3. ADAPTIVE FREQUENCY HOPPING (AFH)

3.1 Overview

Adaptive Frequency Hopping, a Non-Collaborative technique proven to be an effective remedy to the problem of interference in WLAN and similar environments is included in Bluetooth Specification Version 1.2 adopted in 2003.

In Bluetooth, the non collaborative coexistence schemes rely on adaptive control strategies such as frequency hopping, packet selection and MAC parameter scheduling. All the schemes start by assessing the ISM band and then taking actions based on the status of the channels. The first control action known as adaptive frequency hopping (AFH) modifies the frequency hopping pattern so that bad channels are avoided.

In adaptive packet selection technique, packets are selected according to the channel condition of the upcoming frequency hop, resulting in better network performance [7]. Packets are mainly dropped due to random bit error if the network performance is range limited; hence packets using more error protection will increase the performance of the link.

However in coexistence scenarios, the dominant reason for packet drop is due to the strong interference produced by the collocated networks. In this case, increasing FEC protection will cause more interference to the collocated networks, thus the total network throughput is severely degraded and the good neighbour policy is violated.

MAC scheduling is yet another action where packet transmission is carefully scheduled [7]. Since there is a slave transmission after each master transmission, the Bluetooth master checks both the slave's receiving frequency and its own, before choosing to transmit a packet in a given hop.

Adaptive frequency hopping, packet selection and scheduling policy are capable of reducing the impact of interference that Bluetooth exhibits on other systems; But only AFH can increase the throughput and thus it received a lot of attention recently. Due to this importance, a detailed discussion of AFH follows.

3.2 Taxonomy of AFH

Careful examination of AFH algorithms reveals that they belong to two classes:

1. Reducing the cardinality of the hop-set.
2. Probabilistic channel visiting.

3.3 Standard AFH

Standard Adaptive Frequency Hopping (AFH) [9]avoids interference by actively modifying the hopping sequence to use good channels. It is an effective measure in mitigating the interference.

The standard AFH consists of three components as shown in Fig 3. The first component of the AFH mechanism is the selection box, which generates the hopping sequence defined in the IEEE Std. 802.15.1-2002 [8].

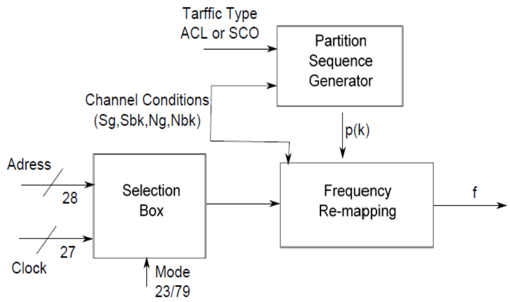

Fig 3 Block diagram of the AFH Mechanism

The second component is the partition sequence generator, which imposes a structure on the original hopping sequence. It divides the set of "bad" channels (SB), into a set of channels that are to be kept in the hopping sequence (SBK), and into a set of channels that are to be removed from the hopping sequence (SBR). The SBK is needed if in case the size of the "good" channels (SG) is less than the minimum number of hopping channels allowed (Nmin).

The third component of the AFH mechanism is the frequency remapping function. It compares the hop frequency generated by the pseudo-random hop selection scheme against the two set of good and bad channels. If the channel belongs to the list of "good" channel, it will be used normally. On the other hand, if the frequency assigned by the original scheme is included in the "bad" channel list, a remapping function.

The Standard Adaptive Frequency Hopping periodically maintains the hop set to handle changing channel conditions. Standard AFH enables the Bluetooth link to operate at a high throughput and reliability, as it avoids the occupied spectrum.

It has two main limitations: first it is specifically designed to coexist with static sources of interference such as 802.11b. Second as the number of interferers increase in a given coexistence environment, a great number of channels are removed from the hopping sequence and bad channels would be used, as a result throughput and reliability are decreased.

4. SMOOTH ADAPTIVE FREQUENCY HOPPING (SAFH)

Smooth Adaptive Frequency Hopping (SAFH) [12] was developed to overcome the disadvantages of existing AFH.

SAFH has four stages as illustrated by the block diagram in Fig 4. First it reads the values of the input parameters α, ξ, c, s and β. 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 FERi(t), and calculates the average FER.

The other steps of SAFH are invoked when the average frame error rate FER exceeds the predefined threshold (ξ), 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.

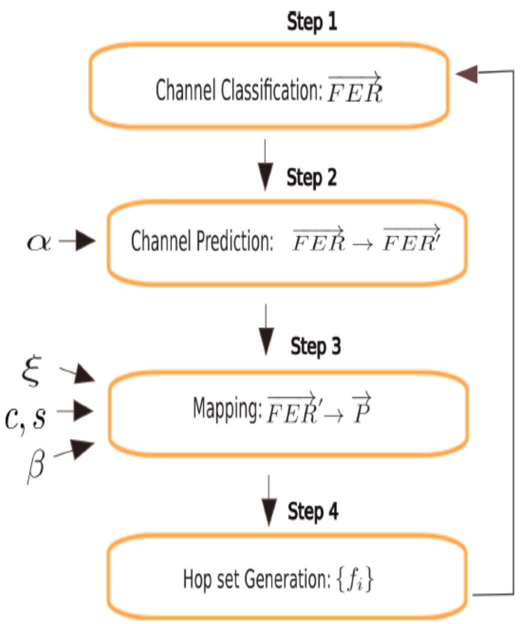

Fig 4 Block Diagram of SAFH

5. SIMULATION

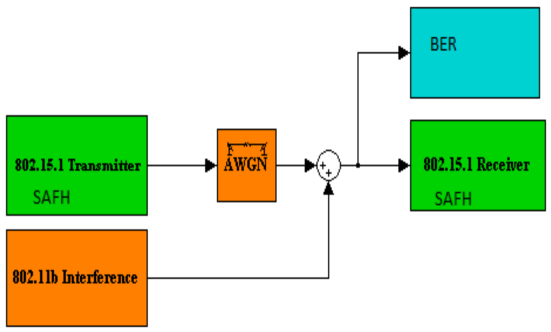

Fig 5 System Model [13]

Simulation of wireless system is a crucial step in performance evaluation [15]. It helps early discovery of design flaws in the development process.

SIMULINK®, an extension of MATLAB is selected for simulation; hence we are able to use all features of the software during the analysis process.

The Model consists of various blocks as shown in fig 5. It shows Bluetooth model employing SAFH algorithm. The 802.11 is generated by a separate independent block which allows us to control precisely the rate of 802.11 transmissions. In our simulation, a Wi-Fi interferer is modelled to demonstrate the performance degradation.In simulation, examination of the performance and the way the BER is affected is done.

6. RESULTS AND DISCUSSION

Simulation results are presented to evaluate the performance of Bluetooth in the presence of WLAN interference. All simulations are run for 5 seconds of simulated time. The Simulation parameters used are shown in Table 1.

TABLE 1
Simulation Parameters

Simulation Parameters	Values
Length of simulation run	5s
Free Space Path loss in Bluetooth	10 dB
Free Space Path loss in 802.11	10 dB
AWGN Es/No	30 dB
802.11b Transmitter packet length	1ms
Bluetooth Slot time	625 us
Bluetooth Data rate	1 Mbps

TABLE 2
Comparison of RAFH, UBAFH & SAFH [14]

Parameters	AFH – Probabilistic Channel Usage		
	RAFH	UBAFH	SAFH
BER	LOW	AVERAGE	LOWEST
PER	LOW	AVERAGE	LOWEST

Author in [14] has compared various AFH techniques based on Probabilistic channel usage like RAFH, UBAFH, and SAFH based on theoretical values of certain parameters as shown in Table 2. SAFH completely avoids the bad channels so it has very good BER and PER.

Simulation of the SAFH for various parameters like BER, residual BER and PER is done. Fig 6 shows the resultant parameters of simulation.

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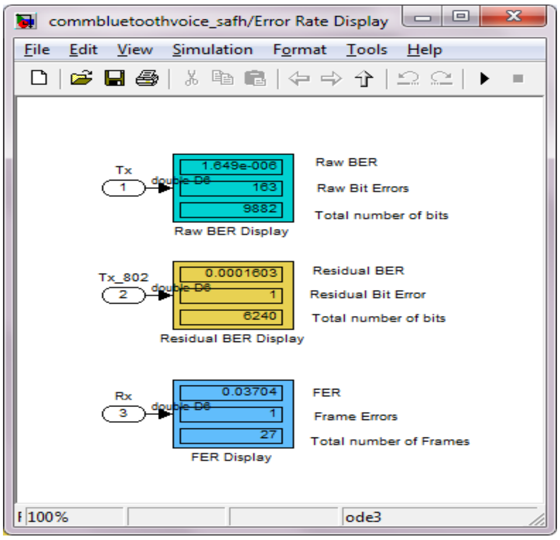

Figure 6Resultant Parameters of SAFH

Simulation of the SAFH for various parameters like BER, residual BER and PER is done.Performance analysis of the SAFH considering BER is as shown below in Figure 7.

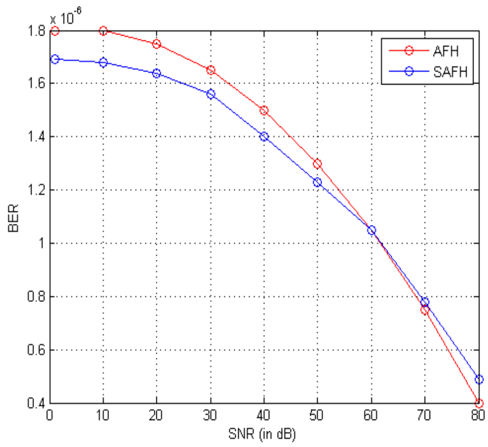

Fig 7Performance of SAFH versus AFH

The graph shown in fig7plots the effect of SNR on BER and compares the effect on standard AFH algorithm and SAFH. It is evident from the graph that for lower SNRs SAFH outperforms AFH. This is as expected due to the enhanced noise immunity in SAFH and also the smoothing function which takes into account the previous channel calculations while making the current decisions. However, as the SNR increases beyond a certain point, AFH and SAFH both perform almost on par because as the SNR improves noise in channels also decrease. So there is no need of blocking any channel and all channels can perform at their optimum even without any advanced hoping mechanisms.However, achieving such high SNR in practice is not always possible.

SAFH assigns usage probabilities to all channels based on an exponential smoothing filter for frame error rates to estimate and predict the channel conditions. The application layer can adapt SAFH by parameter settings in a cross-layer approach. SAFH achieves low average frame error rate and responds fast to changing channel conditions if required from the application. SAFH outperforms AFH in terms of BER.

7. CONCLUSION

This paper gives a brief introduction about Smooth Adaptive Frequency Hopping (SAFH), a non-collaborative method. First, it performs channel classification, then 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.

In order to quantify the performance of SAFH, both theoretical values as well as simulation studies were carried out. The evaluation of the SAFH scheme compared to Standard Adaptive Frequency Hopping results in a smooth operation, lower bit error rate, lower average frame error rate, and stable operation. Simulation shows that SAFH outperforms with respect to Bit error rate.

For the future we suggest an SDR implementation of SAFH and compare the results to the ones obtained in the simulation. Additionally, we will also include overhead calculation for the exchange of the channel states. We further evaluate the parameter sets of SAFH to give advice for the optimumsettings for frequency static and dynamic interference.

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