

Cognitive FH Channel Selection for Bluetooth Network

Yi Peng*, Qingzhi Du, Long Hua, Yubing Shao

Faculty of Information Engineering and Automation
Kunming University of Science and Technology Kunming, China

*Corresponding author, e-mail: topengyi@sina.com.cn

Abstract

Bluetooth is a short-range wireless technology that operates in the 2.4GHz unlicensed ISM band, so it will inevitably encounter the interference from other wireless systems and other Bluetooth piconets. Because of the flexible, efficient and reliable spectrum access by adapting the radio's operating characteristics to the real-time conditions of the environment, cognitive radio technology is applied in Bluetooth network. In this paper, a novel cognitive FH channel selection method which is built based on link quality detection is proposed, interference temperature judgments model is analyzed and cognitive processing cycle of channel access is discussed. The simulation results indicated that cognitive FH Bluetooth network is more anti-interference than conventional Bluetooth systems.

Keywords: Bluetooth, Cognitive Radio (CR), Frequency Hopping (FH)

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1. Introduction

Bluetooth is a short-range wireless technology that operates in the 2.4GHz band. Its physical layer uses FHSS (Frequency Hopping Spread Spectrum) and it pseudo-randomly selects one of 79 channels (1MHz wide) within the ISM band. Only when the frequency hopping sequence and time of the receivers are the same as those of the transmitters, data can be correctly received. Thus the data safety and anti-jamming performance can be enhanced [1].

Since the ISM (Industrial, Scientific, and Medical) band is unlicensed and duty-free, and it is universally available with radio suitability at a low cost, many wireless communication systems use this band. That brings a key problem of various interferences, and it even becomes a bottleneck for rapid development of these systems.

Because of the unrestricted access to the ISM band, Bluetooth is exposed to a high level of interference from unknown systems. In general, present types of interferences are as follows [1-2]:

(1) Interferences from other wireless networks (i.e., IEEE802.11b, HomeRF). Firstly, IEEE802.11b standard uses a fixed 22MHz DSSS (direct sequence spread spectrum) and their bandwidth overlaps with that of Bluetooth by 1/4, so they are easy to collide with Bluetooth. Secondly, the transmission power of IEEE802.11b is from 30mW to 100mW while that of Bluetooth devices is 1mW. That also causes great interferences.

(2) Interferences from microwave ovens Broadband interferences can destroy the entire radio system. Microwave ovens which operate in the 2.4GHz bring about major broadband interferences. Microwave's transmitter frequency is 2.450GHz, and it has strong transmitter power, so wireless data within 15 meters may be destroyed. It can be the key interference source.

(3) Self-interferences between the piconets. The basic network in Bluetooth networks is piconet. A piconet is composed of a "master" cell to determine the frequency hopping sequence and the states of utmost seven "slave" cells. Every slave cell can only communicate with each other via the master. Although every piconet has its respective frequency hopping sequence, self-interference will happen when different piconets are using the same frequency. In a certain region, more frequency overlap will cause more self-interference.

These interferences will bring the serious fading of FH channel and destroy Bluetooth network's communication. To overcome the obstacles, CR (cognitive radio) technology is introduced to Bluetooth system. CRs can flexible, efficient and reliable spectrum access by adapting the radio's operating characteristics to the real-time conditions of the environment [3].

In this paper, we propose a CFH (cognitive frequency hopping) scheme based on channel quality detection. Firstly, the coexistence mechanism of Bluetooth network is discussed and network model is described. Secondly, a novel cognitive FH channel selection method which is built based on link quality detection is proposed, interference temperature judgments and cognitive processing cycle of channel access is discussed. At last, the numerical results and simulations of CFH scheme indicated that CFH is more anti-interference than conventional FH systems.

2. Bluetooth Network

Bluetooth is playing an important role in communications among electronic devices. Bluetooth communication is possible through piconet, where one device plays master role and other act as slaves. There can be more than one piconet in Bluetooth network, which is called scatternet. Different piconets are connected through a common node called gateway. Operating in the 2.4 GHz unlicensed ISM band, a Bluetooth piconet will inevitably encounter the interference from IEEE802.11 WLAN and other Bluetooth piconets. The Bluetooth and WLAN mixed network is shown in figure 1.

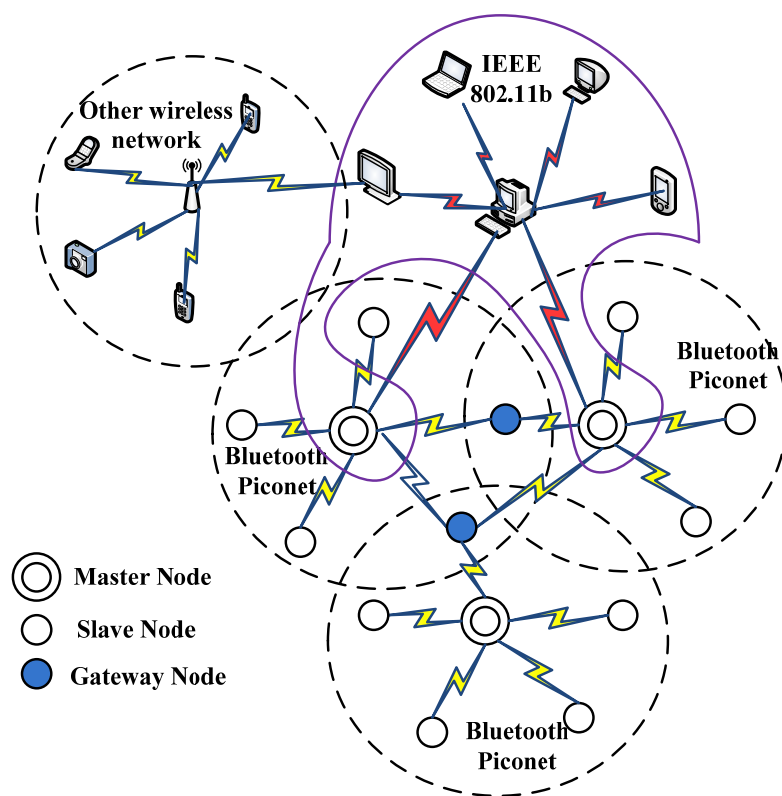


Figure 1. Bluetooth and WLAN mixed network

To enable coexistence of a variety of wireless communication systems coexistence, the AFH (Adaptive Frequency Hopping) technology is proposed. The AFH mechanism attempts to modify the Bluetooth frequency hopping sequence in the presence of IEEE802.11b DSSS devices. Bluetooth devices with AFH can periodically evaluate the channel and modify the Bluetooth hopping sequence so that the Bluetooth devices can avoid the collision with IEEE802.11b.

The AFH scheme has four key components: channel classification, LM (link management), hop sequence modification and channel maintenance. The AFH can effectively

mitigate interferences between Bluetooth and IEEE802.1 lb. But at present the AFH has following limitations [4]:

(1) With the increase of interference sources, more "bad" channels would be cancelled from the AFH sequence and "good" channels would decrease. When every channel has so high a level of interference, the judgment of LM may be that all channels become "bad" ones. FCC regulates that the number of Bluetooth AFH channels cannot be less than 15 and Bluetooth system has to use some "bad" channels if the number of "good" channels is less than 15. Thus AFH mechanism can not entirely avoid the reduction of system's throughput and reliability.

(2) AFH can't distinguish between self-interferences and collisions with other wireless communication systems.

(3) In accordance with different circumstances, AFH needs to formulate corresponding algorithms.

Based on the above considerations, this paper proposes a novel Cognitive Frequency Hopping mechanism in order to maximize system performance and enhance spectrum utilization.

3. Cognitive FH Mechanism for Bluetooth Network

3.1. System Model

In FH system, the frequency hopping system hops according to the frequency map which is predefined. We can define the frequencies in frequency map which are selected pseudorandom used in the FH system hopset. Apparently the hopset cannot trace the link quality. This affects the system's performance. Bluetooth works in the Industrial Scientific and Medical(ISM) band which there are WLAN and Cordless, so it is time-varying. If we want to communicate in this band, we must trace the time-varying radio environment and avoid the frequencies which are used or worse. In this paper, we propose a CFH based on the detection of link quality which utilizes CR. In this system, we detect the link quality at sender and directly use the detecting result in the adaptive frequency hopping system. This can trace the link quality in time. This system model is shown as figure 2.

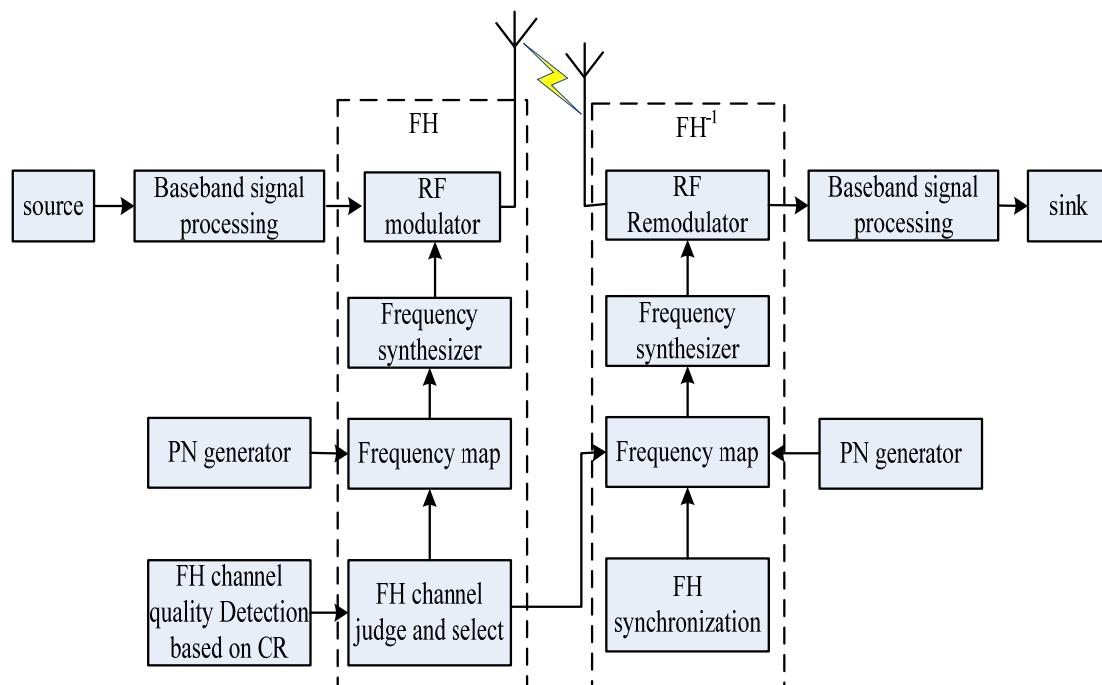


Figure 2. The cognitive frequency hopping system model

3.2. The Judgment of Channel Quality

The currently developed radio environment is transmitter-centric, as the transmitted power is designed to approach a prescribed noise floor at a certain distance from the transmitter to the receiver. However, the unpredictable appearance of the new sources of interference can raise the RF noise floor, and result progressive signal coverage degradation. To eliminate such effect, a new metric called the interference temperature is recommended by the FCC Spectrum Policy Task Force which is intended to quantify and manage the sources of interference in a radio environment. The interference temperature is defined as a measurement of the antenna and will be delivered to a receiver. In addition, it is the temperature equivalent of the RF power available at a receiving antenna per unit of bandwidth, measured in units of Kelvin. Interference temperature is calculated as follow [5]:

$$T_I(f_c, B) = \frac{P_I(f_c, B)}{kB} \quad (1)$$

where $T_I(f_c, B)$ is the interference temperature for the channel c with the central frequency f_c and the bandwidth B . $P_I(f_c, B)$ is the average interference power in Watts (at the antenna of a receiving or measuring device) centered at the frequency f_c and covering the bandwidth B (in Hertz). k is the Boltzmann's constant (1.38×10^{-23} Joules per Kelvin).

All the study is based on the [5]'s generalized interference temperature Model. For a given geographic area, the FCC would establish an interference temperature limit, T_{limit} . This value would be the maximum threshold of the tolerable interference for a given frequency band in a particular location. So, the channel is judged as a "good" channel when it's $T_I \leq T_{limit}$.

In Bluetooth network, the master node can obtain the parameters of wireless environment. Suppose the radio scene be a free spacial transmitting model $H(f, d)$. The parameters offered by the cognitive master users in transmitting the radio operation are the lowest signal-to-noise (SNR) SNR_{min} , communications bandwidth B_c , sending power P_{tr} , sending frequency f , and transmit distance d . Calculate the interference temperature limit. The formula of interference temperature limit is [6]:

$$T_{limit} = \frac{\alpha \times P_{tr} \times H(f, d)}{SNR_{min} \times B_c} \quad (2)$$

where α is the ratio gene of the spectrum estimation algorithm.

The RF power P and signal's bandwidth B can be calculated by the following formula in the generalized model [7]:

$$P \leq \frac{Bk}{M} T_{limit}(f_c) - \frac{1}{M} \int_{f_c - \frac{B}{2}}^{f_c + \frac{B}{2}} s(f) df \quad (3)$$

Where $s(f)$ is used to indicate the power spectral densities, and cannot be expressed as a general closed expression. Consider a simple model, where $s(f) = c$. The constant c is much larger than the value of the interference limit. Note that the constant M in (3) is a fractional value between 0 and 1, which represents a multiplicative attenuation due to fading and path loss between the transmitter and the receiver. Solving for B , the following can be obtained:

$$(KT_{limit} - c)B \geq MP \quad (4)$$

3.3. Cognitive FH Channel Selection for Bluetooth Network

In traditional Bluetooth network, user is hopping on 79 channels randomly, so the communication will be destroy or interrupt because of interference which comes from other wireless system or inner of Bluetooth picnet. The CR-based FH channel selected can solve this problem. The flow of cognitive channel selection based on link quality detection is: First, the Bluetooth network takes CR technology to obtain the parameters of transmitting environment, these parameters is include the lowest signal-to-noise (SNR) SNR_{min} , communications bandwidth B , sending power P_{tr} , sending frequency f , and transmit distance d ; Secondly, compute the interference temperature of FH channel, and compare with the threshold of

system's interference temperature; Finally, according to the comparison result, transmitter select hopping at these good channels.

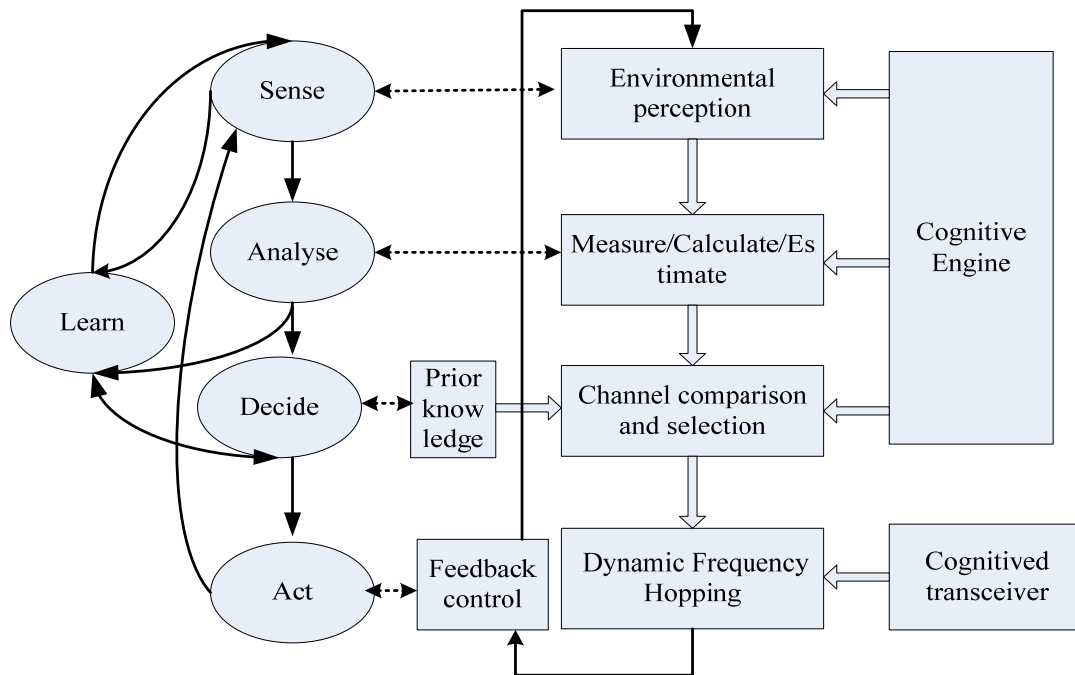


Figure 3. Cognitive processing cycle for channel access

Figure 3 is shown the cognitive processing cycle of channel access. Sense: It senses its local environment, e.g., transmission activities and QoS requirements of other users sharing the spectrum; Analyze: It analyzes the sensed information e.g., to evaluate spectrum occupancy and transmission levels within occupied spectrum, location of transmitters, users' willingness to share etc; Decide: It decides on the optimal transmission parameters e.g., channel, power level; Act: It acts on the decision through software reconfiguration; Learn: It uses long-term analysis to learn about its environment and its own behavior.

4. Simulate Result and Analysis

We construct a frequency scope 2.40-2.4835GHz. It contains 10 communication interference signals in 2.41- 2.415GHz which denote WLAN signals and 2.46-2.465GHz which denote Cordless signals. In Bluetooth system, modulating mode is FH/MFSK with 4chips/code. The hopping interval is 51.2 KHz. The number of hopping frequency is 80. The information speed is 9600bps. The hopping speed is 38400hops/sec. All the processes in the communication system are supposed synchronization. And the channel is AWGN.

Figure 4 show the curves of BER versus SNR respectively for the FH and CFH system. As we can observe from figure 4 that the BER performance of CFH based on the detection of channel quality is better. This mainly roots from the proposed method can trace real-time channel status and select good channel to communication.

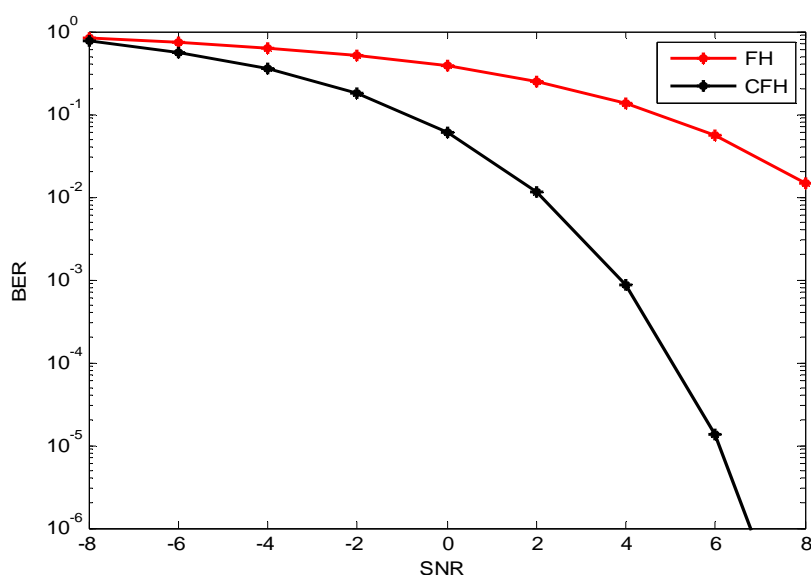


Figure 4. The bite error rate of two systems

4. Conclusion

Because work on the ISM band, Bluetooth is exposed to a high level of interference from other wireless system. To resolve the problem, a cognitive frequency hopping scheme based on channel quality detection is proposed. The system is select good channel to hopping according to channel's interference temperature, analyse and simulations indicated that CFH is more anti-interference than conventional FH systems. In future, cognitive bluetooth network's channel allcation and management will become a focus of research.

References

- [1] Rongxin Zhi, Luyong Zhang, Zheng Zhou. *Cognitive Frequency Hopping*. The 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications. Beijing. 2008: 130-134.
- [2] Wang Feng, Nallanathan Arumugam, Garg Hani Krishna. *Impact of Interference on a Bluetooth networks in the 2.4GHz ISM band*. The 8th International Conference on communication System.
- [3] S Haykin. *Cognitive Radio: Brain-Empowered Wireless Communications*. *IEEE Transactions on Communication*. 2005; 23(2): 201-220.
- [4] Lihua Guo, Xiaomin Mu, Chunhua Zhu, Hao Song. *An Adaptive Frequency Hopping System Based on the Detection of Spectrum Holes*. IEEE International Symposium on Knowledge Acquisition and Modeling Workshop. 2008: 498-50
- [5] T Charles Clancy. *Achievable Capacity Under the Interference Temperature Model*. IEEE INFOCOM. 2007: 794-802.
- [6] FCC. *Establishment of Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed Mobile and Satellite Frequency Bands*. ET Docket 03-289, Notice of Inquiry and Proposed Rulemaking.
- [7] Zhuo Cheng, Shu Wang, Xiaoxu Qu, Shu Yan, Fuping Hu, An Li. *Cogdfh- A Cognitive-based Differential Frequency Hopping Network*. Military Communications Conference. 2009: 1-7.