Journal of Engineering and Applied Sciences 13 (Special Issue 2): 3026-3030, 2018
ISSN: 1816-949X

A Study on Interference Removal of Bluetooth Using Frequency Hopping

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Abstract: In this study, we propose a solution for interference with Bluetooth when connecting Bluetooth and other devices. We evaluate the performance of the random frequency hopping scheme and the adaptive frequency hopping scheme which are Bluetooth frequency hopping schemes when there is wireless LAN interference in all 2.4 GHz Bluetooth channels in the presence of Bluetooth and wireless LAN. The random frequency hopping scheme is a technique for generating a hopping pattern using the entire Bluetooth channel without considering the interference of the wireless LAN. The adaptive frequency hopping scheme is a technique for generating a hopping pattern using some Bluetooth channels in consideration of wireless LAN interference through periodic carrier sensing of Bluetooth. Simulation results show that, the use of adaptive frequency hopping reduces the packet error rate as the Bluetooth carrier sensing interval decreases even in the congestion of WLAN interference. In particular, the frequency hopping scheme has a performance improvement of about 13% in the average packet error rate compared to the adaptive frequency hopping scheme. It is expected that the packet error rate will be reduced through the adaptive frequency hopping even in the congestion of WLAN interference.

Key words: Transfer protocol, self-similar traffic, multiple time scale, time division Duplex, header, WLAN

INTRODUCTION

Recently, as the spread of smartphones has increased, Bluetooth and wireless LAN which are one of Wireless Personal Area Network (WPAN) are widely used. In this study, we propose a solution for interference with Bluetooth when connecting Bluetooth and other devices. Bluetooth is a generic term for short-range wireless communications technologies, standards and products that enable two-way, short-range communications between portable devices at low cost without complex cables. Bluetooth is small in size (0.5 square inches), low cost and low power consumption, enabling wireless connection between sub-stations within 10-100 m between portable devices such as mobile communication terminals, portable PCs, network access points and other peripheral devices (Wang *et al*., 2016). The local area network design usually used internal addresses to manage the sensor network nodes. The address length was relatively short and it was suitable for implementing a low-power built-in sensor network node. However, the internal address management method is not compatible with the IP method of the internet, making interactions between sensor network nodes and traditional wireless network nodes more difficult. Therefore, there is a need to solve the problem of connectivity between the short distance communication and the wireless network (Hatler *et al*., 2012). Bluetooth and WLAN have the advantage of using the unlicensed frequency band Industrial, Scientific and Medical (ISM) bands. As a result, when Bluetooth and wireless LAN coexist, they interfere with each other. Bluetooth technology is not yet, commercialized in earnest. Therefore, based on the potential and growth trend of Bluetooth technology, we estimate market size by research institute. According to an analysis by In-Star, an IT research firm, Bluetooth wireless networking technology will continue to grow in popularity. The configuration concept of Bluetooth is composed of Link Manager, baseband and high frequency in lower level. High frequencies form the system design of the frequency and bit-wise information (Neyestanak and Naraghi, 2011). The baseband is primarily responsible for coding and encrypting data, handling packets and where frequency hopping occurs. The link manager is responsible for connection handling and deals with the authentication process. The wireless range in which the Bluetooth system operates is slightly different for each country. In the United States and Europe, only a portion of the 2.4-2.48 GHz band is available while in Japan, the 2.47-2.49 GHz band is used (Falk and Hof, 2013). When Bluetooth is connected, it is connected with another device and the channel is connected. When it is overlapped with communication using multiple channels like Wi-Fi, the communication connection is unstable because of a problem of interference. In this study, we evaluate the Bluetooth performance according to the Bluetooth frequency hopping technique in the congestion situation where the WLAN interference exists in the entire Bluetooth channel.

MATERIALS AND METHODS

As a short distance communication technology such as a smart phone, the maximum possible communication distance is a technology to exchange wireless data within a very short distance of 10~20 cm and it requires "tagging" which is a method of directly connecting to a receiver because the communication distance is short. It is the technology that was used to acquire various information including the location by letting the radio wave radiated from the ground wireless base station, etc. be received by the device in the moving object such as aircraft, ship, car. But since, Apple announced its Ibi-Cone in 2013, the term beacon has begun to be used in the narrower sense of the next-generation smartphone near-field communication technology that uses low-power Bluetooth (BLE) (Joseph *et al*., 2013; Lee *et al*., 2012). Devices connected to each other via. Bluetooth function as masters and slaves, respectively. The master acts as a Bluetooth channel or traffic control, multiple slaves can be connected to one master. Data transmission using Bluetooth is performed as shown in Fig. 1.

Bluetooth uses an ISM band in the 2.4 GHz band. Bluetooth uses 2.402~2.480 GHz and each Bluetooth channel has a bandwidth of 1MHz, so, a total of 79 channels are used. The frequency of each Bluetooth channel is as follows:

$$F = 2.401+i\text{GHz}, I = 1, 2, \ldots, 79$$

where, F denotes the frequency of the ith Bluetooth channel. When a Bluetooth packet is transmitted, one Bluetooth channel is selected for each slot and hopping is performed. Therefore, 1600 frequency hopping is performed per second at the same rate as the number of slots. One slot has a length of 625 us and there are 1600 slots per second. Bluetooth packet transmission between the master and the slave uses a time division method and the master and the slave alternately transmit the Bluetooth packet. Each device can select one of 1, 3 or 5 slots to transmit Bluetooth packet and the master controls it (Kumar and Shepherd, 2001).

There are two types of Bluetooth links: Synchronous Connection-Oriented (SCO) link and Asynchronous Connection-Less (ACL) link. The SCO link is a method used for voice communication in which one master and one slave are connected and does not transmit or receive data through a reserved slot at a predetermined time interval (Roy, 2010; Myrda and Koellner, 2010). The ACL link is a method used for data communication in which one master and several slaves can be connected and a Bluetooth packet is transmitted without a reserved slot. In this study, we consider a pair of Bluetooth devices and 13 wireless LAN APs as shown in Table 1 to make WLAN interference situation. A pair of Bluetooth devices is composed of a Bluetooth transmitter and a Bluetooth receiver and transmits a Bluetooth packet by data communication. All wireless LAN APs are located at the same distance as the Bluetooth receiver and occupy channels 1-13 of the wireless LAN. At this time, it is assumed that interference between wireless LAN APs is not considered. The Bluetooth transmitter and the Bluetooth receiver transmit data through the ACL link. The Bluetooth standard provides various types of Bluetooth packet types when using the ACL link as shown in Table 1.

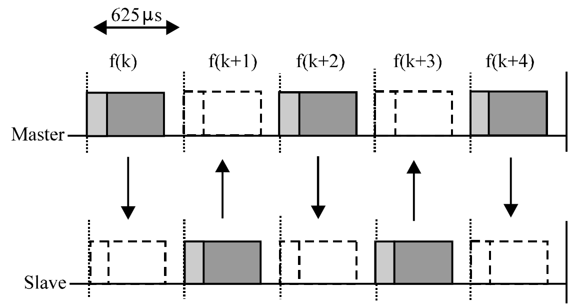

Fig. 1: Bluetooth slot structure

Table 1: Bluetooth channel structure and wireless lan interference environment

Types	Header byte	Payload byte	Max speed	FEC
DM1	1	0.160	108.0	2/3
DM2	1	0.170	172.0	-
DM3	2	0.121	258.0	2/3
DM4	2	0.163	390.0	-
DM5	2	0.214	286.0	2/3
DM6	2	0.329	433.0	-
AUX	1	0.290	185.0	-

Here, the maximum transmission speed means that the Bluetooth transmitter and the Bluetooth receiver transmit the Bluetooth packet at the same speed. In this study, it is assumed that a Bluetooth packet is transmitted using only one slot and corresponds to the Data Medium-rate 1 (DM1) packet type and the Data High-rate 1 (DH1) packet type in the above table. The 13 wireless LAN APs occupying each of channels 1-13 are considered. Each WLAN AP operates independently and does not interfere with other WLAN APs. Each WLAN AP uses the ON-OFF traffic model to generate traffic on a per Bluetooth slot basis. The ON-OFF traffic model is an ON-OFF random process in which the retention times of ON and OFF states follow the exponential distribution.

The frequency hopping channel is determined by the frequency hopping sequence and the phase of this sequence. The sequence of the Bluetooth system is determined by the address of the piconet master device and the phase is determined by the system clock of the master. To generate a master clock on a slave device, the slave adds an offset to its native clock. The repetition rate of a very long frequency hop sequence is determined by the clock. If all devices on the given channel use the same address and clock as the inputs of the hop selection box, then each device continues to select the same hop carrier and keep the synchronization. Also, every piconet has a set of master parameters that generate a unique channel. The goal of the proposed frequency hopping scheme is to solve the problem of not considering the WLAN interference of the random frequency hopping scheme, the carrier sensing time and threshold value of the adaptive frequency hopping scheme and the minimum number of good channels. The proposed frequency hopping scheme consists of three steps: Bluetooth channel grouping, Bluetooth channel classification and hopping pattern determination. After configuring the Bluetooth channel as a channel group, the Bluetooth carrier sensing is performed on a channel group basis. After sorting the Bluetooth carrier sensing result by energy, the Bluetooth channel is classified by comparing the energy difference between adjacent groups. A Bluetooth channel selection probability distribution is generated based on energy using a Bluetooth channel classified as a good channel to determine a hopping pattern.

In general, a WSN can be described as a node network. The nodes cooperatively detect and adjust the environment to enable interaction between the person or the computer and the surrounding environment. Sensing, processing and communication activities using a limited amount of energy typically design layers of distributed signal/data processing, medium access control and communication protocols. By integrating the existing WSN application case with the element technology of the infrastructure system, it is possible to identify new application fields as possible and to develop future technologies and market trends. For example, the application of WSN technology for smart grids, smart waterways, intelligent transportation systems and smart homes produces a large amount of data which can be used for a variety of purposes. In general, a WSN can be described as a network of node devices that cooperatively detects and coordinates the environment to enable interaction between a person or computer and the surrounding environment. WSNs largely include sensor nodes, actuator nodes, gateways and clients. A large number of sensor nodes arbitrarily placed in or near the monitoring area (sensor field) form a network through self-organizing function. The sensor node monitors the collected data and transmits it to another sensor node through hopping. During the processing of the transmission, the monitored data is processed by several nodes and arrives at the gateway node after multi-hopping. Finally, the collected data can reach the management server node via the internet or satellite at the gateway node. The user configures and manages the WSN as a management node and stores the monitored data. The sensor node is one of the major components of the WSN. The hardware of the sensor node is typically combined into a power and power management module, a sensor, a microcontroller, a wireless transceiver and the like.

The power module provides the stable power required by the system. The sensor acts as a link for the WSN node to monitor the status of the environment and equipment. The sensor collects light, vibration and chemical signals, converts them into electric signals and then transfers them to the microcontroller. The microcontroller receives data from the sensor and processes the data accordingly. The radio transceiver (RF module) then transmits the data to perform the physical communication. In designing all WSN nodes, it is important to consider functions such as small size of WSN node and limited power.

RESULTS AND DISCUSSION

In order to evaluate the performance of the random frequency hopping scheme and the adaptive frequency hopping scheme, a simulation environment was constructed using the parameter values shown in Table 1 and simulations were conducted. The WLAN interference is determined by setting the average ON time and the average OFF time according to the predetermined operation cycle and applying the exponential distribution to determine the point of time when the traffic is transmitted. When the Bluetooth carrier sensing interval is 800 slots, the frequency of each Bluetooth channel is shown in Fig. 2.

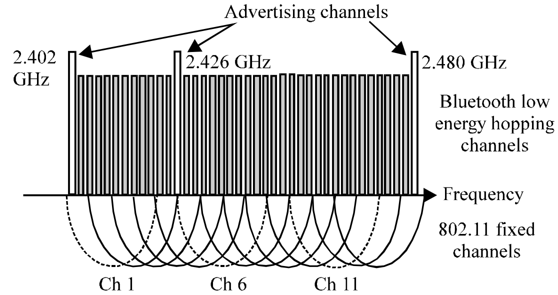

Fig. 2: The operation of the proposed frequency hopping scheme

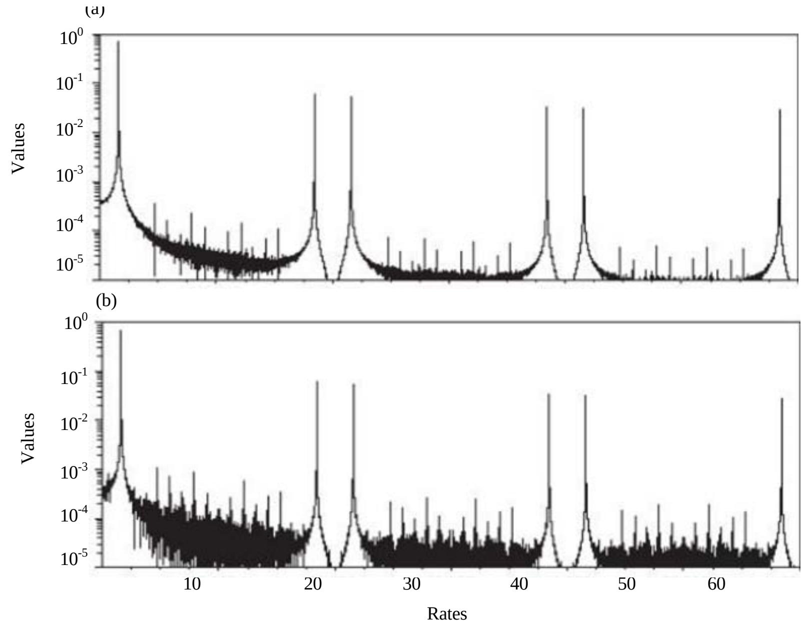

Fig. 3: Packet error rate; Packet error rate (N = 16, P = 16, B = 10, W = 5.169)

Since, the random frequency hopping scheme randomly uses all the Bluetooth channels, the frequency of use of each channel of the Bluetooth is the same. It can be seen that the frequency of use of the adaptive frequency hopping technique increases toward the left or right of the Bluetooth channel. The proposed frequency hopping scheme has 6 Bluetooth channels per channel group except for the 20th channel group, so that, the Bluetooth channels belonging to each channel group have the same frequency of use of Bluetooth channels. In addition, since, the low-energy Bluetooth channel is used more than the other channels, the usage frequency of the leftmost or rightmost channel of the Bluetooth channel is much higher than that of the other channels in the tendency shown in the result of the adaptive frequency hopping technique. As the average ON retention time of the wireless LAN increases, the probability of the wireless LAN interference in each Bluetooth channel increases and the average packet error rate increases. The average packet error rate difference between the random frequency hopping scheme and the other two techniques is large in an environment where there is not much WLAN interference (when the average ON retention time of the wireless LAN is 100 msec) The average packet error rate difference between the random frequency hopping scheme and the proposed frequency hopping scheme is still large but the average packet error rate difference with the adaptive frequency hopping scheme is not large. As described above, the adaptive frequency hopping scheme uses 20 Bluetooth channels to determine a hopping pattern by additionally using some of the bad channels when the number of good channels is <20 in an environment with high WLAN interference, fixed thresholds can not be used to optimize performance over various channel conditions. Therefore, the adaptive frequency hopping technique does not improve the performance in the environment where the WLAN interference is large. Figure 3 shows the average packet error rate according to the average ON retention time of the wireless LAN.

The proposed frequency hopping scheme can improve the performance even in the environment where there is a lot of WLAN interference by using only the Bluetooth channel with low wireless LAN interference using the Bluetooth carrier sensing result and determining the threshold value according to the channel condition. The average packet error rate of the proposed frequency hopping scheme is 50.25% higher than the average packet error rate of the adaptive frequency hopping scheme when the average ON retention time of the wireless LAN is 400 msec.

CONCLUSION

In this study, we evaluate the performance of the frequency hopping technique used by Bluetooth in the congestion situation where the wireless LAN interferes with all channels used by Bluetooth through simulation. It is confirmed that the performance of the proposed frequency hopping scheme is better than that of the conventional frequency hopping scheme. The random frequency hopping scheme is a technique for generating a hopping pattern using the entire Bluetooth channel without regard to the interference of the wireless LAN. The adaptive frequency hopping scheme uses a periodic carrier sensing of the Bluetooth to generate a hopping pattern. The proposed frequency hopping scheme aims to solve Bluetooth carrier sensing time, threshold value and minimum number of good channels which is a problem of the conventional frequency hopping scheme or the adaptive frequency hopping scheme. A Bluetooth channel classification step and a hopping pattern determination step 3. The performance of the proposed frequency hopping scheme is better than the performance of the conventional frequency hopping scheme when the average packet error rate and the average yield rate are used as the performance indexes, respectively. Even in the case of a congested WLAN where the adaptive frequency hopping scheme which is one of the conventional frequency hopping schemes, does not operate properly, the proposed frequency hopping scheme has a 13% improvement in the average packet error rate compared to the adaptive frequency hopping scheme. Therefore, it is expected that the packet error rate will be reduced through adaptive frequency hopping even in the congestion of WLAN interference.

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