An Opportunistic Frequency Channels Selection Scheme for Interference Minimization

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***Abstract*—This paper presents a solution to resolve the interference problems between the Wi-FiTM and BluetoothTM wireless technologies. A new channel selecting approach is being used to select the frequency channel. The signal strength in a channel is assessed, and that value is used to select the channels to send data without interference. Thus we are trying to establish true "Coexistence without Compromise" between BluetoothTM and Wi-Fi TM.**

Keywords—Bluetooth, Frequency hopping spectrum, direct sequence spread spectrum, interference, Wi-Fi.

I. Introduction

Nowadays wireless access networks use many different technologies. Standard 802.11b/g/n is the most extended wireless technology to access Local Area Networks (LAN), which is known as Wi-Fi standard around the world. On the other hand, Bluetooth standards are used frequently in Personal Area Networks (PAN). PAN is low-cost, low-power, secure and robust technology [2]. Both Wi-Fi and Bluetooth are based on spread spectrum signal structuring – a technique where a narrowband signal is expanded to a wideband signal [1]. Both Wi-Fi (802.11) and Bluetooth are located in unlicensed Industrial Scientific and Medical frequency band, which is called ISM. The frequency range of ISM band is 2.4 Ghz (2.402 – 2.480 GHz).

In wireless PAN, Bluetooth is an industrial specification. Connection and exchange of data between devices such as mobile phones, laptops, PCs, printers, digital cameras and video game consoles became very much convenient by Bluetooth. It uses a secure, globally unlicensed short-range radio frequency. But Wi-Fi which was developed to be used for mobile computing devices, such as laptops, LANs, is now increasingly used for more services, including Internet and VoIP phone access, gaming, and basic connectivity of consumer electronics such as televisions and DVD players, or digital cameras. Even more standards are in development that will allow both Bluetooth and Wi-Fi to be used by cars in highways in support of an Intelligent Transportation System to increase safety, gather statistics, and enable mobile commerce etc [3].

In wireless communication system, one or more frequency bands (carrier frequencies) are used to communicate. Both Bluetooth and Wi-Fi share the same 2.4 GHz band, which is under Federal Communications Commission (FCC) regulations, extends from 2.4 to 2.4835 GHz. In this ISM band, a system can use one of the two spread spectrum methods to transmit data. FHSS (Frequency-hopping spread spectrum) and (DSSS) Direct-sequence spread spectrum are the two techniques used. FHSS enables a device to transmit high energy in a relatively narrow band, but for a limited time. On the other hand Direct-sequence spread spectrum (DSSS) allows a device to occupy a wider bandwidth with relatively low energy in a given segment of the band, and it does not hop. Bluetooth uses FHSS, which uses 1-MHz-wide channels and a hop rate of 1600 hops/sec (625 microseconds in every frequency channel). Bluetooth uses 79 different channels in the United States. Wi-Fi opted for DSSS, which uses 22 MHz of bandwidth (passband) to transmit data with speeds of up to 11 Mb/sec. Wi-Fi system uses any of 11 22-MHz-wide sub channels across the allocated 83.5 MHz of the 2.4 GHz frequency band. In the case of Wi-Fi, maximum three networks can coexist without interfering with each other. Regardless of the portion of the band in which Wi-Fi operates, sharing with Bluetooth is inevitable. Two wireless systems using the same frequency band would have a high possibility to interfere with each other.

II. Problem Identification

Since both Bluetooth and Wifi devices operate at the same 2.4GHz ISM band, the probability of interference is very high. In case of Wi-Fi, the client or access point will listen to the transmission medium to check whether that channel is occupied or not. If the channel is occupied, it indicates that data is transmitted at the given point in time. In such an event, the Wi-Fi client will hold off and will listen to a different channel. Once it gets an unoccupied channel, the Wi-Fi client will start transmitting the data using that particular channel. Whenever interference occurs in a channel, Wi-Fi will start retransmitting in the same channel. This technique provides a fairly good method of sharing the radio spectrum without interference.

But in case of Bluetooth, it does not have such techniques like Wi-Fi. Therefore, it hops around the entire 79 channels to transmit the data. The width of a Bluetooth channel is 1MHz, but for Wi-Fi it is 22MHz, (i.e., nearly one fourth of the entire radio spectrum of 83.5MHz). This implies that the Wi-Fi has a wider bandwidth compared to narrow Bluetooth devices. This makes the probability of narrow Bluetooth channels to hop around the wider Wi-Fi channels high. Whenever interference occurs, Bluetooth will hop away and will start to hop again in a new channel.

A critical problem is that Bluetooth and 802.11b neither understand each other nor follow the same rules [7]. A Bluetooth radio may haphazardly begin transmitting data while an 802.11 station is sending a frame. This results in a collision, which forces the 802.11 station to retransmit the frame when it realizes that the receiving station is not going to send back an acknowledgement. This lack of coordination is the basis for RF interference between Bluetooth and 802.11.

III. Related Works

Early Bluetooth devices interfered with 802.11b/g Wi-Fi devices because both devices tried to use the same channel for an extended period of time which caused interference, lost data, and eventually a loss of service for both devices (see Fig. 1). To enable coexistence between Bluetooth and Wi-Fi, various organizations like IEEE, Bluetooth Special Interest Group etc are working on various techniques.

A. Adaptive Frequency Hopping (AFH)

AFH is one such solution that is widely used to nullify interference between these two technologies [4]. In this scheme, the normal Bluetooth frequency hopping sequence is replaced with an adaptive frequency scheme.

Presently a Bluetooth client must hop through the entire 79 different channels (i.e., Wi-Fi is already

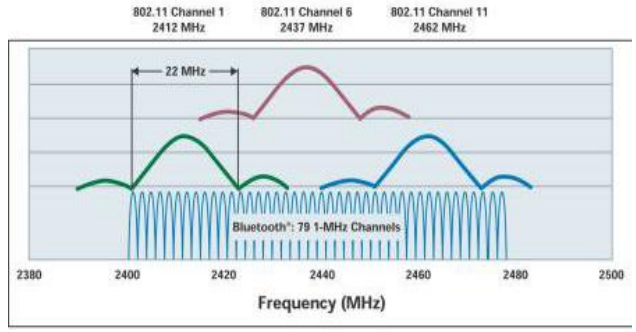

Fig. 1. An Illustration of Bluetooth devices interference with 802.11b/g Wi-Fi standards [7]

occupying the channels). The same concept is illustrated in Fig.2, where Blue Square shows the Bluetooth devices and the yellow square represents the Wi-Fi.

This technique could add some degree of intelligence into the process, so that a Bluetooth device would analyze the available bandwidth and transmit the data to those channels where interference has not encountered.

B. Transmission Power Control

Another technique involves adapting the transmit power used by various devices in the ISM band. The reasoning behind the notion of adaptive power control is based on common sense. Transmitting data at a power level above the minimum needed to meet a predetermined level of acceptable data integrity unnecessarily causes interference to other users in the band [5].

C. Adaptive selection of packet type

The type of Bluetooth packet being transmitted can also affect coexistence performance. Bluetooth packets can carry various payloads, depending on the number

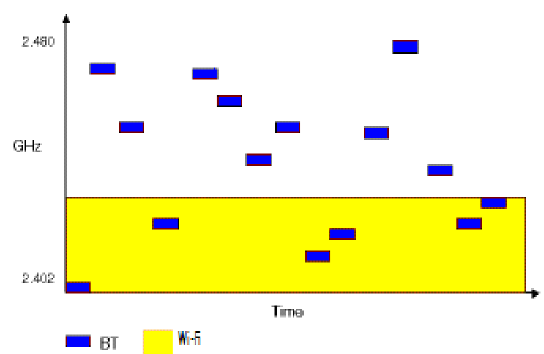

Fig.2. Collisions resulting from random frequency hopping adapting to the environment

of “slots” in the packet. Packets can occupy anywhere from one to five time slots, according to the Bluetooth specifications [6]. While carrying more than 10 times as much data, a Bluetooth packet with five slots will remain on a certain channel at a certain frequency five times longer than a one-slot packet, increasing both the vulnerability of this packet to interference, as well as increasing the chance that the transmission will interfere with others sharing the frequency.

Reducing the packet type to one slot, for instance, would reduce the vulnerability of any one packet to interference because the packet would have a shorter duration. This would improve the chances that a particular packet would be accurately received.

Research has shown that shorter Bluetooth packets can improve data throughput in an environment with interference. A throughput tradeoff arises from the higher level of overhead that must be processed with shorter packets, including additional address and packet header processing, and the dead time between hops that is needed for synthesizer and transmit/receive switching. A point of diminishing returns is reached where the overhead of processing a greater number of smaller packets counterbalances the performance improvements of the shorter packets.

IV. Frequency Channels Selection Scheme

In this section, we present a new algorithm, which modifies the original frequency hopping sequence scheme. AFH is based on the convention that some channels are good and some channels are bad for data transmission. ‘Good’ and ‘bad’ are determined based on whether the channel is already occupied or not. If a channel is occupied, that channel is bad and if the channel is unoccupied that channel is termed good.

In particular, our design modifies the Bluetooth frequency-hopping scheme such that it can choose the channels for transmitting the data intelligently. The goal of our modified scheme is to provide a congestion free scenario without modifying the Wi-Fi DSSS.

A typical Bluetooth network uses a Channel selector to select the random frequency in which the data has to be sent (see Fig. 3). For the intelligent channel

selection, our proposed scheme uses a special parameter called RSSI, which stands for Received Signal Strength Indicator. The IEEE 802.11 standard defines a mechanism to measure RF energy. The RSSI contains numeric value, an integer with an allowable range of 0-255 (a 1-byte value). For example, when an adapter wants to transmit a packet, it must be able to detect whether or not the channel is clear (i.e., nobody else is transmitting). If the RSSI value is zero, then the chipset knows that the channel is clear (i.e., the “Clear To Send”). Different vendors use different signal levels for the Clear Channel Threshold, the Roaming Threshold, and the RSSI value that represents these thresholds differences from vendor-to-vendor because different RSSI_Max values are implemented.

RSSI is an internal circuit which determines the signal power in a frequency channel. The output value of RSSI circuitry is used to determine the best possible frequency channel to send the data without any interference. The RSSI card will issue a CTS (Clear To Send) signal to the network interface card (NIC). Wireless NIC will select those channels whose RSSI value is zero and begin transmitting the data between Master and Slave devices.

Channel selection works as follows. Each Bluetooth receiver will have a Frequency Status Table (FST), where an RSSI value is associated to each frequency channel, as shown in Table (Table 1) below. Frequencies are classified “good” or “bad” depending on whether their RSSI value is 0 or not. Each slave has its own FST, which maintained locally. However, the master has in addition to its

a copy of each slave’s FST. At regular time intervals each slave updates its FST copy kept at the master using a status update message that can be defined in the Layer Management Protocol (LMP). Alternatively, the master can derive information about each slave’s FST by keeping track of the ACK bit sent in the slave’s response packet. Fig. 4 shows the illustration of the proposed scheme.

Table 1. Frequency Status Table

Status	Frequency Channel	RSSI
Good	Channel 17	0
Bad	Channel 26	2
good	channel 0	0
Good	channel 3	0
Bad	Channel 71	5
Good	Channel 78	0
Bad	channel 9	6
Bad	channel 6	12
Bad	Channel 46	58

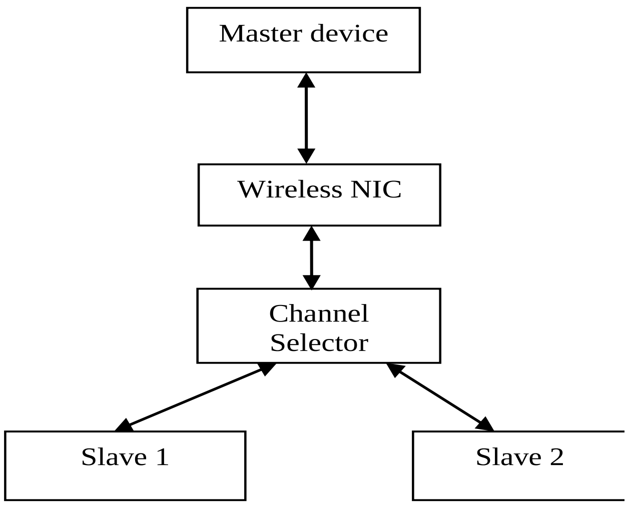

Fig. 3. Modified Bluetooth Block Diagram using AFH

If the status is good the network card is clear to send (CTS) data in that channel. Once the card is clear to send, a packet of information can be sent. On the other hand, AFH requires a master to slave message exchange in order to keep the piconet synchronized.

The following method has to implement at the master device that postpones the transmission of a packet until a slot associated with ”good” frequency becomes available. The master device, which controls all data transmissions in the piconet, uses information about the state of the channel in order to avoid data transmission to a slave experiencing bad frequency.

Furthermore, since a slave transmission always follows a master transmission, using the same principle, the master avoids receiving data on a ”bad” frequency, by avoiding a transmission on a frequency preceding a ”bad” one in the hopping pattern. This simple scheduling scheme needs only be implemented in the master device and translates into the transmission rule.

This simple scheduling scheme is implemented as an algorithm. From the Transceiver in the NIC, we will get the RSSI value. That RSSI value is used as the input of the algorithm. RSSI_val defines the RSSI value input received from the NIC where n = 79 represent the number of channels (see Fig. 5).

S: measured signal strength vector for n channel for 79 channels such as: S = (S0, S1, S2 ,..., S78. Each Si where 0 <= I <=78, containing the RSSI value which is calculated from RF power by the CC2420 transceiver chip and set in all the vector element.

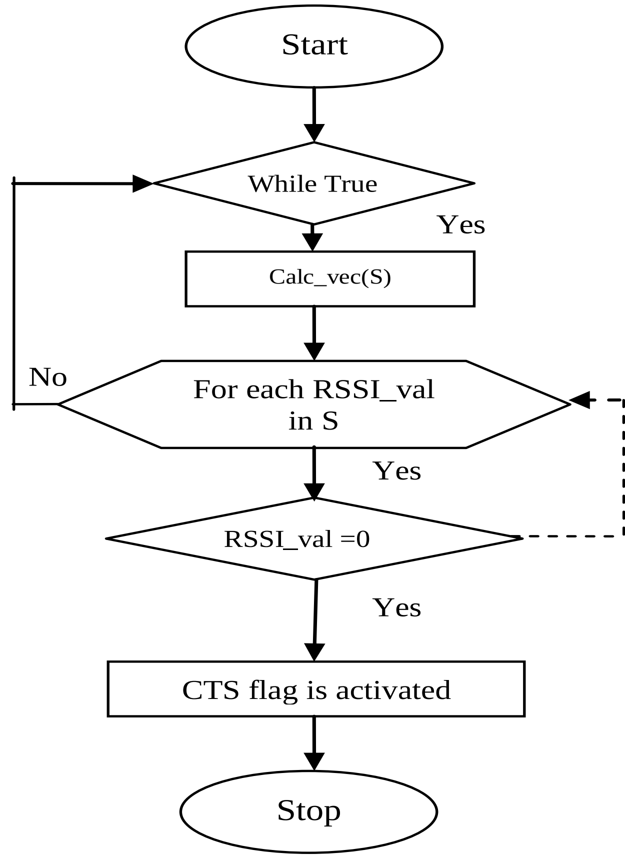

Fig. 4. Channel Selecting Flowchart

Algorithm: Opportunistic frequency selection algorithm

```
Start
Call RF_Power to compute RSSI value for each channel
        While true do
                Calc_Vec(Si); // where i= 0 to 79
                For each RSSI_val є Si do
                        If RSSI_val == 0 then
                                CTS flag is set to true
                                Channel == Free
                                Exit
                        End If
                End For
        End While
End
```

When algorithm is implemented a loop will be activated and a function Calc_vec(S) is called. The Calc_vec(S) function will return RSSI value from NIC. In the wireless Router (NIC), the NIC card will return the RSSI values for each frequency channel. That RSSI value is placed in the S vector.

Now the S vector is scanned for a Zero RSSI value.

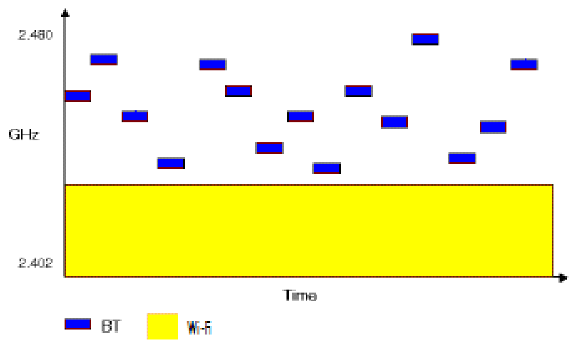

Fig. 5. Collisions avoided using Adaptive Frequency Hopping

When a zero RSSI value is found a CTS flag will be activated. The CTS flag will send a “Clear To Send message” to the NIC. Then algorithm will exit and the devices will start transmitting data using those frequency channels with RSSI value of zero.

The master transmits in a slot after it verifies that both the slave’s receiving frequency and its own receiving frequencies are good”. Otherwise, the master skips the current transmission slot and repeats the procedure over again in the next transmission opportunity.

V. CONCLUSION

In this paper, we presented an opportunistic frequency channel scheme. We discussed how the proposed scheme selects an available channel by analyzing the signal strength and minimizing the potential interference for data transmission. Several illustrations were provided in the context of master-slave scenario to show the practicality of our proposed scheme. Finally, to support the implementation, we also provided an algorithm for the opportunistic frequency selection.

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