2012 International Conference on Information and Computer Networks (ICICN 2012)

IPCSIT vol. 27 (2012) © (2012) IACSIT Press, Singapore

Interference Mitigation Technique for Performance Enhancement in Coexisting Bluetooth and WLAN

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Abstract. The number of devices equipped with IEEE 802.11 and Bluetooth technology is growing drastically, therefore interference may occur between the co-located devices in the 2.4 GHz ISM frequency band. This paper discusses the interference problem between this two co-located devices and intends to find improvement of the existing solutions for this coexisting issue. In addition to this, we consider the power allocation for channels to make the data transmission more energy efficient. We propose the idea of defining different power levels for different clusters according to their packet error rate (PER). In order to reduce the interference between the coexisting Bluetooth and WLAN networks, we determine the PER for each channels, sort them into clusters according to their PER and then provide a more power efficient data transmission through the interfered channel. Simulation results show that our proposed algorithm has better power efficiency and outperforms the interference mitigation techniques of the existing mechanisms.

Keywords: Bluetooth, WLAN, Coexistence, Interference Mitigation, Packet Error Rate (PER), Power Efficiency

1. Introduction

Bluetooth and Wireless Local Area Network (WLAN) share the same unlicensed industrial, scientific and medical (ISM) frequency band of 2.4 GHz. Hence interference could occur during data transmission. Bluetooth is a short range (0m-10m) cable replacing technology for Wireless Personal Area network (WPAN) [1]-[3]. It uses frequency hop spread spectrum, which means that it divides the frequency band into number of hop channels [4]. It has 79 channels, with a length of 1 MHz each. WLAN uses radio waves as its carrier and link two or more devices using a wireless distribution method and provides a connection through an access point to the wider internet. It is mostly used for enabling internet connections in various devices such as mobile phone, notebooks, etc. WLAN has 13 channels, where each channel has a length of 22 MHz which are 5 MHz apart from each other [5]. When both of these devices are in close proximity to each other, interference is bound to occur and the factors affecting the level of interference are: WLAN and Bluetooth transmission power, the offered load and the traffic type of Bluetooth. Our work mainly intends to mitigate interference between the coexisting Bluetooth and WLAN network while transmitting data packets at the minimum level of power required for transmission. We improve some of the existing coexistence mechanisms by defining the clusters according to the channels PER and then allocate power for each channel according to their PER in order to reduce interference during data transmission, and thereby achieve power efficiency.

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The rest of the paper is organized as follows: Section II reviews several related works in this topic and the problems with the existing mechanisms. In section III, we discuss our system model and the proposed algorithm of our scheme. Section IV shows and analyses the results of our simulation. Finally, in section V, we conclude our work by stating the limitations of our research and the ways of further improvements that we can work on in future.

2. Background

There are several interference problems caused by the proximity and simultaneous operation of Bluetooth and WLAN networks. The coexistence and the interference mitigation mechanisms are classified into two categories: Collaborative mechanism and Non-Collaborative mechanism [6]. Collaborative mechanism is used when both the WLAN and Bluetooth devices are integrated within the same physical unit and it is feasible for them to exchange information. When Bluetooth devices are not collocated with the interfering WLAN devices within the same physical units, non-collaborative mechanisms are used [8], [9]. To detect the presence of WLANs in the ISM band where Bluetooth devices are collocated, similar techniques are used by the existing non-collaborative mechanisms. A single Bluetooth device can estimate its own packet error rate (PER) or received signal strength indicator (RSSI) for each channel. The techniques used for detecting the presence of WLAN devices in the band are based on measuring the bit or frame error rate, signal strength, or signal-to-interference ratio (also known as RSSI) [7]. Since each Bluetooth device can maintain a packet error rate measurement per frequency visited, therefore frequency hopping devices know which frequencies are occupied by other users of the band and modify their frequency hopping pattern according to that. If one frequency is occupied then they can also choose not to transmit on that certain frequency. When it is detected that a WLAN device is present in the ISM band then the Bluetooth channel where interference occurs is known as the 'bad' channel, otherwise it is detected as a 'good' channel. Since Bluetooth can estimate its own PER, the channel that exceeds the predefined threshold value of the PER or RSSI, is marked as a 'bad' channel and the channel that does not exceeds the predefined threshold value of the PER or RSSI, is marked as a 'good' channel [11]. The main problem of the existing mechanisms are that when multiple WLAN or multiple Bluetooth piconet exists in the area of interference then the number of bad channel increases as the packet drop is higher in the interfering area. We investigate the following papers for better understanding of the problem at hand.

2.1. Dual Channel Transmission

The frequency diversity technique [9, 10] uses dual channel transmission (DCT) for Bluetooth piconets. The idea of DCT is to transmit the same packet on two distinct frequency hopped channels simultaneously and the power in each channel is half of what would be used in single channel transmission (SCT). A packet is successfully received if at least one channel survives. When neither of the two channels experiences collision, the two channels are combined to improve performance against noise. Theoretical analysis in [9] shows that with DCT, the PER can be reduced significantly compared to SCT when a small number of piconets coexist. The two channels are intentionally separated by at least 22 MHz so that DCT is also robust to WLAN interference, because a WLAN usually occupies a fixed frequency band of 22 MHz If one Bluetooth piconet with DCT and a WLAN coexist, the Bluetooth piconet will have zero PER due to collisions because at least one frequency channel of Bluetooth will fall outside the WLAN frequency band. By using two channels to transmit the same packet, the spectral efficiency of DCT is reduced to half of SCT [10]. DCT is certainly a very innovative approach to mitigate interference & to ensure data transmission but the method has several limitations. First of all, when multiple WLAN exists it may happen that most of the channels fall under the category of 'bad' channel. If so, then a huge amount of power is getting wasted over bad channels if we use DCT. And if there are two consecutive channels of WLAN colliding with Bluetooth channels, then having 22 MHz difference will not help the system any more. On the other hand if both of the channels are ‘good’ then also 50% is wasted as both channels transfer the same data. So we can conclude on this, no matter it’s a ‘good’ or ‘bad’ channel, a percentage of power is always wasted in DCT.

2.2. Channel Clustering

The channel clustering technique in [11] also utilizes the estimated PER. However, different from the existing PER-based channel classification methods, it does not depend on a predefined PER threshold, but uses the intrinsic pattern of the observed PER values. The “bad” channels occupied by a WLAN usually cluster together and have a higher average PER than the “good” channels due to the possibility of collisions with both WLAN and BT packets. So the main idea of channel clustering is whenever a steepness is found in the PER level, a cluster is made. Clusters having lower PER are considered as “good” clusters and clusters having higher PER are considered as “bad” clusters. And while transmitting data, Bluetooth will prioritize “good” clusters over “bad” clusters.

We see in [11] that it takes less time for data to transmit through a Bluetooth channel and also generates less interference to the WLAN channels when compared to the classification methods. But there are other problems with this existing channel clustering methods which are discussed as follows: When WLAN and Bluetooth coexist then the clusters are formed from one fluctuation of the estimated PER to the other and the edges are calculated accordingly. Therefore when the collision of packets in the WLAN and Bluetooth channels increases the estimated PER will fluctuate more often to create a large number of clusters and if this fluctuations occur at every estimated PER then the number of clusters and the number of channels will become almost same and hence the idea of clustering will not exist. If the estimated PER of all the channel in a Bluetooth device maintain an average PER then no cluster can occur as there will not be any fluctuations in the PER estimation. Another problem that may arise in this method is that if multiple Bluetooth or WLAN devices coexist, then the number of ‘bad’ channel will be higher. If the threshold value is predefined then the number of ‘good’ channel will be less. Hence the signal traffic will be higher.

2.3.Channel visiting

Once the channels are classified into either ‘bad’ or ‘good’ in terms of interference from WLANs, it is required to know in which channel data should be transmitted. According to the existing Bluetooth mechanism, if one channel is marked as ‘bad’, then it will not be visited at all. The problem will become even worse as the number of ‘bad’ channel will increase and the number of ‘good’’ channel will decrease. Hence a channel which is marked as ‘bad’ previously will not be visited any longer after the interference increases which results in higher traffic load. In [11], [12] the author tried to improve this mechanism by stating that channels should be visited more often to see whether a WLAN channel collides with the Bluetooth channel to make it a ‘bad’ channel, as interference may occur anytime with the presence of WLAN network. Since this channel visiting mechanism is quite effective to detect the interference between the two coexisting network, hence we have included this channel visiting mechanism with our algorithm.

3. System Model

In our model we assume only one coexisting Bluetooth piconet and one WLAN network, for ease of our simulation,. It, however, could be extended for multiple coexisting piconet and WLAN scenario.

3.1. Power Efficiency Mechanism

In our algorithm, our experiment shows three different scenarios where different numbers of clusters are formed based on the PER. We define multiple power level for different range of PER for all the scenarios. In our model, power level is mostly defined from 50% to 100%. The lowest limit of power is assumed to be the 50% of the total power for transmission of data as the authors in [9], [10], proved that data transmission takes place at 50% of power. Unlike other models, only the channels with very high traffic are assigned 30% of power. The area which is outside the range of WLAN network has a lower PER (0~0.4) and hence low power is assigned to transmit data, because data packets can be sent easily through the channels with less interference. When interference occurs due to the presence of WLAN network, most of the channels are assumed to have an average PER (~0.5) and therefore the offered load increases as the packet loss increases. Data is transmitted with 100% power as signal traffic will be higher in such areas. When multiple Bluetooth piconet or multiple WLAN coexists, the PER is much higher (0.6~1.0) as interference increases and hence packet drop increases. More 'bad' channels are present in the channels, so a very small power is given to transmit data. The signal strength is very high and it is hard to transmit data through these channels. However if we give more power to transmit data then the signal strength of the channel increases and as a result collisions increase due to interference between the data packets and the high power signal. Therefore, to mitigate such problems a very small amount of power is applied to make the transmission more power efficient. Channels having PER higher than 0.8 are not allowed to transmit any data. Our power efficient method implies that when there is an interference in the Bluetooth channel due to the presence of WLAN network, the packet drop increases and as a result PER increases. Therefore it is not viable to send the data packets at full power all the time because more collisions will be created due to the higher signal strength of the channel.

Two types of power level charts are shown in the following tables, which show the power assigned for different PER range for five and ten clusters respectively. Similarly more numbers of clusters can be created according to user inputs.

PER Range	Power Level
$0.00 \le PER < 0.20$	0.50
$0.20 \le PER < 0.40$	0.75
$0.40 \le PER < 0.60$	1.00
$0.60 \le PER < 0.80$	0.30
$0.80 \le PER \le 1.00$	X

Table 1: Power level for 5 clusters

PER Range	Power Level
$0.00 \le PER < 0.10$	0.50
$0.10 \le PER < 0.20$	0.60
$0.20 \le PER < 0.30$	0.70
$0.30 \le PER < 0.40$	0.80
$0.40 \le PER \le 0.50$	0.90
$0.50 \le PER \le 0.60$	1.00
$0.60 \le PER \le 0.70$	0.50
$0.70 \le PER \le 0.80$	0.30
$0.80 \le PER \le 0.90$	X
$0.90 \le PER \le 1.00$	X

Table 2: Power level for 10 clusters

3.2. Algorithm

The proposed channel clustering technique utilizes the estimated PER of each channel and segment the PER at different range to form a cluster. Since the clusters formed maintain the same PER value, it does have a fixed number of clusters which can be classified as 'good' or 'bad' clusters. The bad channels cannot enter the good clusters; similarly good channels are not present in a bad cluster. Since a predefined power level is defined for each segment of PER, if multiple WLANs exist, then transmission of data packets will not stop as data can be sent at low power level through the channel with higher PER. And unlike other mechanisms we propose a new threshold level of PER which is 0.8, whereas in [9] data transmission stops when the threshold level of PER exceeds 0.5 because channels having PER above 0.5 is considered as 'bad' channels.

We propose the power efficient algorithm to detect the PER of each channel and then cluster all the channels according to their PER range, which is given a predefined power level in order to transmit data at minimum power. Then this sorting and clustering follows a loop and this is how Bluetooth works in order to make its data transmission energy efficient. The flowchart for the power efficient algorithm followed by the Bluetooth defined algorithm is shown in figure 1 and 2 respectively.

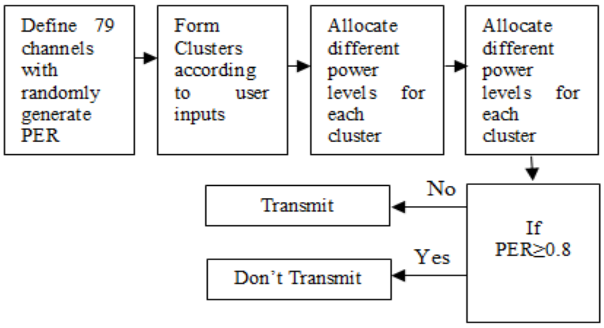

Fig. 1 Power Efficient Algorithm

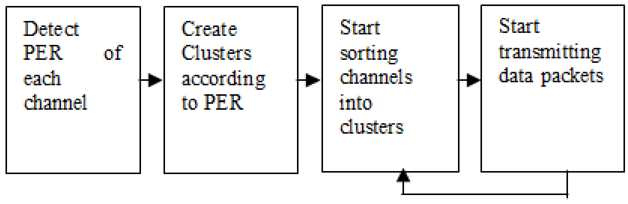

Fig. 2 Bluetooth Defined Algorithm

The steps in the power efficient algorithm are shown below:

1) At the beginning, PER for all the 79 channels in a Bluetooth are detected. If a WLAN is present within close proximity of the Bluetooth network, then the channels in that area have a high PER otherwise the channels have lower PER. Detecting the PER helps us to form clusters and define the power at which data will be transmitted.
2) To form the clusters the user will be asked for PER differences. For example, if the PER difference is given as 0.1, 10 clusters will be formed as PER measurement is taken between zero to one. Hence the first cluster will contain all the channels which have a PER ranging from 0.0 -0.1, and so on.
3) The power level is defined for different range of PER according to the Power Charts shown in table 1 and 2.
4) When the PER range is greater than or equal to 0.8 then we have decided not to transmit any data because of higher interference in that area data will not be able to go through the channel and hence power efficiency increases. If the PER range is below 0.8 then data is transmitted according to the defined power level.
5) After the power efficient algorithm, the Bluetooth defined algorithm follows the loop of detecting PER and sorting the channels into clusters according to PER and then starting transmission of data from the transmitter to the receiver.

4. Simulation And Result

We have done our simulation using MATLAB. We have simulated our algorithm for 5, 10 and 20 clusters. Our simulation is focused on two factors: Power Efficiency and Throughput. We carried out 100 test runs. For 5 clusters the system used 51.0589% of power, for 10 clusters it used 53.1278% of power and for 20 clusters it used 56.4482% of power. The results for 5, 10 and 20 clusters are shown in figure 3, 4 and 5 respectively. To show that in the same environment our system performs better than the proposed mechanism in [11], we calculate the throughput using the formula from their proposed throughput equation which is,

$$S = G\,[p_g^{2}\,(1 - p_{bt}) + p_g^{2}\,(1 - p_{bt})^{2}]/2$$

Where, S is Throughput, G is Packet Transmission Probability, p_g is Probability of Good Channels, P_{bt} is Probability of a Bluetooth Packet Transmission colliding with other Bluetooth packet.

We consider a scenario for 10 clusters where P_{bt} is 30% in both the cases. In the previous work [11] threshold value of PER is 0.5, therefore, Packet Transmission Probability is also taken as 0.5. But in our system we consider our threshold level to be 0.8, hence G equals to 0.8. We did 100 test runs for randomly generated PER using MATLAB. It can be seen from figure 6 that almost every time our proposed system outperforms by having higher throughput when compared with [11].

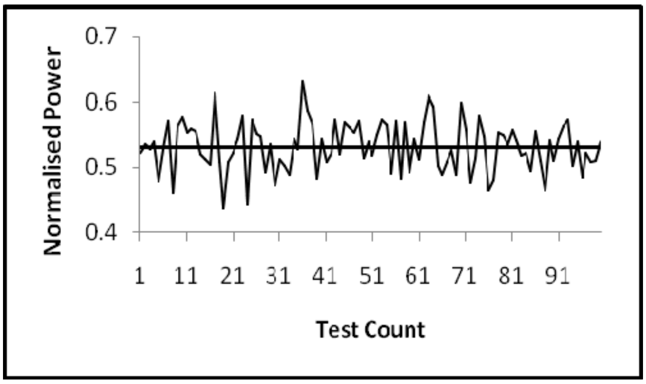

Fig. 3: Power chart for 5 clusters

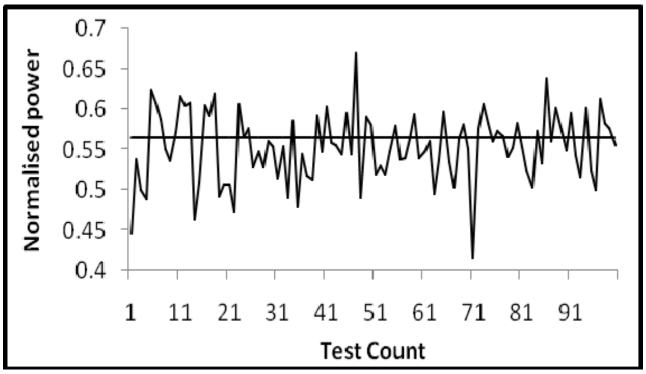

Fig. 5: Power chart for 20 clusters

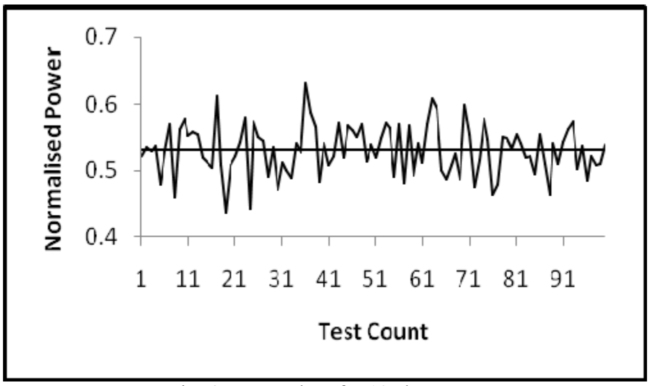

Fig. 4: Power chart for 10 clusters

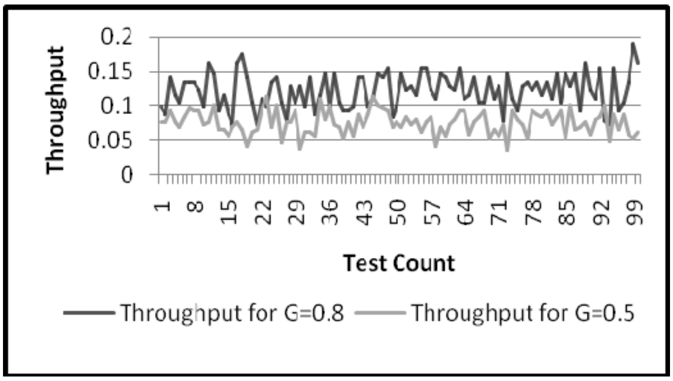

Fig. 6: Throughput

5. Conclusion

In this paper, we address the issue of inference in the coexisting Bluetooth and WLAN network. Based on the modifications of previous work, we develop solution for this problem in the setup of single piconet and WLAN pair. We also enhance the power efficiency of our solution by defining different power levels for different clusters according to their packet error rate. We determine the PER for each channels, sort them into clusters according to their PER and then provide a more power efficient data transmission through the interfered channel. Simulation results show that our proposed algorithm has better power efficiency and outperforms by having a higher throughput when compared with the existing mechanism.

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