Postprint of: Klajbor T., Woźniak J., Performance analysis of co-existing Wi-Fi and Bluetooth networks, POLISH JOURNAL OF ENVIRONMENTAL STUDIES, Vol. 16, Iss. 4B SI (2007), pp. 78-82

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# Performance Analysis of Co-existing Wi-Fi and Bluetooth Networks

**Abstract**

*Unlicensed ISM band is used by various wireless technologies. Thereby, issues related to ensuring a required efficiency and quality operation of co-existing networks become essential. The paper analyses the influence of mutual interferences between IEEE 802.11b transmitters (colloquially named Wi-Fi) and Bluetooth (BT) devices on the quality of their transmissions. Exemplary network scenarios have been investigated. New results, related to the Adaptive Frequency Hopping (AFH) technique are presented.*

**Keywords:** *Bluetooth, IEEE 802.11b, interference, co-existence, AFH*

## Introduction

The number of various wireless technologies and network devices making use of ISM band (e.g. Bluetooth (BT) [1], IEEE 802.11b (Wi-Fi) [2] or IEEE 802.11g) is growing very fast. Due to this, it becomes more and more difficult to provide transmission parameters that can guarantee the quality of services required by co-existing networks. This specially refers to specific network devices operating in a close vicinity around other devices belonging to different independent networks, very often based on different technical and functional solutions. This paper presents new simulation results, showing the importance of co-existence mechanisms [3] (e.g. AFH – Adaptive Frequency Hopping), introduced in order to decrease mutual network interferences and interactions.

Performance analysis of IEEE 802.11b networks operating in a certain environment together with BT devices, is quite often discussed in the literature (see for example [3], [13]). Also, analytical models for BT piconets influenced by 802.11b networks have been presented. For example, in [9] and [10] the impact of interferences coming from Wi-Fi transmitters is analyzed. These studies have been carried out without taking into account the interferences coming from other BT devices which may operate in a scatternet. On the other hand, an analysis of BT scatternets can be found in [8], while considerations concerning aggregated scatternet throughput were presented in [11] and [12].

This work investigates the problem of mutual interferences of IEEE 802.11b networks and BT transmitters. The novelty this research consist in investigation of mutual interferences generated by Wi-Fi and BT technologies as well as internal BT interferences coming from other piconets. The following sections present a problem formulation, and results of both simulation experiments and theoretical analyses carried out in order to determine the influence of such interferences.

The paper structure is organized as follows: the first section deals with the problem of co-existence of BT and Wi-Fi devices. The following section focuses on a solution proposed to decrease mutual interferences. The last section summarizes the results and gives final comments and conclusions.

## Problem Formulation

Unlicensed ISM band gives opportunity to run in this common band different systems and devices. At the same time it generates quite essential problems with effective sharing of this resource, crucial to the proper wireless network operation. In the paper we consider one of possible scenarios of ISM utilization, connected with co-existence of Bluetooth (BT) network [1] and IEEE 802.11b (Wi-Fi) [2], i.e. networks with different transmitting powers and different, non-compatible transmission techniques (FHSS - Frequency Hopping Spread Spectrum in BT - and DSSS - Direct Sequence Spread Spectrum in Wi-Fi solutions). Fig.1 illustrates an exemplary visualization of interference between BT and 802.11b transmissions, taking into account both frequency and time domains as well as powers of transmitted signals.

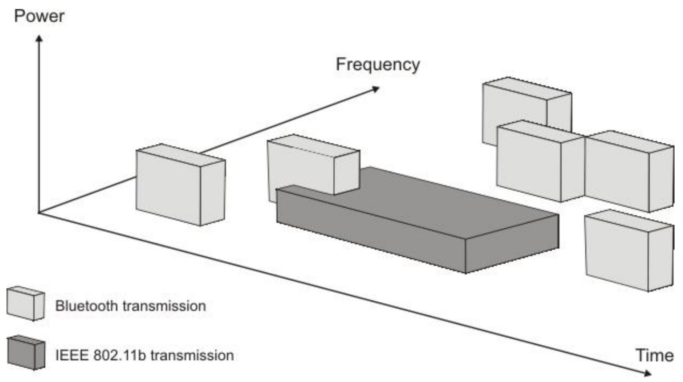

Fig. 1. An illustration of Bluetooth and 802.11 networks co-existence problem. Prepared on the basis of [5].

The exchange of data in the physical layer of BT network is based on a wideband FHSS transmission. FHSS constitutes a multi-access technique applied in a radio system. This method is connected with making use of a significantly wider band compared to information signal band. Data is transmitted in frames, each transmitted on a different carrier frequency. ISM band has been divided into 79 channels placed at intervals of 1 MHz. Transitions between frequencies take place 1600 times per second.

DSSS technique makes use of a single, permanently assigned transmission channel (band) with the width of 22 MHz. This technique consists in spreading signal spectrum in the channel via coding transmitted information bits sub-sequences with the help of specified chip sequences. 802.11b standard allows for a higher nominal transmission speed in the same radio channels in ISM band of 2.4 GHz: 5.5 Mbps and 11 Mbps, thanks to the application of CCK modulation technique (Complementary Code Keying), coding respectively 4 or 8 bits with a single CCK codeword (a sequence of eight QPSK chips).

IEEE 802.11b standard allows also for transmission in FHSS technique; however it is relatively rarely applied due to a significant reduction of transmission speed (to 1 Mbps as in BT). It also allows for the application of the power of 100mW in a single channel.

BT standard defines three classes of devices (class 1: 100 mW; class 2: 2.5 mW; class 3: 1 mW), which as for the transmitter power, have various operation ranges (100 m, 10 m and 10 cm respectively). While theoretically analyzing the above values, a significantly higher maximum value of power density in a single BT channel may be observed compared to Wi-Fi channel.

Summarizing, common usage of ISM band, in a situation where in close vicinity devices coming from various technologies operate, can decrease the performance parameters of all the bands' users. The level of interference will depend on the distance between various devices, their technology solutions and powers of transmitted signals.

## Problem Solution

In order to provide higher efficiency of a number of technological solutions operating within the same area, co-existence mechanisms have been worked out [3]. Such mechanisms can be divided into two groups [3]:

1. *Collaborative mechanisms*, requiring information exchange between IEEE 802.11b and Bluetooth devices:
   - Alternating wireless medium access,
   - Packet traffic arbitration,
   - Deterministic interference suppression.
2. *Non-collaborative mechanisms*, which can be adopted by 802.11b and/or Bluetooth devices without a direct collaborative system:
   - Adaptive interference suppression,
   - Adaptive packet selection,
   - Packet scheduling for ACL links,
   - Packet scheduling for SCO links,
   - Adaptive frequency-hopping.

The most interesting proposal of those mechanisms is AFH (Adaptive Frequency-Hopping), broadly adapted to new BT devices (version 2.0). AFH algorithm generally consists in avoiding busy frequency bands (see Fig. 2B).

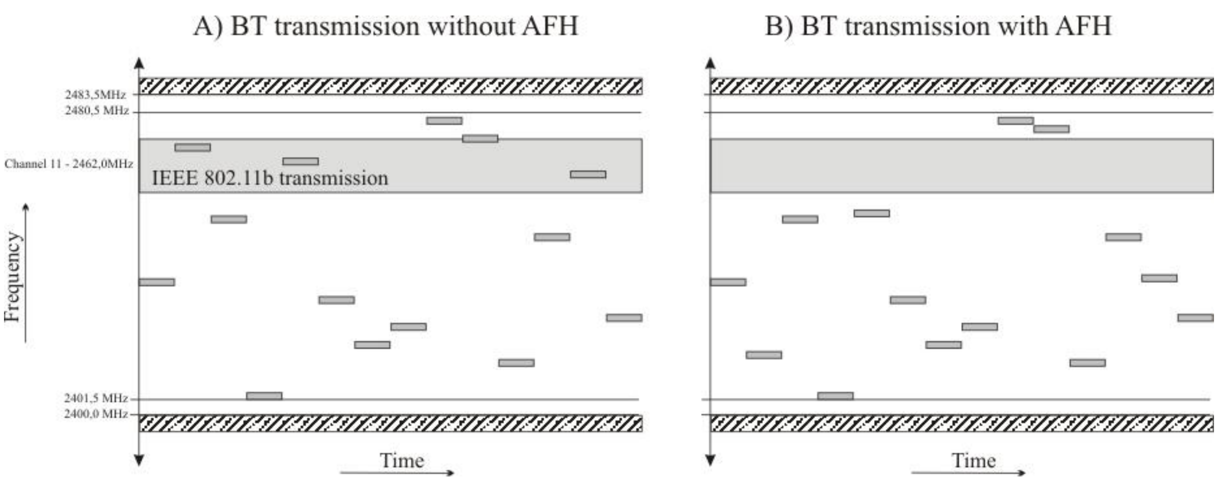


Fig. 2. An illustration of AFH mechanism operation.

In order to prove the importance of AFH non-collaborative mechanism a number of simulation experiments with the use of simulator [6] was carried out. Example results illustrating the co-existence problem are presented below. All simulations have been performed in series of 30 measurements to ensure a high reliability of results.

Fig. 3 presents simulation results concerning the throughput of IEEE802.11b network for a few cases: lack of interference, interference coming from one BT piconet and in the function of BT piconets number (located in the surroundings of a considered Wi-Fi network). This simulation scenario has been carried out under the condition that BT transmitters (without AFH mode) are placed within 1 m from a Wi-Fi receiver. IEEE 802.11b throughput changes have been analysed for class II BT devices and distance between Wi-Fi device (STA) and access point (AP) of 5 m. For the sake of simplicity of analytical calculations, it has been assumed that the masters in the BT scatternet are synchronized with each other (it means that each interference occurs during the whole BT frame duration) and transmission takes place via DH1 frames (Bluetooth) and 1500B-long frames (802.11b). In considerations no coding gain and fading channel impact was taken into account.

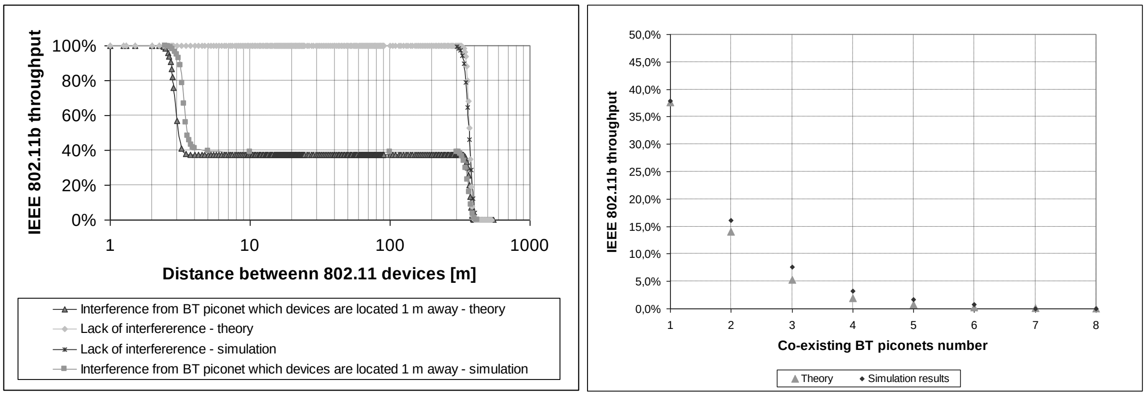


Fig. 3. 802.11b network throughput in case of: lack of interference, interference coming from one BT piconet and in the function of BT piconets number. Source: simulator presented in [5].

As it has already been presented, even a relatively small number of BT piconets (under given operating scenarios) can significantly limit number and/or quality of transmissions within a given IEEE 802.11b network.

To better illustrate such effects Fig. 4 presents a throughput of the examined BT piconet for the following cases:

- Lack of interferences,
- Interference coming from IEEE 802.11b network and
- Interference from Wi-Fi network and 10 piconets (of a given scatternet or independent networks).

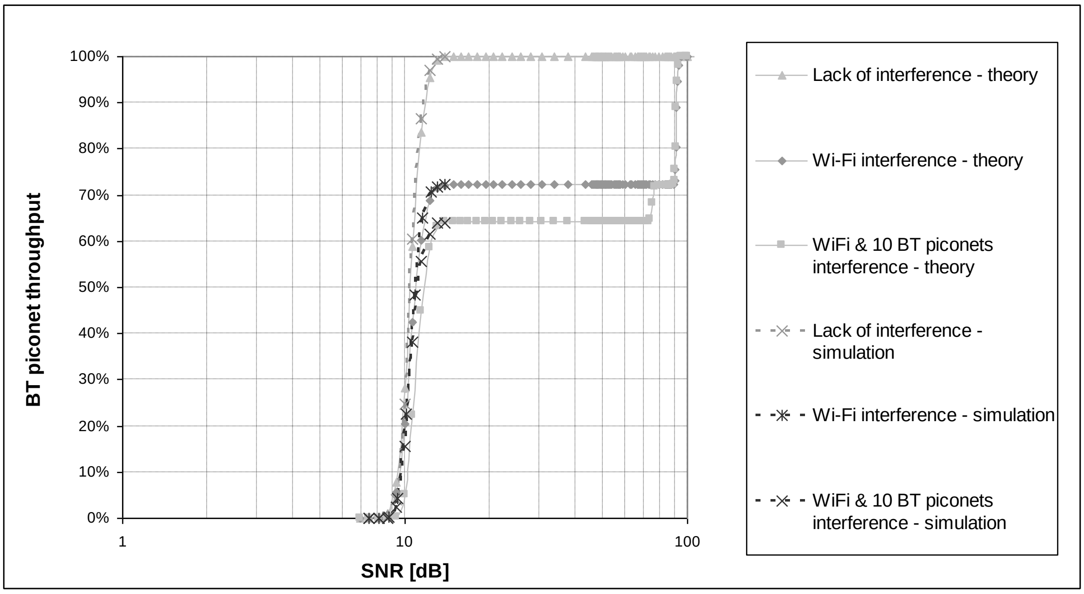


Fig. 4. BT piconet throughput in scatternet, depending on the interference type.

A fixed (temporary) level of throughput is a characteristic element in this diagram. It results from the fact that for a certain level of a signal to interference ratio (SNR), retransmissions of BT frames are required. Operating scatternet, comprising 10 piconets may additionally result in a decrease of the examined piconet throughput by approx. 8 %.

In the last series of experiments an ISM environment consisting of 3 independent 802.11b networks and a scatternet with 6 BT piconets (18 class II devices) spread over the radius of 10m was investigated. In our scenario a BT master devices are evenly located within 4 m from the centre. Table 1 presents the results of simulation measurements in two cases. Co-existence of BT and 802.11b networks was analyzed with or without taking into account co-existence collaborative mechanism (either FH – Frequency Hopping BTs or with AFH mechanism [3]).

Table 1. Average Frame Error Rate (FER) of Bluetooth (class II devices) and 802.11b networks.

| | Mechanism used | |
|---|---|---|
| | FH | AFH |
| Average BT FER [%] | 85,6 | 20,7 |
| Average 802.11 FER [%] | 68,0 | 0 |

As it is shown in Table 1, usage of AFH algorithm has a very positive impact on both networks operation, consisting in decreasing their average frame error rates.

Nevertheless, the algorithm may also prove to be an inefficient solution, due to the fact that it does not guarantee the compliance with many BT devices (for example of 1.1 version) and in some specific scenarios it will not ensure an efficiency level, for many BT networks operating within the same ISM band (see Table 1), as their users could expect. AFH may be more suitable for slow changing environments in which the same sequence could be used for a long period of time. On the other hand, in environments where the interference levels change more rapidly, AFH may not be the best interference mitigation solution of choice [4].

There are on-going research works to improve ISM environment effectiveness. For instance, in [7], an IBLUERA control mechanism, based upon the use of a new model comparing the efficiency of ISM environment, is investigated. It has been shown that IBLUEREA can facilitate the co-existence mechanisms in use (including AFH mechanism).

## Conclusions

In the paper the usefulness of AFH mechanism in case of co-existence of BT and Wi-Fi networks has been shown. Based on carried out simulation experiments, the following conclusions can be drawn:

- Interference rate depends on the propagation conditions, and traffic load generated by a given BT scatternet (and the same the number of BT piconets) and IEEE 802.11b networks,
- By increasing the distance between devices, the standard “vulnerability” to interferences from other transmitters and networks (respectively BT and 802.11) increases,
- For short distances between devices in a network, technologies tend to be significantly resistant to interferences coming from other sources,
- Impact of interferences coming from other piconets is significantly smaller compared to interferences from IEEE 802.11b system (for BT).

It has also been proved that AFH [3] algorithm may reduce the impact of mutual interferences coming from many different technologies and therefore be particularly useful for sensor networks comprising of a large number of Bluetooth devices.

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