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Bluetooth and Wi-Fi Coexistence Simulation

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Abstract: - The paper deals with simulation of *Bluetooth* and *Wi-Fi* systems *coexistence* over *Physical Layer* with help of the new program in *Matlab*. Basic description of the program is provided in the first part of the paper and the results in graphical and numerical form are introduced as the *BER* to power ratio dependences. The program can also compute the frequency components and waveforms of Bluetooth and Wi-Fi signals.

Key-Words: - Bluetooth, Wi-Fi, Matlab, BER, E_S/N_0, Physical Layer, coexistence

1 Introduction

At present time, wireless access networks use many different technologies. The most extended wireless technology for access to Local Area Networks (LAN) is standard 802.11b, which is known all over the world as Wi-Fi standard (Wireless Fidelity). We can see that Wi-Fi standard enables internet connection in restaurants, airports, universities, shopping malls and in many other public places. Nowadays, this technology is implemented to almost every notebook, PDA or mobile equipments. Wi-Fi help to cover local area places with internet access.

On the other hand in Personal Area Networks (PAN) is very much-used Bluetooth standard, which is low-cost, low-power, secure and robust technology providing connection for up to 10 meters range. The technology promises to eliminate the confusion of cables, connectors and protocol confounding communications between today's high tech products. Mobile phones, pagers, laptops, PDAs, digital cameras and more, all now have a common structure for communicating across their product platforms. Bluetooth is used widely for connecting equipment like wireless keyboard, wireless mouse, Bluetooth headset, mobile phones and enables wireless printing on Bluetooth-enabled printer.

Both introduced standards are located to without license frequency band ISM 2,4 GHz (2,402 – 2,480 GHz). Frequently, both systems are built-in into same electronic equipment, for example notebook. In this case the cross distortion can be arise between systems.

The cross distortion investigation of the systems is concentrated on determination of a bit error rate (BER) for given the signal to noise ratio (SNR), which is proportional to energetic efficiency given by E_b/N_0, where E_b is one bit signal energy and N_0 is spectral noise density. For multilevel modulation systems, the BER to E_s/N_0 dependence is used, where E_s is 1 symbol signal energy.

2 Basic Program Description

Program in Matlab provides Physical Layer simulation of Bluetooth and Wi-Fi standards. Both systems work in 2,4 GHz frequency band which is not suitable for Matlab simulation (long time of simulation and large memory).

Simplification of simulation was realized by transposition of the ISM band from 2,402 – 2,480 GHz range to 202 - 280 Hz range. In this case the whole band is used for frequency hopping in Bluetooth system and for spread spectrum signal in Wi-Fi system. Bluetooth simulation uses 79 channels, which are 1 Hz wide and Wi-Fi uses 13 carriers in the 202 – 280 band. There is also one added Wi-Fi carrier frequency out of the ISM band for correct program working verification.

The program consists from three main parts. In the first part, the transmission of the Wi-Fi signal throughput environment with distortion is simulated. The second part of the program simulates transmission of the Bluetooth signal in the same environment. Coexistence of the both signals and BER calculations are provided in the third part of the program. Block diagram of a simulation is introduced on Fig. 1 and Fig. 2. The Matlab program calculates BER to power ratio (Wi-Fi/Bluetooth power).

2.1 Wi-Fi Simulation

In Wi-Fi Physical Layer simulation are basic rates of 1 Mbps (BPSK) or 2 Mbps (QPSK) used and also DSSS (Direct Sequence Spread Spectrum) is used for spreading the signal. Simulation starts with generating pseudorandom sequence of chosen length. This bit sequence is spread with the Barker code [1 0 1 0 0 1 1 1 0 0 0] and modulated with BPSK or QPSK. Special internal AWGN Matlab function is used for simulation of the modulated signal transmission in noise environment. This function adds together data signal and equivalent noise signal, which is proportional to SNR value. Calculation of SNR with help E_s/N_0 ratio is given by formula

$$SNR = 10 \cdot \log \frac{E_s}{N_0} - 10 \cdot \log \frac{f_{vz}}{f_s} \quad \text{[dB]}, \qquad (1)$$

where f_{vz} is a sample frequency and f_s is a symbol frequency. The modulated "noised" signal is demodulated and despreaded by analogy. Input pseudorandom bit sequence is used not only for simulation of data transmission in communication channel, but also for comparing with demodulated signal and determination of the BER on the output. You can see the block diagram of Wi-Fi simulation in the Fig. 1.

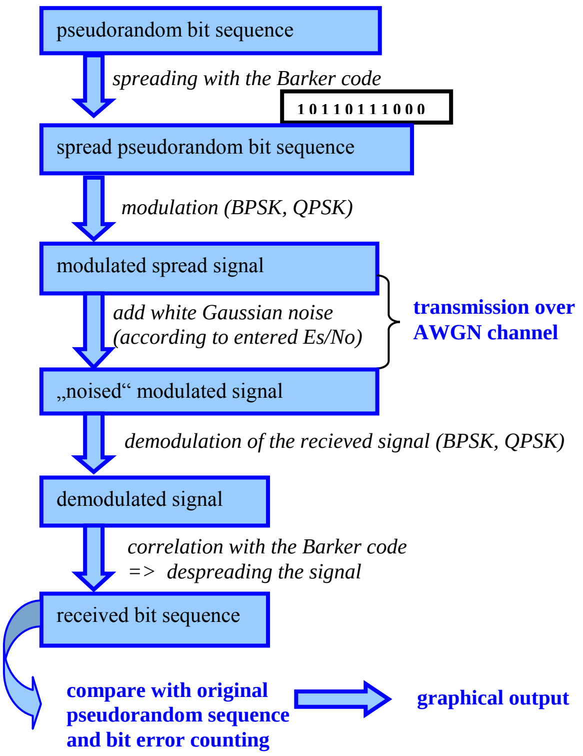

Fig.1: *Block diagram of Wi-Fi simulation*

2.2 Bluetooth Simulation

In Bluetooth Physical Layer simulation 2FSK modulation is used. For spreading the signal over the ISM band FHSS (Frequency Hopping Spread Spectrum) is applied. The simulation starts with generating the pseudorandom data bit sequence (i.e. 10 000 bits). In this case, the same pseudorandom sequence as in Wi-Fi simulation is used. We also need to generate pseudorandom sequence of Bluetooth carrier frequencies for Frequency Hopping. Than pseudorandom data bit sequence is divided into timeslots (10 bits per timeslot) and each timeslot is modulated with a relevant carrier frequency. You can see the block diagram of the Bluetooth simulation in the Fig. 2.

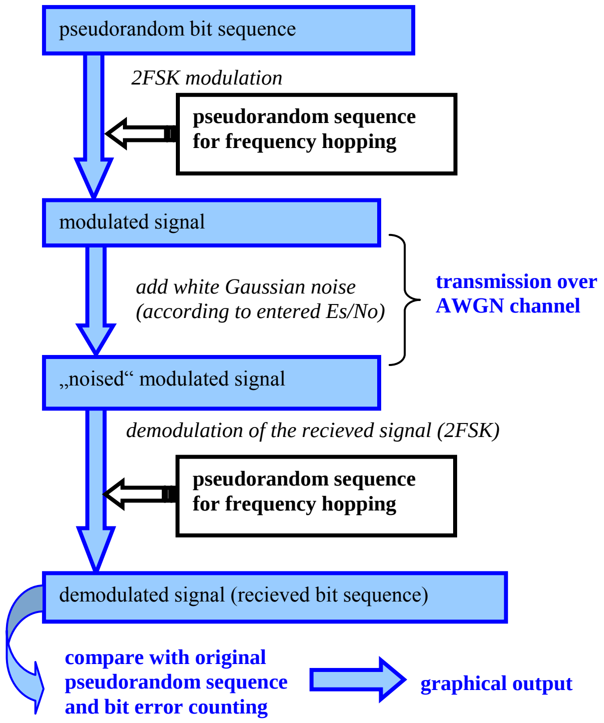

Fig.2: *Block diagram of Bluetooth simulation*

2.3 Simulation of Coexistence

In the simulation of coexistence we use the modulated signals from Bluetooth and Wi-Fi simulations. These signals are adjusted for simulation of Wi-Fi signal transmission in presence of Bluetooth and by analogy for simulation of Bluetooth signal transmission in presence of Wi-Fi. The simulation

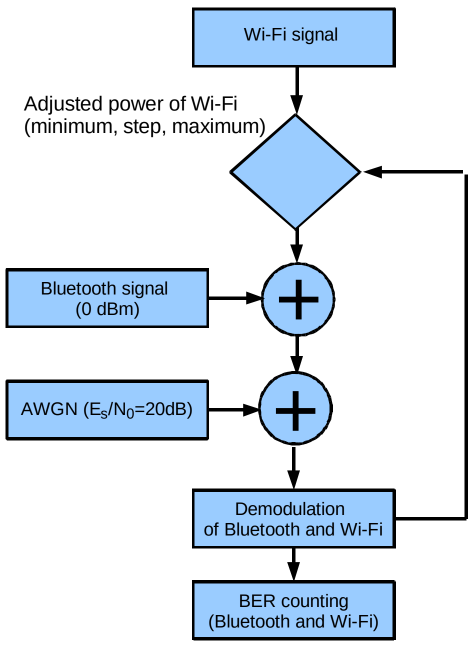

Fig. 3: *Block diagram of coexistence simulation*

Spectrum of Wi-Fi and BT modulated signals (without noise) are calculated with help of Fast Fourier Transform (FFT). For Wi-Fi system is considered one-second time range of modulated signal. Spectrum of the Bluetooth signal is calculated as a sum of one-second time ranges of modulated signals on each carrier.

2.4 Graphical Interface

Program window offers several possibilities, which must be accepted before simulation starts. On the left side of the window (Fig. 4) we can adjust common parameters for Bluetooth and Wi-Fi systems. On the upper left side, the length of input pseudorandom bit sequence can be adjusted. Bluetooth power is set to 0 dBm through the whole simulation while Wi-Fi power can be adjusted from -20 to 20 dBm. Program makes it possible to determine the minimum and maximum Wi-Fi power together with its step. Graphical presentation possibilities are arranged in the lower position. On the left side can be chosen parameters such as Wi-Fi carrier frequency and also power of AWGN noise signal, which is set to default 20 dB. Beside these settings we can see a window for signal coexistence simulation and window for power drawing.

3 Simulation Results

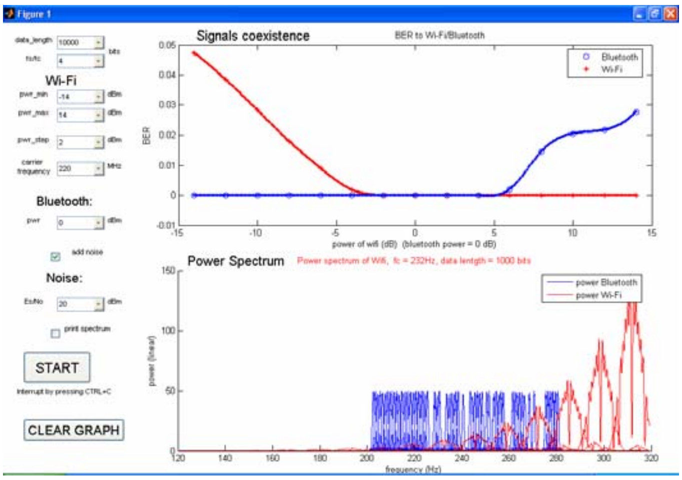

Fig.4: *Graphical Interface- simulation layout*

Example of simulation shows Fig. 4. In this case was used 10 000 samples, timeslot length 10 bits, i.e. BER = 10-4, the signal power of Bluetooth was adjusted on 0 dBm and the signal power of Wi-Fi was adjusted in range from -14 dBm to 14 dBm with a 2 dBm step. Spectrum of both systems is printed in the Fig. 4. The Wi-Fi power carrier frequency is 220 Hz through whole simulation, but in the Fig. 4 (Power Spectrum) it is printed to the whole ISM band due to the better display of the Wi-Fi/Bluetooth power portion for each step.

Matlab simulation shows that in the particular conditions, both systems (Bluetooth and Wi-Fi) are able to coexist and communicate with zero BER. If power of Wi-Fi is less than 4 dB under the level o Bluetooth power, or no more than 6 dB above the Bluetooth power, both systems are able to work without any bit errors (Fig. 5, Fig. 6). In these pictures you can see the bit error rate to power ratio dependence.

Tab. 1: *BER to power ratio dependence*

Wi-Fi - Bluetooth [dB]	BER Wi-Fi [-]	BER Bluetooth [-]
-14	0,0437	0
-12	0,0437	0
-10	0,0237	0
-8	0,0237	0
-6	0,0101	0
-4	0	0
-2	0	0
0	0	0
2	0	0
4	0	0
6	0	0
8	0	0,0122
10	0	0,0212
12	0	0,0212
14	0	0,0212

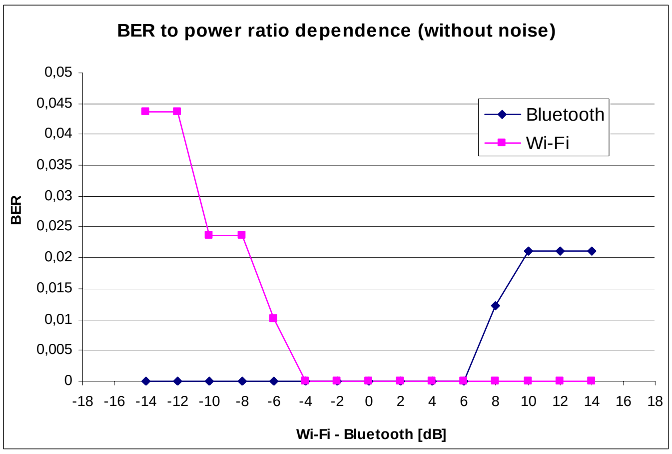

Fig. 5: *BER to power ratio of Wi-Fi and Bluetooth dependence (without noise)*

Because there is always noise in a real environment, we have a choice to add AWGN noise in the program. Power of the noise signal is calculated for E_s/N_0 = 20 dB and the noise doesn't affect the BER of signals very much. AWGN noise signal is used in this simulation to make smoother the final graphics and to put it near to the real measurement. You can see the results of the simulation in a Tab. 2 and graphical output in a Fig. 6.

Tab. 2: *BER to power ratio dependence, noise for E_s/N_o=20 dB*

Wi-Fi - Bluetoo	BER Wi-Fi [-]	BER Bluetooth [-]
-14	0,0473	0
-12	0,0384	0
-10	0,0283	0
-8	0,018	0
-6	0,009	0
-4	0,0018	0
-2	0	0
0	0	0
2	0	0
4	0	0
6	0	0,0019
8	0	0,0144
10	0	0,0205
12	0	0,0217
14	0	0,0278

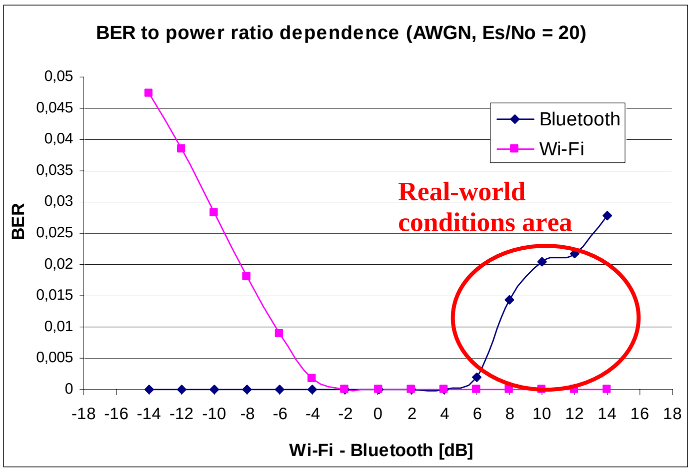

Fig. 6: *BER to power ratio dependence (noise for E_s/N_o=20 dB)*

In a Fig. 5 and Fig. 6 you can see, that Wi-Fi starts to have nonzero value when its power level is more than 4 dB less than power level of Bluetooth. Also Bluetooth starts to have nonzero values when its power level is more than 6 dB above Wi-Fi signal. Because most of all Bluetooth equipment uses much lower power (0 to 10 dBm) than Wi-Fi which uses 20 dBm, we reach the right side of the graph on Fig. 6. This range is marked as a “Real-world conditions area” and you can see that Bluetooth is less resistant to the interference.

4 Conclusion

There was made a new program in Matlab that count Wi-Fi and Bluetooth coexistence as a BER to power ratio dependence. Simulation results are introduced in Tab.1, Tab.2, Fig.5 and Fig.6. Bluetooth and Wi-Fi systems coexistence befouls in the higher amount Bluetooth system by reason of lower transmitted signal power and lower ability stand up to wideband distortion of Wi-Fi system.

A model of physical layer for the Bluetooth and Wi-Fi standards has been provided. The Matlab program described simulates the coexistence of these two wireless standards. The simulation results are given in numerical and graphical forms as dependence relations between BER and power portion. The frequency characterizations of the signals can be also displayed. From the point of view of the noise and distortion of other systems working in the same frequency band, the coexistence of two wireless systems is preferable for the system with greater wideband.

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