IEEE 802.11g Baseband Physical Layer Simulation

JAN MIKULKA
Brno University of Technology
Department of Radio Electronics
Purkynova 118, 612 00 Brno
CZECH REPUBLIC

STANISLAV HANUS
Brno University of Technology
Department of Radio Electronics
Purkynova 118, 612 00 Brno
CZECH REPUBLIC

Abstract: This paper deals with a Matlab simulation of IEEE 802.11g physical layer specification. The Matlab program simulates data transmission over awgn communication channel for mandatory data rates defined in specification. Program includes Barker coding, CCK and OFDM implementation for data rates from 1 Mbit/s to 54 Mbit/s. Basic description of the program and results in graphical and numerical form are introduced as a BER to E_b/N_0.

Key–Words: IEEE 802.11g, Wi-Fi, standard, specification, Barker codes, CCK, OFDM, QPSK, QAM, Matlab

1 Introduction

In 1997, the IEEE *Institute of Electrical and Electronics Engineers, Inc.* released 802.11 standard for wireless LANs, defining 1 and 2 Mbit/s data rates. In September 1999 was ratified the 802.11b "High Rate" amendment to the IEEE 802.11 standard, which added two higher speeds (5.5 and 11 Mbit/s) using CCK. In 2003 the IEEE 802.11g was ratified to support speeds up to 54 Mbit/s using OFDM. This work is aimed on the IEEE 802.11g revision of the standard, which includes all new features as Complementary Code Keying and Orthogonal Frequency Division Multiplex.

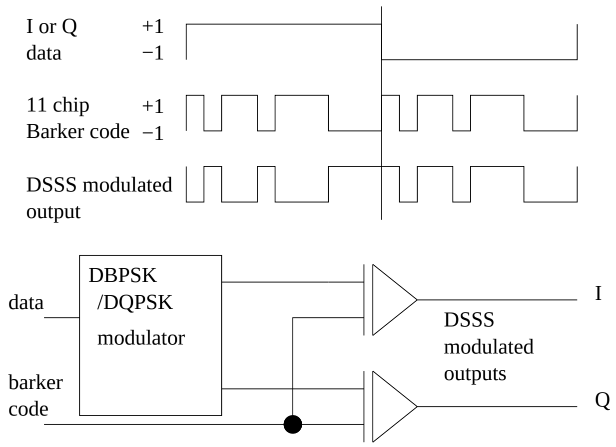

Figure 1: Spreading of the signal with Barker code.

2 Physical Layer

2.1 Barker Coding

Barker coding is a modulation technique, that was used in the first specification of IEEE 802.11 and it provides 1 Mbit/s (2 Mbit/s) data rates while using BPSK (QPSK). All amendments and specifications as 802.11b and 802.11g are backward compatible, so every IEEE 802.11 specification includes Barker coding.

$$G = 10log(\frac{chipping\_rate}{data\_rate}) = 10log(11) = 10.4dB \quad (1)$$

IEEE 802.11 DSSS *Direct Sequence Spread Spectrum* works by taking data stream of zeros and ones and modulating it with a second pattern, the chipping sequence (Fig. 1). The sequence is also known as the Barker code which is an 11-chip sequence (10110111000). The ratio between the data and width of spreading code is called processing gain. The processing gain for IEEE 802.11 when using Barker coding is 10.4 dB according to formula 1.

IEEE 802.11b specifies 14 twenty-two MHz channels in the 2.4 GHz band in which 11 adjacent channels overlap partially and the remaining three do not overlap. Data is sent across one of these 22 MHz wide channels without hopping to other channels, causing noise on the given channel.

2.2 Complementary Code Keying

To increase the data rate in the 802.11 standard, in 1998, Lucent Technologies and Harris Semiconductor proposed to IEEE a standard called CCK *Complementary Code Keying*. Rather than the two 11-bit Barker codes, CCK uses a set of 64 eight-bit unique com-

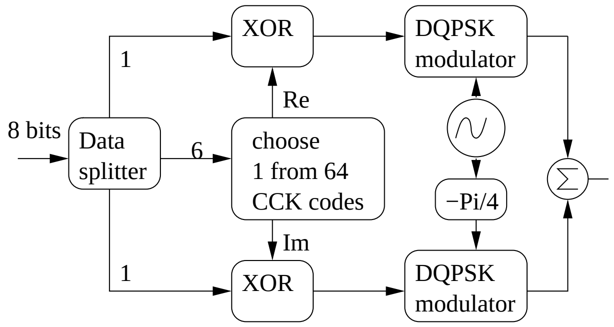

Figure 2: IEEE 802.11b 11 Mbit/s CCK generation.

plex code word (instead of the 1 bit represented by a Barker symbol). As a set, these code words have unique mathematical properties that allow them to be correctly distinguished from one another by a receiver, even in the presence of substantial noise and multipath interference (e.g. interference caused by receiving multiple radio reflections within a building).

The CCK modulation used by 802.11b transmits data in symbols of eight chips, where each chip is complex QPSK bit-pair at a chip rate of 11 Mchip/s. In 5.5 Mbit/s and 11 Mbit/s modes respectively 4 and 8 bits are modulated onto the eight chips of the symbol c0,...,c7, according to formula 2,

$$c = \left\{ \begin{array}{l} e^{(j\varphi_1+j\varphi_2+j\varphi_3+j\varphi_4)}, e^{(j\varphi_1+j\varphi_3+j\varphi_4)}, \\ e^{(j\varphi_1+j\varphi_2+j\varphi_4)}, -e^{(j\varphi_1+j\varphi_4)}, \\ e^{(j\varphi_1+j\varphi_2+j\varphi_3)}, e^{(j\varphi_1+j\varphi_3)}, \\ -e^{(j\varphi_1+j\varphi_2)}, e^{(j\varphi_1)} \end{array} \right\} \quad (2)$$

where φ_1 to φ_4 are determined by the bits being modulated. The 5.5 Mbit/s rate uses CCK to encode 4 bits per carrier, while the 11 Mbit/s rate encodes 8 bits per carrier (Fig. 2). Both speeds use DQPSK as the modulation technique and signal at 1.375 MS/s. DQPSK uses four rotations (0, 90, 180 and 270 degrees) to encode 2 bits of information in the same space as BPSK encodes 1.

Table 1: IEEE 802.11b Data Rates Specifications.

Data Rate	Code Length	Mod.	Symbol Rate	Bits/Sym.
1 Mbit/s	11 (Barker code)	DBPSK	1 MS/s	1
2 Mbit/s	11 (Barker code)	DQPSK	1 MS/s	2
5.5 Mbit/s	4 (CCK)	DQPSK	1.375 MS/s	4
11 Mbit/s	8 (CCK)	DQPSK	1.375 MS/s	8

The trade-off is that you must increase power or decrease range to maintain signal quality. Due to the fact the FCC regulates output power of portable radios to 1W (100 mW in Europe - ITU) EIRP *equivalent isotropically radiated power*, range is the only remaining factor that can change. Thus, for 802.11b devices, as you move away from the radio, the radio adapts and uses a less complex (and slower) encoding mechanism to send data, resulting in the lower data rates. Table 1 identifies the differences of 802.11b data rates.

2.3 OFDM

OFDM *Orthogonal Frequency Division Multiplex* is used at 2.4 GHz as a mandatory part of the IEEE 802.11g and supports data rates up to 54 Mbit/s. The main advantage of using ofdm is robustness to multipath fading channels because of much longer symbol period, than without ofdm. IEEE 802.11g uses 48 data OFDM sub-carriers used and 4 pilot carriers, where every carrier is modulated with BPSK, QPSK, 16QAM or 64QAM. There are used the same frequency channels as in older 802.11b and the standard is also backward compatible. The channel is 20 MHz wide.

Table 2: IEEE 802.11g Data Rates Specifications.

Data Rate	Coding Rate	Modu- lation	Coded Bits per Sub-carrier	Data Bits per OFDM Symbol
6 Mbit/s	1/2	BPSK	1	24
9 Mbit/s	3/4	BPSK	1	36
12 Mbit/s	1/2	QPSK	2	48
18 Mbit/s	3/4	QPSK	2	72
24 Mbit/s	1/2	16QAM	4	96
36 Mbit/s	3/4	16QAM	4	144
48 Mbit/s	2/3	64QAM	6	192
54 Mbit/s	3/4	64QAM	6	216

3 Program Description

In this paper is provided the Matlab simulation of the IEEE 802.11g Physical Layer. There was made a model for 4 data rates using Barker Coding and CCK and other 4 data rates using OFDM and particular modulation technique. Coding Rate and Correction codes are not counted and this will be part of the future work.

For the lower rates (1 Mbit/s and 2 Mbit/s), there is used DBPSK and DQPSK and the signal is spread over 22 MHz channel with help of the 11 chips long Barker Code (10110111000). For both higher rates (5,5 Mbit/s and 11 Mbit/s) DQPSK modulation is used and signal is spread with help of the 64 CCK codes.

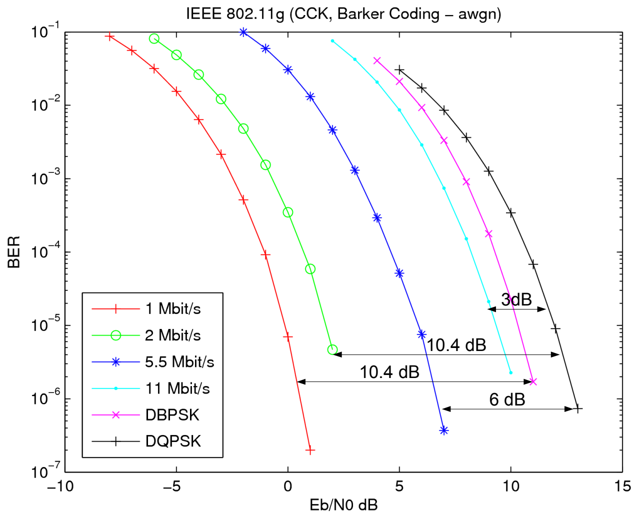

Figure 3: IEEE 802.11b data rates comparison.

Example of the simulation is on the fig. 3 and tab. 3. You can see BER to E_b/N_0 dependence of 1, 2 Mbit/s, 5.5 Mbit/s and 11 Mbit/s data rates in the table 3. The simulation was made from E_b/N_0 = -8 dB to E_b/N_0 = 10 dB. E_b/N_0 can be evaluated from SNR by formula 3 [3]

$$\frac{E_b}{N_0} = \frac{S}{N} \cdot \left(\frac{W}{R}\right) = \frac{S}{N} \cdot (W.T) \qquad (3)$$

where S/N is the received SNR, R is the rate at which data is sent in bits/second and W is the channel bandwidth in Hz and T is the bit duration or by formula 4 in dB

$$\frac{E_b}{N_0} = SNR + 10.log\left(\frac{T_{bit}}{T_{samp}}\right) \qquad (4)$$

where T_{bit} is signal's bit period and T_{samp} is the signal's sampling period.

The coding gain of the CCK used in IEEE 802.11 can be counted by equation 5.

$$\begin{aligned} G &= 10log(\frac{chipping\_rate}{data\_rate}) + 10.log(2) \\ G_{cck5.5} &= 10log(8/4) + 10log(2) = 6dB \\ G_{cck11} &= 10log(8/8) + 10log(2) = 3dB \end{aligned} \qquad (5)$$

This is theoretical gain of CCK coding. Results are shown in fig. 3.

IEEE 802.11g uses OFDM, that is used for data rates from 6 to 54 Mbit/s according to the table 2. The biggest advantage of using OFDM is multipath fading resistance, because of the longer symbol period. This paper is aimed only on awgn channel simulation. You can see results of the simulation in tab. 4, tab. 5 and figure 4.

Table 3: Wi-Fi Data Rates Comparison (1, 2, 5.5, 11 Mbit/s)

$\frac{E_b}{N_0}$	BER [-] 1 Mbit/s	BER [-] 2 Mbit/s	BER [-] 5.5 Mbit/s	BER [-] 11 Mbit/s
-8	0,08746191			
-7	0,05589394			
-6	0,03165797	0,08114000		
-5	0,01548898	0,04861000		
-4	0,00638600	0,02617000		
-3	0,00215400	0,01222000		
-2	0,00051500	0,00481200	0,09958000	
-1	0,00009200	0,00154100	0,05943000	
0	0,00000700	0,00034900	0,03059000	
1	0,00000020	0,00005900	0,01318000	
2		0,00000467	0,00462500	0,07568000
3			0,00130400	0,04239000
4			0,00029360	0,02075000
5			0,00005150	0,00865200
6			0,00000753	0,00288400
7			0,00000037	0,00074230
8				0,00015140
9				0,00002110
10				0,00000227

Table 4: Wi-Fi Data Rates Comparison (bpsk-ofdm, qpsk-ofdm)

$\frac{E_b}{N_0}$	BER [-] bpsk-ofdm	BER [-] qpsk-ofdm
-7	0.15966153	
-6	0.13309038	
-5	0.10607500	
-4	0.08056153	
-3	0.05821153	
-2	0.03894230	
-1	0.02375769	0.15607307
0	0.01353461	0.11356538
1	0.00635576	0.07706923
2	0.00251923	0.04773076
3	0.00085000	0.02656346
4	0.00024038	0.01278846
5	0.00004615	0.00524807
6	0.00000384	0.00169038
7		0.00046730
8		0.00007307
9		0.00001153

Table 5: Wi-Fi Data Rates Comparison (16qam-ofdm, 64qam-ofdm)

$\frac{E_b}{N_0}$	BER [-] 16qam-ofdm	BER [-] 64qam-ofdm
7	0.16586538	
8	0.11330192	
9	0.06999230	
10	0.03911730	
11	0.01932692	
12	0.00783076	
13	0.00259807	0.20795769
14	0.00074807	0.14524615
15	0.00015000	0.09235000
16	0.00001730	0.05303846
17	0.00000192	0.02731153
18		0.01174423
19		0.00434230
20		0.00121153
21		0.00023461
22		0.00004615
23		0.00000384

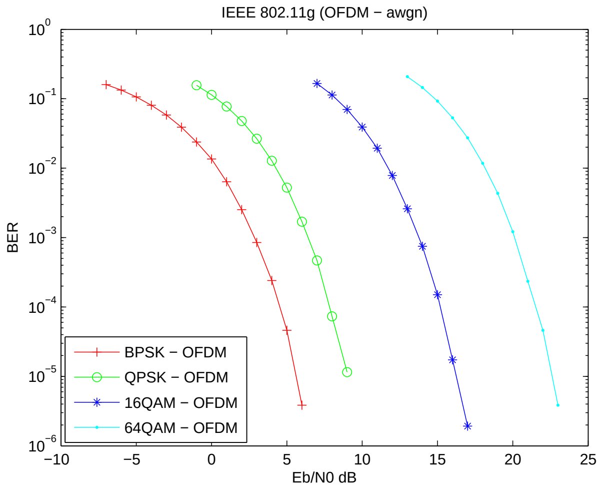

Figure 4: IEEE 802.11g data rates comparison.

4 Conclusion

There was a Physical Layer simulation of the standard IEEE 802.11g provided. In Matlab program 4 data rates of the specification using Barker coding and CCK were compared to find the coding gain of each data rate. There were also simulations for higher data rates provided using OFDM. The results are given in BER to E_b/N_0 dependencies and you can see results in figure 3 , figure 4 and tables 3, 4, 5. You can see, that the 11 Mbit/s data rate is less resistant to the white Gaussian noise channel and the coding gain is ”only” 3 dB against DQPSK without coding. On the other hand, we can get 10.4 dB gain by using Barker coding. In case of ofdm, to support full 54 Mbit/s, the E_b/N_0 must be at least 20 dB or higher.

The Matlab program will be used for single-path AWGN channel and multi-path channel simulations in the future and for Bluetooth and Wi-Fi system coexistence simulation.

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