# Analysis of Physical Layer Model of WLAN 802.11g Data Transmission Protocol in Wireless Networks Used by Telematic Systems

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**Abstract.** WLAN 802.11g wireless network specification used in telematic systems was discussed in this paper. A model of physical layer used in WLAN 802.11g developed in Matlab/Simulink was analysed. Parameters of data transmission under different operating conditions were investigated.

**Keywords:** wireless communications, WLAN 802.11g specification, telematic system.

## 1 Introduction

Modern transport, especially in big urban agglomerations revolves around advanced technical and organisational solutions. They are intended to reduce congestion caused by excessive traffic volumes and thereby decrease environmental impact of road transport. An example solution used in small and medium transport enterprises involves email and SMS based information services [1]. Another example is comprehensive passenger information systems using wireless transmission. The passenger information system interacts directly with the passengers therefore ease of access is assured (voice messages). Furthermore, the vehicle is equipped with location devices providing passengers with information about current location and can feed that data to the management centre. First and foremost, the passenger information system, described in this article, is an advanced IT system consisting of devices enabling data transmission between the vehicle and passenger information system and the traffic control centre [2]. Electronic equipment used for those purposes are WLAN 802.11a/b/g wireless modems installed in vehicles and variable message signs assuring mobile access to reliable passenger information. It is one of the services offered by transport telematics systems. Therefore, the reliability and accuracy of wireless transmission determines how passenger information system operates as well as organisational activities reducing environmental impact of road transport. It is then justified to research wireless transmission performance under different operating conditions. Analysis of physical layer model of WLAN 802.11g data transmission protocol in wireless networks used by telematic systems (passenger information system) was

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carried out in this paper. This system is currently used by the Public Transport Authority in Mielec.

## 2 Model of WLAN 802.11g Physical Layer

Physical layer of the WLAN 802.11g specifications, responsible for data transmission, may be described by a model developed in Matlab/Simulink. By running a simulation of the model, both broadcasting and receipt of data via radio waves between the transmitter and receiver may be traced. The model presents implementation of the OFDM (Orthogonal Frequency Division Multiplexing) method modulated by quadrature amplitude modulation and phase modulation, and multipath fading depending on road conditions and frequency. The models simulated signal fading in order to reveal changes in data transfer rate. The model contains all the necessary components of the WLAN 802.11g [3] specification. Figure 1 shows a diagram of the model of physical layer used in WLAN 802.11g developed in Matlab/Simulink. The model shares some of its elements with model of 802.11a physical layer through adding further modules and adjusting considerably simulation parameters. Elements depicted in top part of the diagram denoted by green shading comprise the transmission scheme of the WLAN 802.11g wireless specification. Elements depicted in bottom part of the diagram denoted by red shading constitute the receiver side (figure 1).

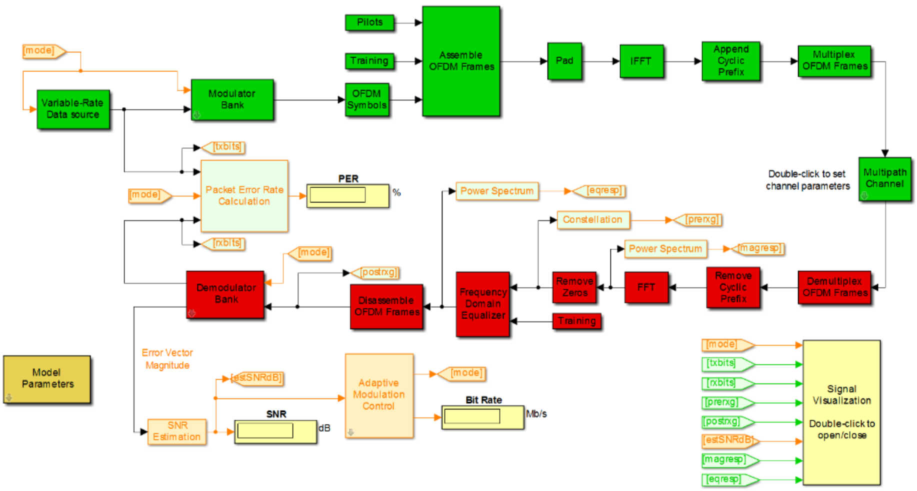


**Fig. 1.** Model of WLAN 802.11g physical layer

Figure 2 shows the transmitter side of WLAN 802.11g physical layer model using Orthogonal Frequency Division Multiplexing.

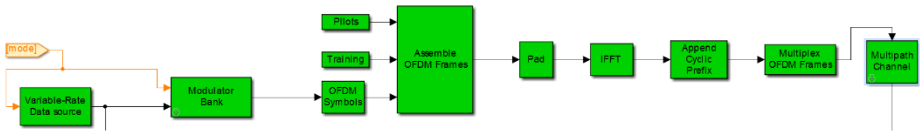


**Fig. 2.** Transmitter side of WLAN 802.11g physical layer model

Figure 3 shows a general diagram of the OFDM transmitter, whose functions were simulated by blocks in fig. 2.

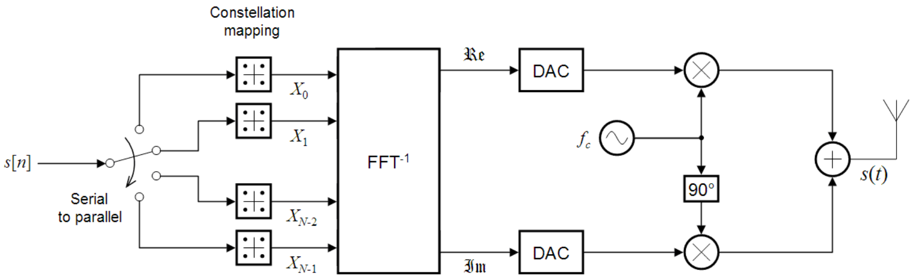


**Fig. 3.** General diagram of OFDM transmitter

The transmitter of the WLAN 802.11g model generates random data transfer rates varying over the course of simulation. Changes in data transfer rate of random data are controlled by the data source block. Encoding and modulation (using given scheme defined by the IEEE 802.11g standard) is carried out by the modulator bank shown in figure 4.

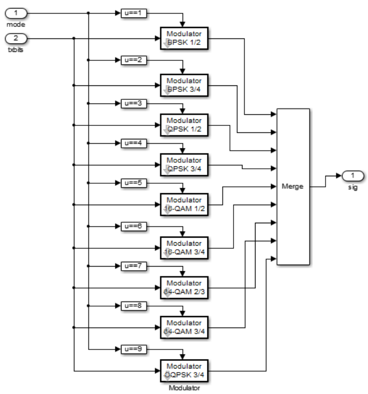


**Fig. 4.** Modulator bank of WLAN 802.11g transmitter

Amplitude modulation 16-QAM and 64-QAM or phase modulation QPSK, OQPSK, DQPSK and BPSK may be used in modulator bank. Cyclic Redundancy Check was used for error detection: 1/2, 2/3 and 3/4. Modulation types change depending on bits per OFDM symbol. BPSK modulation is used for 1 bit per symbol encoding, QPSK for 2 bit per symbol encoding, 16-QAM modulation for 4 bit per character encoding, 8 bit per symbol DQPSK and 16 bit per symbol OQPSK. For instance, in 6 Mb/s version, bits are packaged into 24 bit groups for encoding and modulating. Each group is translated into 48 bit OFDM symbol, each symbol is carried by one of 48 subcarriers subject to BPSK modulation at 250 kHz (24 data bits x 250 kHz = 6 Mb/s). Similarly, in 9 Mb/s version data bits are packed into 36 bit groups. Each group is translated into 48 bit OFDM symbol, each symbol is carried subject to BPSK modulation at 250 kHz (36 data bits x 250 kHz = 9 Mb/s). That process is similar for remaining operating modes of the DQPSK and OQPSK modulators. The OFDM modulation process uses $FFT^{-1}$ whose parameters are as follows: sampling frequency 20 mHz in 64 points. In OFDM method 48 subcarriers is used by data, 4 for pilot signals and 12 remains unused. Pilot signal is used for frame detection, estimating frequency offset of carriers and determining channel performance. OFDM modulation and frame detection through pilot signal is carried out by model blocks shown in figure 5.

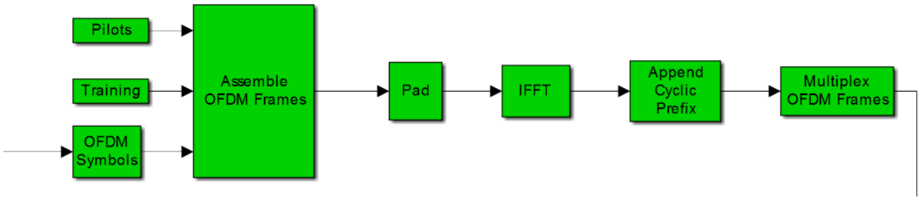


**Fig. 5.** Model blocks performing OFDM modulation

In OFDM modulations signal is transmitted both by signal phase and its amplitude. Fading occurs due to multipath, which distorts signal amplitude. Reference signal is transmitted by pilots thus allowing to obtain status of the channel and demodulation of neighbouring sub-channels. The OFDM signal generated using blocks illustrated in fig. 3 comprises *N* orthogonal subcarriers modulated by *N* parallel data streams. Data symbols $(d_{n,k})$ are built-up into data blocks containing *N* characters and modulated using amplitude modulation or phase-shift keying with exponential waveform $(\varphi k(t))$. After completed modulation data blocks are transmitted simultaneously as transmitter's data streams. A complete signal comprising OFDM blocks is given by the following formula [4]:

$$x(t) = \sum_{-\infty}^{\infty}\left[\sum_{k=0}^{N-1} d_{n,k\varphi k}(t - nT_d)\right] \tag{1}$$

Where: $\varphi k(t)$ describes each data subcarrier as:

$$\varphi k(t) = \begin{cases} e^{j2\pi f_k t} & t \in [0, T_d] \\ 0 & t \notin [0, T_d] \end{cases} \tag{2}$$

Where: $d_{n,k}$ transmitted signal, $n_{th}$ time interval using $k_{th}$ subcarrier, $T_d$ duration of data symbol, *N* no of OFDM subcarriers and $f_k$ is $k^{th}$ subcarrier frequency derived from $f_k = f_0 + \frac{k}{T_d}, k = 0 \ldots N - 1$ where $f_0$ is lowest available frequency.

Mutual orthogonality of subcarrier frequencies in OFDM modulation meets [4], [8]:

$$\langle s_{n1}, s_{n2} \rangle = \int_0^{T_d} s_{n1}(t), s_{n2}(t)dt = 0 \quad (3)$$

where: $T_d$ duration of data symbol, $s_{n1}(t) = sin(n\omega t), n\epsilon\aleph$

The multipath channel block is located between transmitter and receiver side. It simulates the signal multipath process along with all related phenomena. Figure 6 shows details of the block.

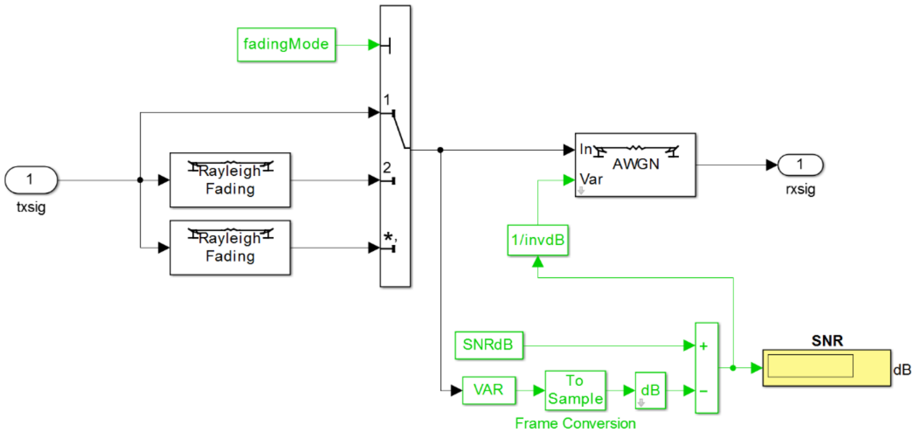


**Fig. 6.** Details of the WLAN 802.11g multipath channel block

It may also determine parameters of signal fading:

- fading mode:
  - no fading,
  - flat fading,
  - dispersive fading,
- maximum Doppler shift [Hz],
- Channel SNR [dB].

The most popular fading channel models are Rayleigh fading and Rician fading. Rayleigh fading model was used to simulate fading in this paper. The model assumes that channel delay and Doppler spectrum power are distinctive [5]. Let $s_i$ denote input samples. Then output samples $y_i$ satisfy [5]:

$$y_i = \sum_{n=-N_1}^{N_2} s_{i-n} g_n \tag{4}$$

where $g_n$ is defined as:

$$g_n = \sum_{k=1}^{K} a_k sinc\left[\frac{\tau_k}{T_s} - n\right], -N_1 \leq \text{n} \leq N_2 \tag{5}$$

where: $T_s$ the period of input sample, $\tau_k$s sample stream delays in fading channel, $a_k$ sample gains in fading channel.

Relationship (6) determines the distribution function of fading probability [6]:

$$F(p) = 1 - e^{-p \cdot p} \tag{6}$$

where: $p = \frac{s_y}{s_x}$, $s_y$ – received signal, $s_x$ – reference signal (no fading)

Simulation of Rayleigh fading is possible by inverse relationship (6) and expressing its product in [dB] [6]:

$$\Psi = -20 log \sqrt{-ln(1-x)} \text{ [dB]} \tag{7}$$

where: $\Psi$ - fading, $x$ - random variable of uniform distribution within interval (0;1)

Another negative phenomenon affecting wireless transmission is Doppler shift which also was simulated in this example. The Doppler shift with regards to wireless devices e.g. standard-issue GSM, is defined as follows [7]:

$$f_d = \frac{vf}{c} \text{ [dB]} \tag{8}$$

where: $v$ - velocity of moving mobile device, $f$ - transmission carrier frequency [Hz], $c$ - the speed of light in vacuum [m/s]

Based on (8) with reference to velocity of moving mobile device broadcasting a signal, the maximum Doppler shift of signal transmitted by a vehicles on the move is 80 [Hz]. The signal transmitted by a mobile device carried by a pedestrian may be subject to a maximum Doppler shift of 4 [Hz]. Those values hold true for carrier frequency 900 MHz [7].

The input signal, described by formula (1) and satisfying (3) and subjected to phenomena i.e. signal multipath and Doppler effect, is received by the WLAN 802.11g physical layer receiver side. Figure 6 shows the receiver side represented by model blocks.

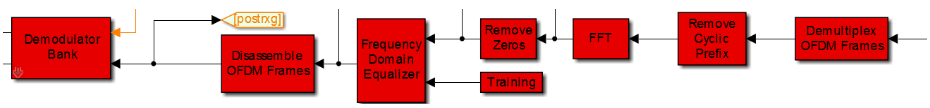


**Fig. 7.** Receiver side of WLAN 802.11g physical layer model

Figure 10 shows a general diagram of the OFDM receiver, whose functions were simulated by blocks in fig. 9.

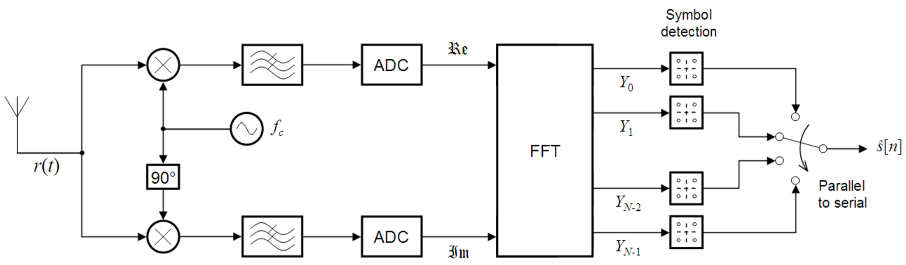


**Fig. 8.** General diagram of OFDM receiver

The physical layer of the WLAN 802.11g specification demultiplexes the input signal consisting of OFDM blocks. Then Fast Fourier transform FFt is calculated, signal demodulated and OFDM symbols detected. Obtained *N* parallel streams are combined into a single original bit-stream.

## 3 Model Simulation and Visualisation and Interpretation of Results

In order to run simulation of the Matlab/Simulink model correct input data needs to be entered first. Input data is entered by running the S-function on model level (developed in Simulink environment) or by entering them manually into text fields in model blocks. Model parameters used for simulation may be defined in Model Parameters block and the Multipath channel block (figure 1). Input data characteristic for 802.11g specification defined for simulation are as follows:

- OFDM bits per transmitted block (48 bits in 802.11g standard),
- OFDM bits and pilot bits (48 + 4 = 52 bits in 802.11g standard),
- OFDM bits per cyclic prefix (16 bits in 802.11g standard),
- Number of points where fast Fourier transform FFT occurred (64 bits in 802.11g standard),
- Hysteresis coefficient for adaptive modulation [dB],
- Depth of decision by Viterbi algorithm for decoding convolutional codes,
- SNR (signal-to-noise ratio) thresholds for different modulation schemes used in the model,
- Fading mode,
- Maximum Doppler shift [Hz],
- Channel SNR [dB],

Simulation results were observed on displays and via the Signal Visualization module producing graphic representation of results. The following output data (in graphic representation as per figure 11) were produced by the simulation:

- Packet of randomly sent binary data, tracing variable data transfer rate on the channel,
- Scatter charts depicting the signal prior and post equalization (correction). Scatter charts allow to determine modulation mode currently in use by the 802.11g protocol, because the chart represents a diagram of modulation constellations consisting of 2, 4, 16 or 64 constellation points.
- Spectrum power of received signal prior and post equalization (correction),
- SNR value estimated based on error vector magnitude,
- Bit rate,
- Bit error rate per packet,
- Packet error rate,
- Signal-to-noise ratio (SNR),
- Bit rate shows which of flowabilities defined by the specification is currently in use.

The charts above show results of model simulation using the following input data characteristic for 802.11g specification:

- OFDM bits per block = 48 bits,
- OFDM bits and pilot bits = 52 bits,
- Cyclic prefix bits = 16 bits,
- Implementation of FFT algorithm = 64 points,
- Maximum Doppler shift = 180 [Hz],
- Flat fading,
- Change in signal to noise ratio: 10, 20, 40 [dB] respectively

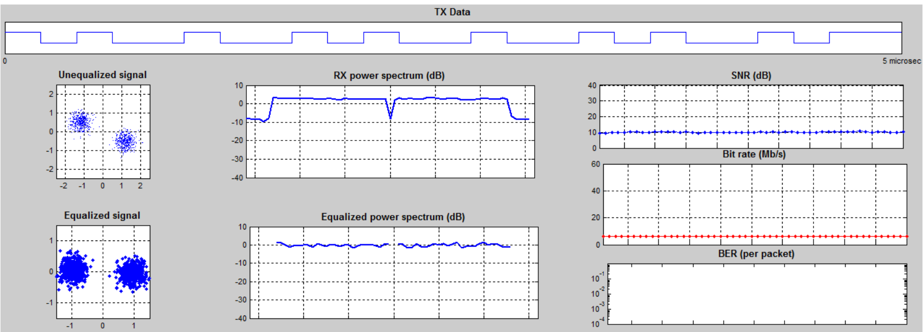


**Fig. 9a.** Simulation results given SNR = 10 [dB], 6 Mb/s transmission rate

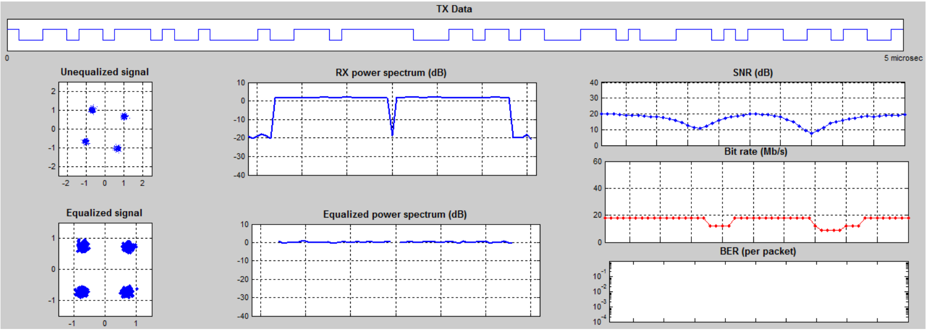


**Fig. 9b.** Simulation results given SNR = 20 [dB], 18 Mb/s transmission rate

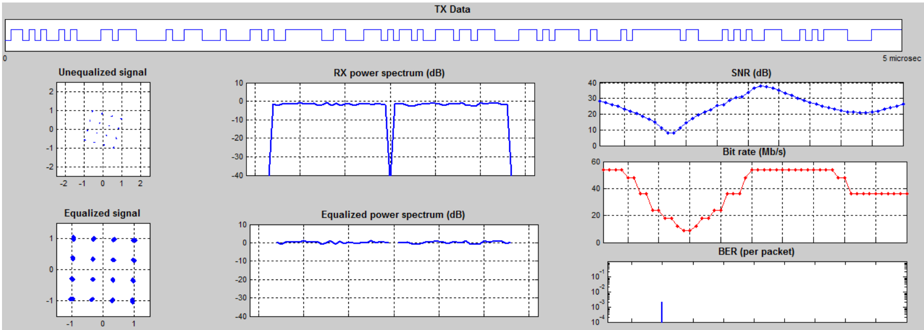


**Fig. 9c.** Simulation results given SNR = 40 [dB], 54 Mb/s transmission rate

Analysis of obtained results proves that fading has great impact on correct demodulation of signal in WLAN 802.11g standard, especially given high SNR values. Changes in power spectrum of received signal depend on fading parameters (figures 11a and 11c). Constellation diagrams shown in figure above are a graphic representation of digitally modulated signal. After receiving the signal, demodulator checks received symbol, which could have been distorted by either the channel or the receiver. Signal quality analysis (based on constellations during simulation) showed white noise represented by blurry constellation points and phase noise represented by arched constellation points. The orthogonal multiplexing of OFDM frequencies causes susceptibility to Doppler effect and distorts synchronization of carrier frequency. Furthermore, data transmission efficiency is lower due to cyclical prefix (figures 11b and 11c). Obtaining high data transfers reaching 54 Mb/s is difficult because of high loads and noise occurring during the transmission (figure 11c).

In further research work is expected to carry out simulations to other WLAN standards, which will include contemporary and future technologies (with particular emphasis on the use of transport telematics systems).

## 4 Conclusions

Simulation tests in Matlab/Simulink environment of physical layer comprising the WLAN 802.11g specification determined wireless transmission performance under different operating conditions. The WLAN 208.11g standard is susceptible to the Doppler effect. This is particularly important in case of mobile receivers and transmitters installed in public transport vehicles as in passenger information system (variable message signs). An additional disturbance is the fading mode caused by signal multipath which distorts the amplitude of radio signal. Achieving upper transfer rates reaching 54 Mb/s using the analysed specification poses substantial difficulties due to noises occurring during data transmission.

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