Multipath Effects in High Speed Digital Radio Communications

Boris Yosifov Ribov

Abstract – **The performance of high-speed wireless radio communication channels depends on the topology of the link. It is customary to define the performance in terms of the delay spread that can be tolerated. The multipath destroys the received signal in the receiver. This increases the errors in the demodulator. However, as we show in this tech brief, a parallel transmission on orthogonal coded basis can be use on the same channel to increase the signal to noise ratio and to reduce the errors especially on high speed data transmission. The paper presents an investigation of the errors due to some known channel models of the traditional transmission. Also we present simulation of the same channel speed using orthogonal frequency division multiplexing. The results for the orthogonality and the errors in the demodulator are published on the conclusion of the paper.**

Keywords – **Multipath, OFDM, Wireless Sensor Network**

I. INTRODUCTION

As shown on figure 1, when a communication signal is transmitted through the air to a receiver, that signal would take several different paths before it reaches the receiver. The transmitter does not know precisely where the receiver is; therefore it must transmit in several different directions. However, the direct path from the transmitter to the receiver is not the only signal that is received. Reflectors in the environment (filing cabinets, computers, etc.) reflect aberrant signals back to the receiver. All of these signal paths are combined at the receiver to produce a signal that is a distorted version of the transmitted signal.

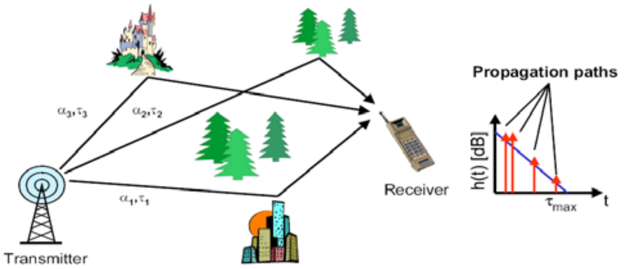

Fig. 1. Multipath environment

II. THE MODEL

The ***2-ray channel model*** includes only two paths, a direct path and a reflected path with equal strength. The model is parameterized by the duration of the second delay, τ_d. In other words, the model can be completely characterized if τ_d is known. Since the actual channel model can vary over time, the path delay profile is used to describe the average power of each path in the channel.

B. Ribov is with the Department of Computer Systems and Technologies, Faculty of Electronic and Automation, Technical University – Sofia, branch of Plovdiv, 63, Sankt Peterburg, 4000, Plovdiv, Bulgaria, e-mail: Ribov@developer.bg

Tree different path delay parameters on the path delay profile exist: mean excess delay, τ_μ; maximum excess delay, τ_m and RMS delay spread, τ_σ. The mean excess delay is simply the average delay of all the paths. The maximum excess delay is the last path delay with any "noticeable" amplitude. A "noticeable" amplitude is typically 20 dB below the peak amplitude. The RMS delay spread is a measure of how "spread" the delays about the mean are. The 2-ray channel model is attractive because it is simple. It is not a common scenario because the two paths have equal amplitude on average. Since the second path will suffer greater loss because the signal must travel further, the only way that this scenario will occur is when the first path passes through a barrier that absorbs some of the signal strength, as shown in figure 2A.

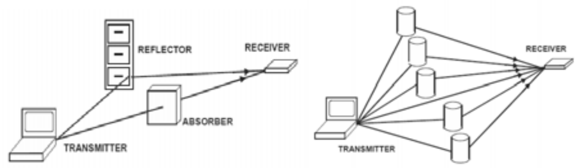

Fig. 2. Models:
a) two-ray; b) exponential.

An ***exponential channel model*** has a path delay profile that drops off exponentially. The channel model that is recommended in the IEEE 802.11 WLAN specification is an exponential channel model [2]. As shown in Figure 2B, this model represents a real world scenario in which the positions of the reflectors generate paths that are longer and longer.

For this investigation was developed a simulation [4] with channel model based on the topology of the figure 2B. The block diagram of the simulation test bench is placed on figure 3. It consists of data generator, transmitter, channel model, receiver and BER calculator tool.

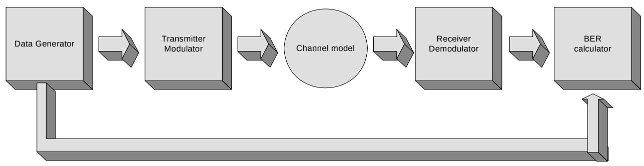

Fig. 3. Simulation flow chart

The simulation requires two binary sources: random binary input (message) and a barker sequence generator. The random binary input is achieved using a Bernoulli binary generator [1] that will output a sequence with a probability of 50% of the bits being one. In order to provide spreading of the signal, each bit of the message is multiplied by a pseudo random noise (PN) sequence. The 11-chip Barker's sequence [3] is the same length as the symbol transmitted and correlated at the receiving end with the same Barker code. Since only one spreading code is used for a network, a handshaking protocol is used so only one node transmits at a time. A Barker's code is a string of digits $a_i= +/-1$ of length $l \geq 2$ such that:

$$\left| \sum_{i=1}^{l-k} a_i a_{i+k} \right| \leq 1 \qquad (1)$$

for all $1 \leq k < l$.

The transmitter multiples the random binary input with the barker sequence. This results in the binary input being spread across the spectrum. The multiplied binary bits are then inputted to the BPSK modulator [1], which will convert the bit stream to a cosine wave.

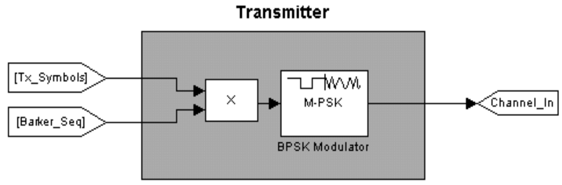

Fig. 4. Transmitter

The receiver is the most complex block diagram of the simulation. The output of the channel is fed to the BPSK demodulator [1]. The demodulator's main purpose is to predict what bit is sent by the modulator with the noise that has been added to it. Next, correlation will be performed to determine if this signal was in fact sent by our receiver and not from another nearby transmitter. The output of the demodulator is a bit stream consisting of '1' and '0'. In order to perform the correlation the '0's in the bit stream need to be converted to '-1's before they are sent to the multiplier. To achieve this the bit stream of '1' and '0' are put multiplied by two and then added to a –1, called the shifted bit stream.

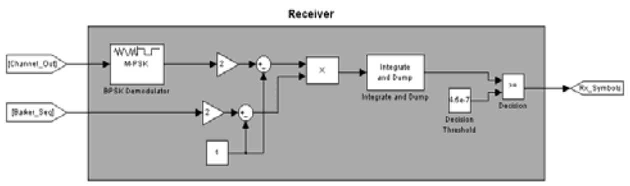

Fig. 5. Receiver

The Barker's sequence [3] and the shifted bit stream are multiplied together bit by bit. The result of the multiplier is fed into an integrator that will add the results for 11 (the bit length of the Barker's sequence) samples. A comparator [1] will compare the output of the integrator with a predefined threshold level. If the output of the integrator is above the threshold then it outputs a one, otherwise it outputs a zero. The block diagram below shows the receiver.

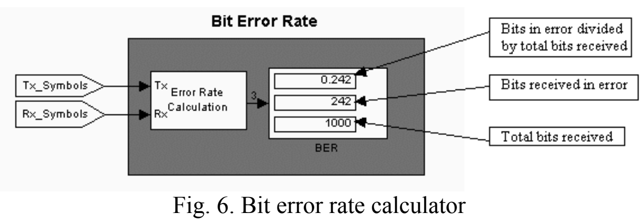

Fig. 6. Bit error rate calculator

In order to analyze the system a bit error calculation is done between the bits that were transmitted by the transmitter and that what the receiver has received. Each transmitted bit is compared to each corresponding received bit to check if they match. If they do not match then a counter increments to point that another bit was received in error.

In a previous investigation [4] we showed that the errors increases in high-speed wireless radio links. When the channel speed increase then the ISI increases, too. That reflects to the overall BER. The BER increase when the channel speed increase. The simulation results for speed of 1Mbit/s and 11Mbit/s are shown on figure 7 and figure 8. The simulations are made for different delay spreads based on scenario shown on figure 2b. The curves show how received signal is degraded due to the effects of multipath.

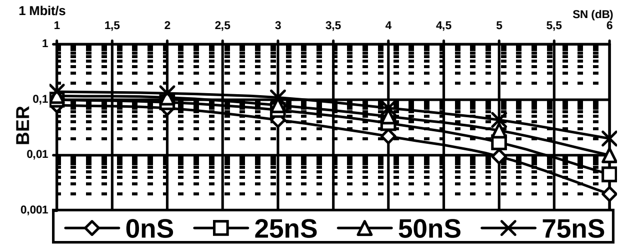

Fig. 7. BER vs. MULTIPATH at 1Mbit/s

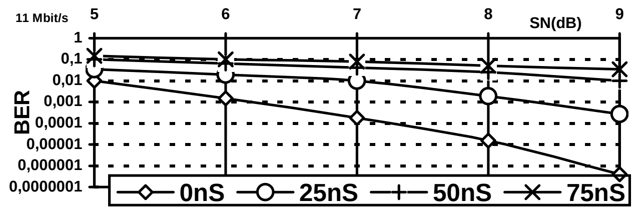

Fig. 8. BER vs. MULTIPATH at 11Mbit/s

As shown on figures the bit-error-rate increase in multipath channels. Different simulations were made depends on parameter τ_d. When τ_d is 0nS that means no reflected paths in the link. Then only direct path is used in the simulation. As the reflected path delay spread increase then the BER increase, too. The graphics shows four different situations for the mean delay – 0nS (no reflected paths), 25nS, 50nS and 70nS. The maximum delay τ_μ of the longest path for the τ_d 25nS equals to 115nS. For the 50nS scenario it equals to 230nS and for the 75nS scenario it equals to 345nS. The duration of a single data bit on 1Mbit/s equals to 90.9nS and for 11Mbit/s it equals to 8.26nS.

III. Orthogonal Multiplexing

One approach for minimization of BER in hi-speed channels is to be used multi-channel methods.

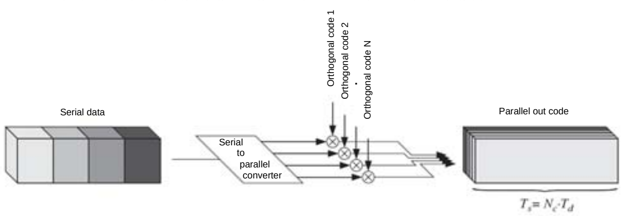

Fig. 9. Orthogonal multiplexing

Suitable method is OFDM, which uses multiple orthogonal carrier frequencies and every orthogonal sub-carrier transmits a small portion of data. Then the equivalent channel speed per carrier is smaller than the entire data stream. The sub-carrier channel speed can be determined by the fraction of the message bit rate and the number or sub-carriers.

A Walsh matrix is used to form the spread orthogonal code for every sub channel:

$$C_L = \begin{bmatrix} C_{L/2}, C_{L/2} \\ C_{L/2}, -C_{L/2} \end{bmatrix}, \forall L = 2^m, m \geq 1, C_1 = 1 \quad (2),$$

where L is the maximum quantity of the orthogonal codes and m is the iteration number for the matrix generation. In the simulation we used the matrix (3):

$$C_4 = \begin{bmatrix} 1111 \\ 1010 \\ 1100 \\ 1001 \end{bmatrix} \quad (3)$$

So we have 4 sub channels and based on the diagram on figure 9 the high-speed data is split into 4 relevantly low-speed channels. The demodulator side uses the same matrix and multiplies the input data with the code for every channel (the code in the rows of the matrix). We made a simulation to ensure that multi-channel method do not destroy SN performance compared to the traditional single channel methods. The results of the simulation on figure 10 show that there are no increased errors and both methods give the same results.

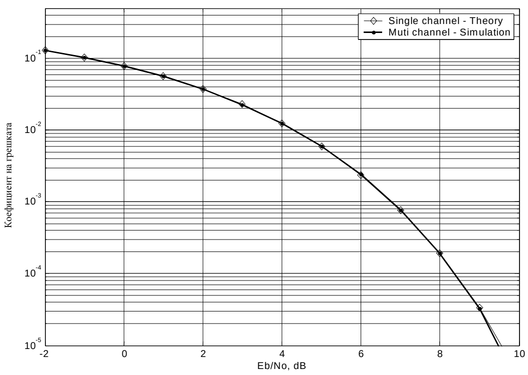

Fig. 10. BER comparison

The other part of the research covers the situations when there is no orthogonality in the spread code. Here we used the matrix (4), where the chips in the matrix were randomly generated using rand function in Matlab.

$$C_4 = \begin{bmatrix} 1100 \\ 1101 \\ 0110 \\ 0001 \end{bmatrix} \quad (4)$$

The simulation in this scenario (figure 11) shows increased errors compared to the traditional single channel method. Then we decide to examine the situation when only one single bit (chip) was changed to the base matrix (3). The Matrix in this scenario is shown on equation (5). In this matrix the last element in the raw four was changed from zero to one.

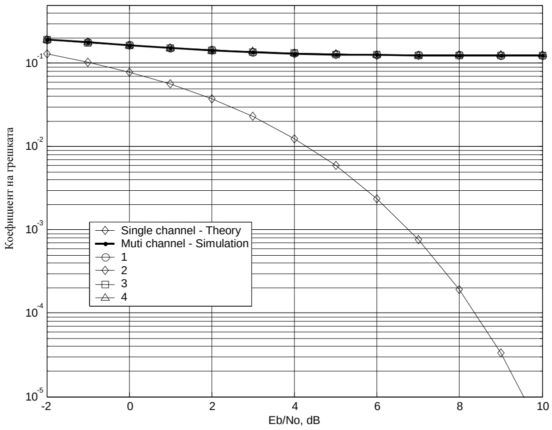

Fig. 11. BER on RAND WALSH MATRIX

$$C_4 = \begin{bmatrix} 1111 \\ 1010 \\ 1100 \\ 100\mathbf{0} \end{bmatrix} \quad (5)$$

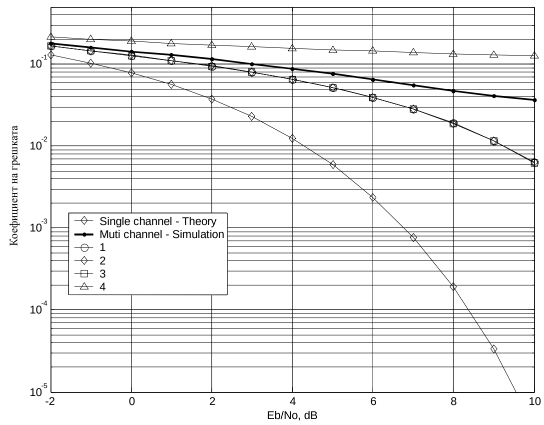

Fig. 12. BER on one chip error

Figure 12 shows the BER results using matrix (5) when a single bit in the orthogonal matrix was changed. The graphics show the errors in the different sub-channels, also the common error in the stream compared to the theoretical expectations. Both graphics from figure 11 and figure 12 shows increased errors when the orthogonality of the spreading code in the sub-channels is not correct.

IV. CONCLUSION

We decided to made final simulation based on 4 channel orthogonal frequency division multiplexing and compare the results with the theoretical expectations, also with the single channel transmission. The channel model was exponential based on figure 2B. The channel speed in the simulation was 4Mbit/s and the maximum delay of the last reflected ray was 330nS.

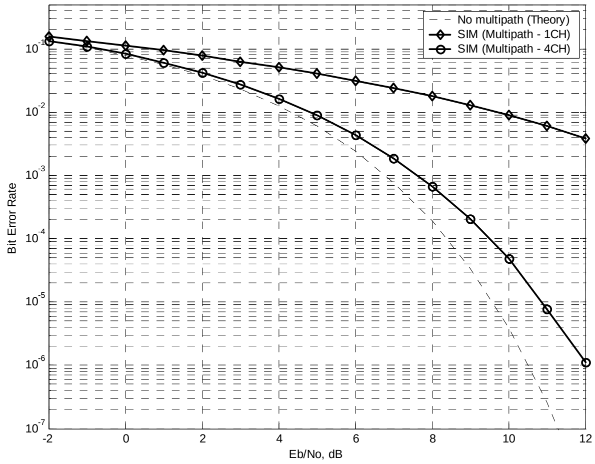

Fig. 13. BER on single and multichannel

Figure 13 shows the results from the simulation, where symbol "◊" marks the BER using the common single channel scheme using BPSK. The doted line shows the theoretical expectation of the channel without multipath effects, while the graphic marked with the symbol "o" present the results in the same channel topology with 4 orthogonal sub-channel transmission. As it can be noted the multi-channel methods are more efficient in complex multipath environment but are also far from the theoretical expectations.

REFERENCES

[1] Xiaodong Wang, H. Vincent Poor, "Wireless Communication Systems", Prentice-Hall, 2004, ISBN-10: 013021435-3

[2] B. Crow, I. Widjaja, J. G. Kim, P. Sakai, "IEEE 802.11 Wireless Local Area Networks", IEEE Communications Magazine, pp.116-126, September 1997

[3] Ryuji Kohno, Reuven Meidan and Laurence B. Milstein, "Spread Spectrum Access Methods for Wireless Communications", IEEE Communications Magazine, January 1995, pp.58–67

[4] Ribov B., "Investigation of a Bit-Error-Rate in Multipath Wireless Data Radio Transmission", 19-20 Oct. 2009, V. Turnovo, 2009, ISSN 954-753-035-6, Bulgaria