6-RAY MULTIPATH FADING CHANNEL

Ing. Jakub DŽUBERA, Doctoral Degree Programme (1)
Dept. of Radio Electronics, FEEC, BUT
E-mail: xdzube00@stud.feec.vutbr.cz

Supervised by: Dr. Aleš Prokeš

ABSTRACT

The simulation of a multipath fading channel is the main topic of this paper. A 6-ray model of a quasi-static multipath fading channel is considered and the spread delays and the attenuations of each ray (path) are the parameters of the simulation. The channel is affected by AWGN. The QPSK signal is transmitted over the channel and the BER performance of the system is estimated. The graphs of the dependency of BER on E_b/N_0 are result of the simulation. The BER performance is compared with the same QPSK system operating over an ideal AWGN channel which is not affected by multipath signal propagation.

1 INTRODUCTION

Modern communication systems utilize many various types of communication channels including metallic cables, optical fibers or wireless channels. All natural channels introduce some distortion such as noise or interference. It is necessary to examine the behavior of the channel in detail because then the signal can be reconstructed efficiently and its quality can be increased. The mobile radio channel is rich in various factors which negatively influence the quality of transmitted signal. The attenuation, the interference and the noise are the most significant factors. In addition, the channel parameters are time-varying and they change randomly. The mobile radio channel also introduces fading. The design of wireless communication systems is complicated according to the conditions above. It must be considered that the wireless communication systems should operate efficiently in various environments all over the world.

2 SIMULATION OF WIRELESS CHANNEL

The communication channel represents a natural environment which is located between the transmitter and the receiver. The channel model can be considered as a mathematical or an algorithmic expression of the input-output relationship of the natural channel. The communication channels are linear and the parameters are time-invariant in the most cases. The radio mobile channel is an exception. It behaves linearly but the parameters are random time-varying.

Tapped delay line models are mainly used for a time-varying mobile communication channel simulation. Assuming that the channel parameters change in a small time interval, which corresponds to the bit duration, the channel is called *fast fading channel*. If the time interval is significantly longer, the channel is called *slow fading channel* or *quasi-static channel*.

3 MULTIPATH FADING CHANNEL

There are some possibilities of how the signal can be propagated from a transmitter to a receiver antenna in the wireless mobile communication. The signal can travel in many paths (rays). The direct path is called *LOS* (*line-of-sight*) path. It exists if there is no obstacle between the transmitter and the receiver. The phenomena, such as *reflection*, *refraction* or *scattering* introduce multiple indirect paths. Thanks to these phenomena, the communication between the transmitter and the receiver can be realized also when the LOS path does not exit.

Fig. 1 illustrates a two-path (ray) wireless mobile channel. This situation can be easily generalized to N-paths. The channel output for the N-path channel is [1]

$$y(t) = \sum_{n=1}^{N} a_n(t) x[t - \tau_n(t)] \tag{1}$$

where $a_n(t)$ represents the attenuation and $\tau_n(t)$ represents the propagation delay of the n^{th} multipath signal component. The attenuation, the propagation delay and the number of the paths change in time randomly.

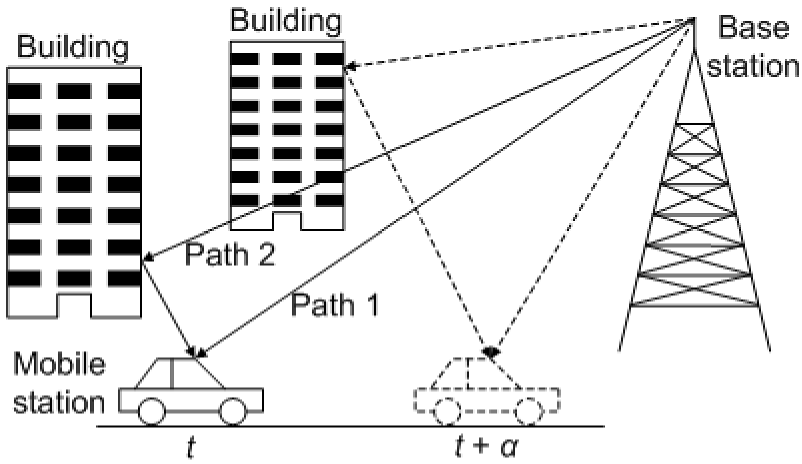

Fig. 1: *Multipath fading channel.*

The received signal is a composite signal including all components from all paths. The components are added vectorially. The phases of the components are random and thus the complex envelope of the composite signal can be represented by a complex Gaussian process. The vector sum of the components can be both destructive and constructive. This leads to fluctuations in the amplitude of the received signal. This phenomenon is called *small-scale signal variations* or *fast fading*. The distribution of the instantaneous amplitudes is described by Rayleigh distribution and the phenomenon is also called *Rayleigh fading*. If a LOS component exists, the distribution of the instantaneous amplitudes is described by Ricean distribution.

The complex envelope of the composite signal can be derived [1] from (1) as

$$\tilde{y}(t) = \sum_{n=1}^{N} \tilde{a}_n(t)\tilde{x}[t - \tau_n(t)] \tag{2}$$

The simplification can be applied. Assuming that during one simulation cycle the channel parameters are time-invariant, the attenuation and the propagation delay become constant and

$$\tilde{y}(t) = \sum_{n=1}^{N} \tilde{a}_n \tilde{x}(t - \tau_n) \tag{3}$$

This fixed-channel can be represented in the time domain by an impulse response

$$\tilde{h}(\tau) = \sum_{n=1}^{N} \tilde{a}_n \delta(\tau - \tau_n) \tag{4}$$

The corresponding channel transfer function can be derived from (4) in the form of

$$H(f) = \sum_{n=1}^{N} \tilde{a}_n e^{(-j2\pi f \tau_n)} \tag{5}$$

4 6-RAY MULTIPATH FADING CHANNEL

The wireless communication channel models used in practise consist of 12 rays. These models are defined for three various environments including urban, hilly and rural. Each model is determined by a set of propagation delays and attenuations associated with corresponding paths.

The simplified 6-ray channel models are also defined. The received composite signal for such model can be written as

$$\begin{aligned}\tilde{y}(t) = a_0\tilde{x}(t) + a_1R_1\tilde{x}(t-\tau_1) + a_2R_2\tilde{x}(t-\tau_2) + a_3R_3\tilde{x}(t-\tau_3) + \\ + a_4R_4\tilde{x}(t-\tau_4) + a_5R_5\tilde{x}(t-\tau_5)\end{aligned} \tag{6}$$

where R_n, n = 1, 2, …, 5, determines five independent Rayleigh random variables representing the attenuation of the five Rayleigh paths, and τ_n, n = 1, 2, …, 5, determines relative delays between the Rayleigh components, and a_n, n = 0, 1, …, 5, determines the relative power level P_n, n = 0, 1, …, 5, of the six multipath components.

Some simplifications must be considered. The LOS component is unfaded and the instantaneous phase is not affected. The model affects only the amplitude of the transmitted signal. The Doppler spread phenomenon is not considered, either.

The BER performance is simulated and the following graphs showing the dependency of BER on E_b/N_0 are the results. The QPSK signal is transmitted over the 6-ray channel with AWGN. The composite signal is evaluated according to the formula (6). It must be noticed that no shaping filter is used in the transmitter model and the receiver model is an ideal integrate-and-dump receiver. The simulation is processed for four sets of the channel parameters. Each set of the parameters determines one type of fading. The sets of the parameters are summarized in Table 1. The relative delay is defined as a number of samples. The bit duration consists of 16 samples and thus the 8-sample delay corresponds to the one-half the bit duration.

The sets of parameters are chosen more or less randomly. The main idea is to examine the different performance of the flat fading and the frequency selective fading channel. That is the reason why the values of the attenuation are the same for both types of the Ricean and the Rayleigh fading channel. The value of 1.0 determines no attenuation and the value of 0 determines total attenuation of the corresponding multipath component. The attenuation values of the indirect components are chosen significantly smaller according to the idea that multiple reflections strongly degrade the signal power level. The values of the relative delay are chosen around the half of the bit duration to assure a great destruction of the following bits.

Sim.	P_0	P_1	P_2	P_3	P_4	P_5	τ_1	τ_2	τ_3	τ_4	τ_5	Fading Type
1	1.0	0.2	0.3	0	0.1	0.1	0	0	0	0	0	Ricean Fast Fading
2	1.0	0.2	0.3	0	0.1	0.1	8	16	20	29	35	Ricean Freq. Selective Fading
3	0	0.9	0.3	0.1	0.2	0.1	0	0	0	0	0	Rayleigh Fast Fading
4	0	0.9	0.3	0.1	0.2	0.1	0	8	16	20	29	Rayleigh Freq. Selective Fading

Tab. 1: *Sets of Channel Parameters.*

Fig. 2 shows the results of simulation 1 and 2. The trend signed as AWGN Channel expresses the estimation of BER performance of a channel including AWGN only (no fading). Fig. 2-left shows the situation when the Rayleigh components are added to the LOS component. This results in a Ricean flat fading channel. If the propagation delay of the Rayleigh components exits, the channel becomes frequency selective and this leads to ISI.

The results of simulation 4 and 5 are presented in Fig. 3. The main feature is that the composite signal does not include the line-of-sight component and the channel is a Rayleigh fading channel. If the channel is affected by the delay, the channel becomes frequency selective again, and the performance is worse.

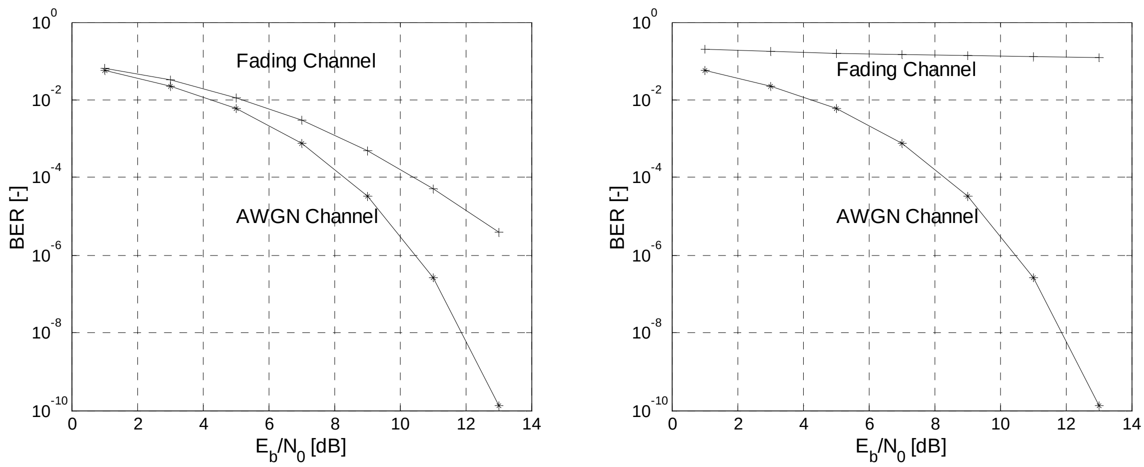

Fig. 2: *Ricean flat fading (left) and frequency selective fading (right) channel.*

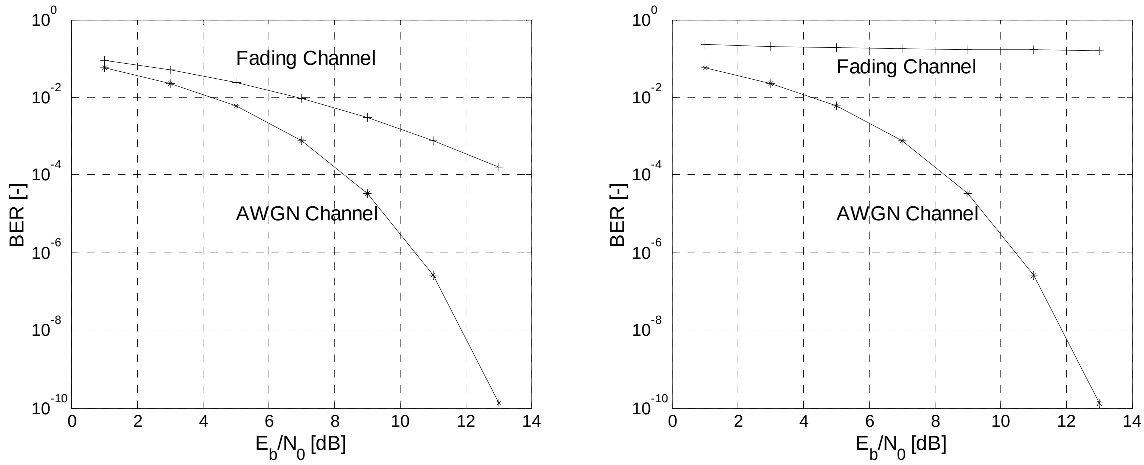

Fig. 3: *Rayleigh flat fading (left) and frequency selective fading (right) channel.*

5 SUMMARY

As it can be seen from the graphs, the performance of the frequency selective channel is always much worse. This situation is caused by the relative delays between the Rayleigh components. The ISI phenomenon occurs. The QPSK symbols are shaped in time and they are spread into the following symbols. The amplitude interferes and the symbols can be completely changed. In this simulation an ideal integrate-and-dump receiver is used. More advanced techniques, such as matched filter or correlation receiver, can be used to improve the BER performance. Special shaping filters can be used in transmitter. Adaptive filters used for channel equalization are modern approach, because these techniques can efficiently combat with the problem named above. The simulation of the radio mobile channel requires more complex models to point out all negative phenomena, such as Doppler spread. The simulation parameters are the main disadvantage of the model used in this simulation because the attenuation and the spread delay change randomly in natural channels.

REFERENCES

[1] Tranter, W. H., Shanmugan, K. S., Rappaport, T. S., Kosbar, K. L.: Principles of Communication System Simulations with Wireless Applications, 1st ed, New Jersey, Prentice Hall 2004

[2] Žalud, V.: Moderní radioelektronika, 1. vydání, Praha, BEN – technická literatura 2000

[3] Chien, Ch.: Radio Systems On A Chip – A System Approach, Boston, Kluwer Academic Publisher 2001