Influence of a Real Radio Channel Parameters on the Quality of the OFDM Signal in Mobile Applications. Estimation of Parameters of the Channel as an Element of Improvement of the Transmission Quality

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Abstract:

The article deals with issues related to transmission of a signal with the OFDM multitone modulation in a real radio channel. Following short characteristics of the OFDM modulation, the article includes an analysis of typical radio channels from the angle of amplitude and phase on the basis of delay profiles referred to in the literature. The study contains results of simulated receipt of the OFDM signal in the multipath conditions. On the basis of diagrams of constellation of the modulation symbols, the author presented differences in the quality of the signal before and after the phase correction and improvement in the quality due to application of cyclic prefix. Influence of noise as well as the fact that the terminals are non-stationary on operation of the frequency characteristics estimation algorithm was analyzed. At the end, an example was presented of application of a linear model of estimation of phase characteristics of a channel with the shift in frequency occurring in mobile systems as a consequence of the Doppler effect being compensated.

Keywords: *OFDM, radio transmission, multipath, radio channel estimation*

1. Introduction

The sending of information over a distance is one of fundamental issues that mankind has been developing through centuries. A precondition of information reaching the recipient is the existence of certain carrier called a transmission medium. Nowadays, at the age of fast development of technology, the most broadly used medium is electromagnetic waves propagating in the surrounding space or appropriate wave-guides. The electromagnetic wave spectrum is very broad. In nature, electromagnetic waves occur within a range from very low frequencies (energy sent through electric power network) through frequencies exceeding $3 \cdot 10^{20}$Hz (cosmic radiation).

Frequencies of electromagnetic waves used in contemporary terrestrial mobile applications usually come within the range from 30 MHz through 30 GHz. When waves propagate in inhomogeneous space, which inhomogeneity consists of the structuring of the land, buildings, trees, etc., phenomena deteriorating the conditions of signal transmission occur, which include: reflections, diffractions or interferences conducive to origination of multipath in the radio channel. In addition, a Doppler effect occurs under circumstances where one terminal is in motion with respect to the other. Notwithstanding the above phenomena, the utility signal received is always accompanied by noise that limits the available sensitivity of the receiver.

2. OFDM modulation

Thanks to dynamic development of the signal digital processing technologies, it is possible to use multi-tone modulations, including the OFDM (Orthogonal Frequency Division Multiplexing) modulation, which is the subject matter of this study. Since the information is contained in modulated subcarriers, the number of which ranges from several dozen through several thousand, it is possible to demodulate each subcarrier individually, depending on the system. Thanks to the latter fact, under circumstances where, as a consequence of multipath, a portion of subcarriers will be suppressed or interfered by other system, the other subcarriers may be properly demodulated. If appropriate corrective redundancy codes are applied, it will be possible to correctly receive all the information under the above circumstances.

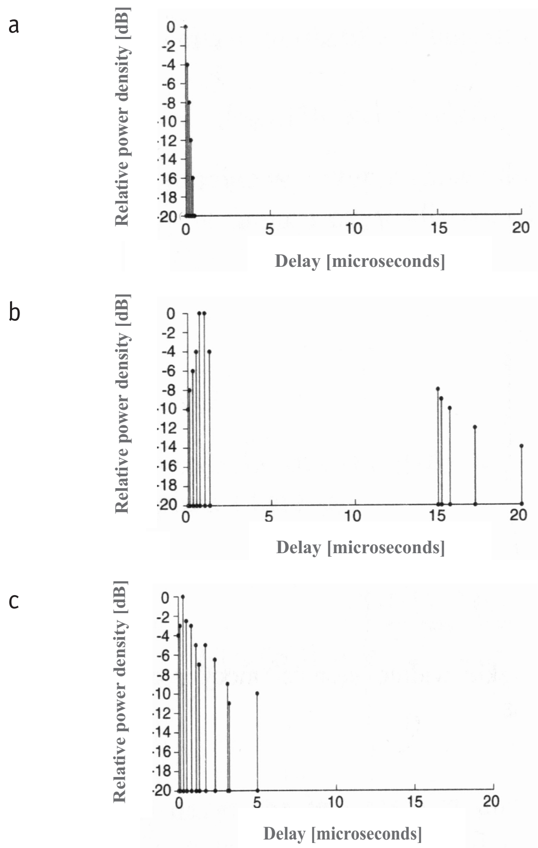


Fig. 1. Delay profiles for various types of terrain: a) flat area (non-built), b) mountain area, c) built-up area (city) source [2].

Multipath radio signal occurs in practically every mobile system. Its consequences can be analyzed in three areas. In terms of space, multipath causes origination of inhomogenous distribution of electromagnetic field in the propagation space; in terms of time it causes inter-symbol interferences, and selective fading in terms of frequency. Figure 1 presents exemplary profiles of radio channel delays for various types of terrain. On the basis of the said profiles, we can calculate relative amplitudes of signals reaching the receiver through different paths. We still have to determine the phases of the signals. Let us assume that the system operation frequency amounts to 870 MHz (wavelength 0.345m). Thus, if we know the channel delay profile to an accuracy of several hundred nanoseconds, we might determine a difference in the propagation paths to an accuracy of no more than several dozen meters. This is much more than the carrier wave length; therefore it is justifiable to assume random distribution of phases for individual components of the delay profiles. Figures 2 and 3 present delays calculated on the basis of the data of profiles, based on an assumption of random distribution of phases, the amplitude and phase characteristics of a channel for different types of terrain. The values on the abscissae axis identify the subcarrier number of the given OFDM signal.

a

b

c

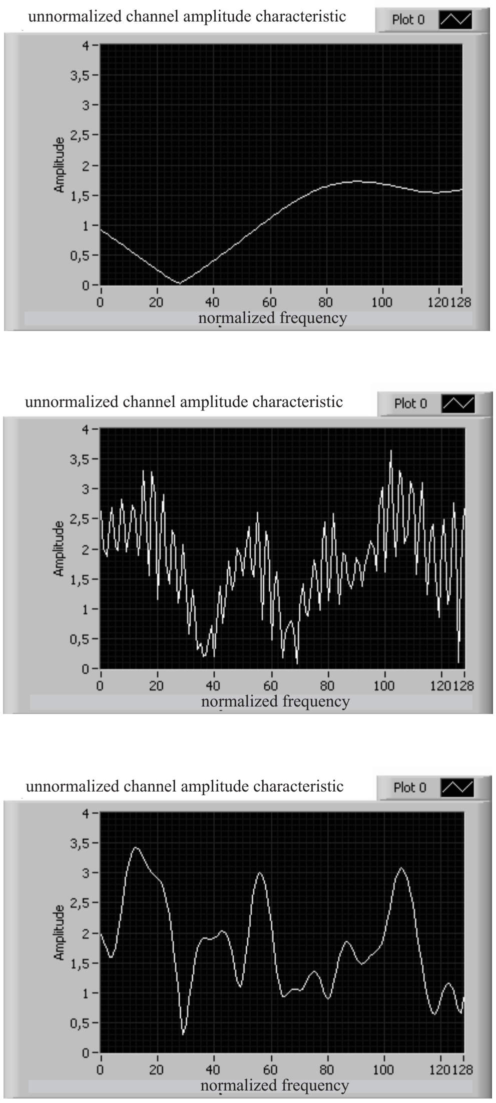


Fig. 2. Radio channel amplitude characteristics for: a) non-built area, b) mountain area, c) built-up area (city).

a

b

c

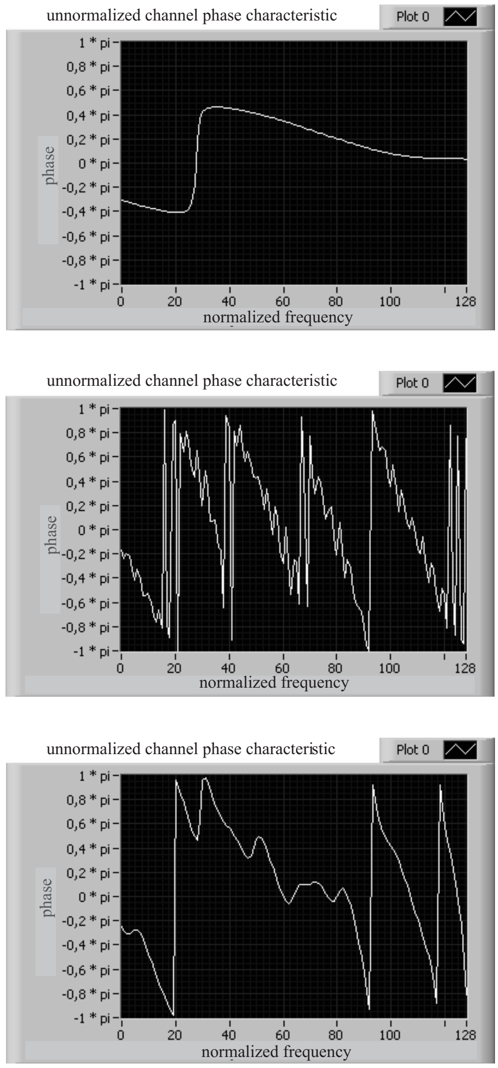


Fig. 3. Radio channel phase characteristics for: a) non-built area, b) mountain area, c) built-up area (city).

3. Methods of the improvement of radio transmission quality

A cyclic prefix is added to the OFDM modulation symbols in order to protect them against inter-symbol interferences, as well as to ensure orthogonality (independence) between individual subcarriers. The protection of the signal is fully effective when differences in delays of individual paths of signal propagation do not exceed the duration of the cyclic prefix. Figure 4 presents the structure of the OFDM symbol with the cyclic prefix attached.

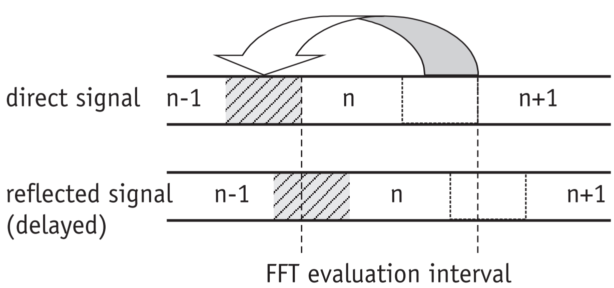


Fig. 4. OFDM symbol with cyclic prefix enclosed. Picture shows the mechanism of the protection agains intersymbol interferences.

The key element of procedure of preparation of an OFDM signal received for demodulation is to perform a phase correction on the basis of estimation of phase characteristics of a radio channel. In the formula below, $\widetilde{R}_0(k)$ means discreet Fourier transform (DFT) of the synchro-nization symbol received. DFT of the original synchro-nization symbol, which the receiver knows beforehand, is marked as $R_0(k)$. The following relation exists between these two transforms:

$$\widetilde{R}_0(k) = R_0(k) \cdot H_0(k) + \Delta R_0(k) \quad (1)$$

Where $H_0(k)$ is the channel frequency response, and $\Delta R_0(k)$ an error of the transform related to presence of noise in the signal received during transmission of the synchronization symbol. Energy of a noise accompanying the utility signal per modulation symbol is associated with error $\Delta R_0(k)$, as follows:

$$E_N = \sum_k \Delta R_0^2(k) \quad (2)$$

If we know DFT of the broadcast (original) and recei-ved symbol, we can set an estimation of characteristics of a channel:

$$\widehat{H}_0(k) = \frac{\widetilde{R}_0(k)}{R_0(k)} = H_0(k) + \Delta H_0(k) \quad (3)$$

In the above formula, $\Delta H_0(k)$ is an error of the estimator caused by presence of noise in the received signal. This is a stochastic error, and, therefore, it cannot be eliminated through a correction. However, we can minimize its value using the method of averaging estima-tions calculated on the basis of several synchronization symbols.

When we know the estimation of transmittance $\Delta\widehat{H}_0(k)$, on the basis of DFT of the nth information symbol received $\widetilde{R}_n(k)$ we set estimation $\widehat{R}_n(k)$ DFT of an appropriate original symbol $R_n(k)$:

$$\widehat{R}_n(k) = \frac{\widetilde{R}_n(k)}{\widehat{H}_0(k)} \quad (4)$$

Figures 5, 6 and 7 present distribution of the points of constellation of one of subcarriers of the OFDM signal received on the IQ plane in different field conditions and different configurations of the signal protection ele-ments. The phase equalizer, the effect of operation of which is visible in figures 5b, 6b and 7b, rotates the signal so that the points of its constellation are located in an appropriate quarter of the complex IQ coordinate system. In absence of cyclic prefix, as a consequence of intersymbol interferences, the signal constellation points located in individual quarters of the IQ plane are somehow dispersed. A definite improvement in the quality of the signal thanks to application of the cyclic prefix is conspicuous in figures 5c and 7c. In one of the discussed cases, which were a mountainous area, the difference in the paths of propagation exceeds an allowable value resulting from the fixed length of cyclic prefix. Therefore, even though the signal is protected with a cyclic prefix the intersymbol interferences still occur. (Fig. 6c).

a

b

c

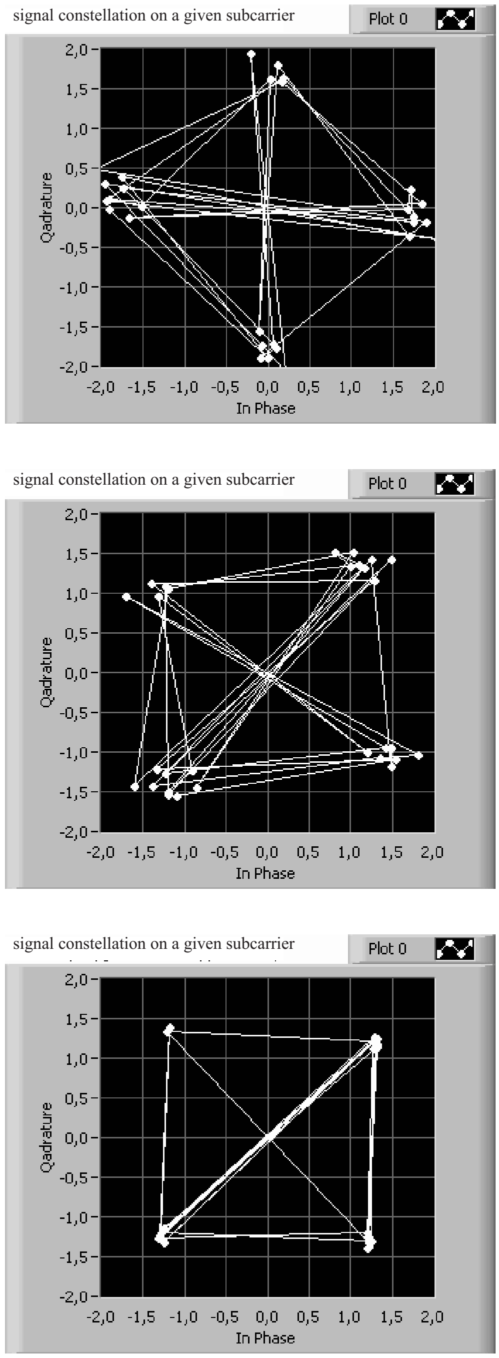
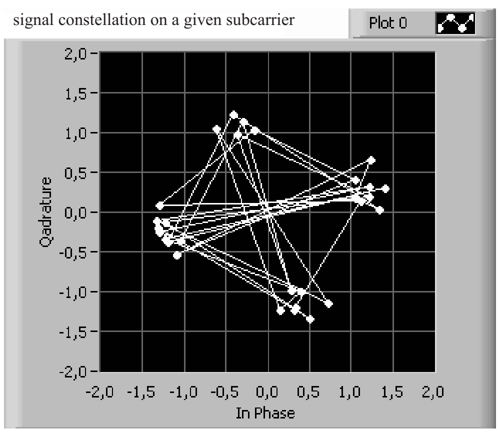


Fig. 5. OFDM sub carrier constellation with propagation in non-built area: a) without cyclic prefix and correction, b) with a correction only, c) with correction and cyclic prefix.

a



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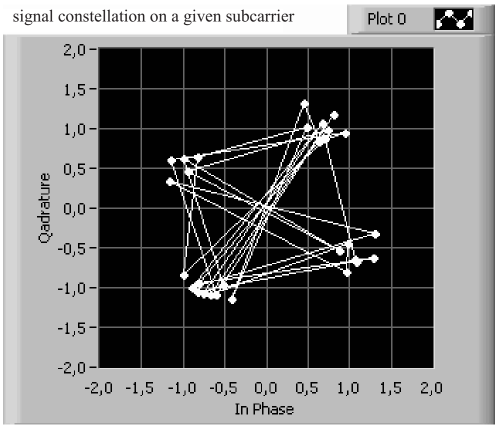

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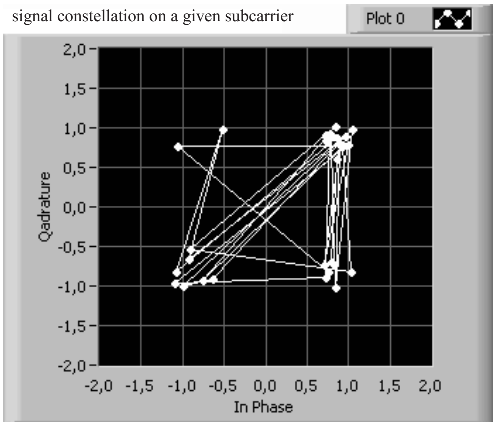
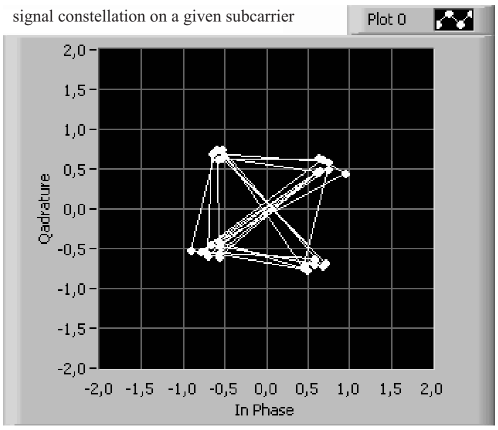
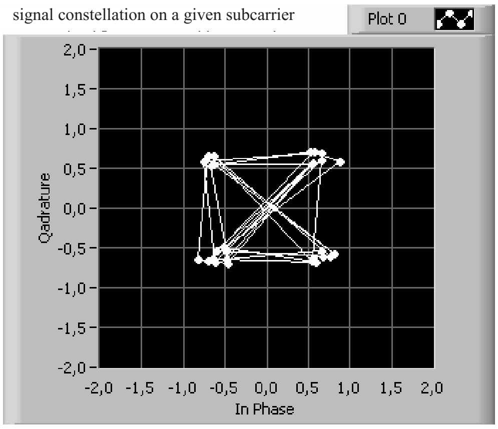


Fig. 6. OFDM sub carrier constellation with propagation in mountain area: a) without cyclic prefix and correction, b) with a correction only, c) with correction and cyclic prefix.

a



b



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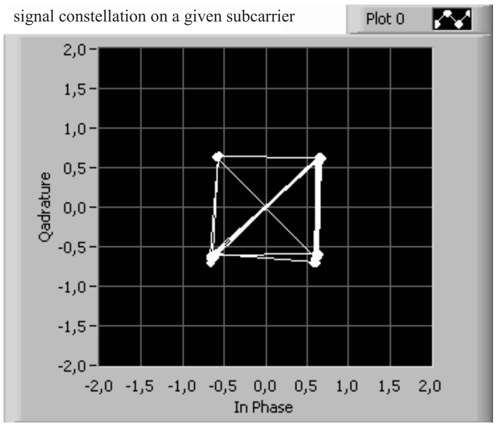

Fig. 7. OFDM sub carrier constellation with propagation in built-up area (city): a) without cyclic prefix and correction, b) with a correction only, c) with correction and cyclic prefix.

In the case of non-stationary radio channel, the transmittance estimation error is increased by additional component $\Delta H'_n(k)$ resulting from changes in the parameters of the channel over time. Therefore:

$$\hat{H}_n(k) = \widehat{H_0}(k) + \Delta H'_n(k) \quad (5)$$

An error of non-stationary channel grows in pace with increase in the number of estimations of transmittances that are subject to averaging and may be minimized through creation of a channel variability model.

In mobile applications based on the OFDM system, individual sub carriers are quadrature modulated (QPSK). Therefore correction of the frequency characteristics of the channel may be limited to a correction of its argument (phase).

$$\hat{\varphi}_0(k) = arg[\widehat{H_0}(k)] \quad (6)$$

When applying a linear (first order) model of esti-mation of transmittance argument acknowledging a linear phase reverse over time, for the nth symbol of modulation, the estimated value is:

$$\hat{\varphi}_n(k) = \widehat{\varphi_0}(k) + n \cdot \widehat{d\varphi}(k) \quad (7)$$

Where n is the number of the symbol.

Using the linear model of estimation of argument of channel frequency characteristics, we can describe the Doppler effect occurring in mobile system. Shift of a component of the signal spectrum by Δf as a consequence of effective motion of the receiver with respect to the transmitter at a velocity the component of which parallel to the propagation direction amounts to υ consists of the following dependence:

$$\Delta f = -f \cdot \frac{\upsilon}{c} \quad (8)$$

where f is a frequency with which the given component of the spectrum was transmitted, and c is the velocity of propagation of electromagnetic wave in vacuum.

Let us assume that the Doppler shift in the k-th sub carrier of the OFDM signal amounts to Δf_k, and duration of the modulation symbol amounts to τ. Thus, the estimation of the transmittance argument of m-th signal path will be as follows:

$$\hat{\varphi}_{m,n}(k) = \hat{\varphi}_{m,0}(k) + 2\pi\Delta f_k \cdot n \cdot \tau = \hat{\varphi}_{m,0}(k) - 2\pi \cdot f_k \cdot \frac{\upsilon_m}{c} \cdot n \cdot \tau \quad (9)$$

It would be still better to apply a model of higher order, the second one for example, which would acknowledge alteration of speed of a car moving with a constant acceleration. However, to increase the order of the estimation leads to increased amount of calculation related to the setting the said order, which enforces making a compromise between the channel parameters fluctuation immunity and the degree of complexity of channel estimation algorithms.

4. Conclusion

In conclusion, I would like to emphasize great importance of the mechanisms of estimation of radio channel parameters in the process of receipt of broadband signals, which is proven by the results of the simulation performed. Due to limited volume of the article, I have given up a thorough analysis of the problem and presented it in a possibly simple form. People interested in the problem of channel correction parameters should refer to the literature where it is discussed in more detail.

AUTHOR

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