ON THE EFFECT OF TIME-SELECTIVE FADING IN OFDM FOR MOBILE APPLICATIONS

Nenad Miloš eviæ, Ivana Arsiæ, Bojan Dimitrijeviæ
Faculty of Electronic Engineering, Niš

I INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a new promising technique for future mobile wireless data systems in order to achieve high-bit data rate. It is proposed to combat the frequency selectivity, but its performance is affected by the time selectivity. This paper focuses on the effects of time-selective multipath fading on OFDM systems for broadband mobile applications. We investigate how various parameters, such as carrier offset and Doppler spread affects the system performance. Further the values of carrier offset and symbol duration will be determined in order to achieve a signal-to-interference ratio (SIR) of 20 dB. Also, the bound of Doppler tolerance will be determined since it is important in design of broadband OFDM systems for mobile environments.

OFDM is a bandwidth efficient signalling scheme for digital communications that was first proposed by Chang [1]. Nowadays, this technique is considered to be mature and well-established technology for digital broadcasting applications, and it is used in several standards, such as Digital Audio Broadcasting (DAB) and Digital Terrestrial Television Broadcasting (DTTB), and lately for HYPERLAN II.

This technique have many advantages over conventional single carrier systems, such as robustnes against multipath delay spread, adaptive channel alocation, adptive modulation of subcarriers according to the channel conditions etc.

One of the major OFDM disadvantages is high sensitivity to carrier offset, which results in reducing desired symbol amplitude and introduces intercarrier interference (ICI). When comparing OFDM to a conventional single carrier system it is in orders of magnitude more sensitive to frequency offset and Wiener phase noise [2]. This problem is more expressed in mobile applications since a mobile channel has a time-varying nature. In some previous publications this problem was ignored [3],[4]. In this paper the effect of time-varing features of a mobile channel on OFDM system performance are analyzed.

II OFDM BASICS

Orthogonal Frequency Division Multiplexing (OFDM) is a special case of multicarrier transmission based on a principle of transmitting single datastream over a number of lower rate subcarriers. Basically, an OFDM signal consists of the superposition of N sinusoidal subcarriers with frequency spacing T, where each of them is modulated by data symbols that have a duration T equal to the inverse channel spacing. Although the modulated subcarriers spectrally overlap, the signal associated with each sinusoid can be recovered as long as the channel does not destroy their orthogonality. In other words, the total signal frequency bandwidth

III CHARCTERISTICS OF MOBILE RADIO CHANNEL

In order to analyse the effect of time-varying characteristics, following mobile radio channel is considered.

First of all, it is important to define a complex baseband representation of the mobile wireless channel impulse response as described as in [5]

$$h(t,t) = \sum_{K} g_k(t) \times d(t - t_k) \qquad (1)$$

where $t_k(t)$ is the delay of the kth path and $g_k(t)$ is corresponding complex amplitude.

Using the Fourier transform of (1) it is possible to define the time-varying frequency response of channel at time t, as follows

$$H(t, f) = \int_{-\infty}^{+\infty} h(t,t) e^{-j2pft} dt = \sum_{K} g_p(t) e^{-j2pt_p f}$$

(2)

For mobile applications it is necessary to take into account the vehicle velocity and due to its motion, parameters $g_k(t)'s$ from (1) are modelled to be wide-sense-stationary (WSS) narrowband complex Gaussian processes, independent for different paths, [5]. Furthermore, $g_k(t)'s$ for all k have the same normalized time correlation functions and different average powers.

As it was shown in [3], it is possible to exploit the correlation in both time and frequency domain separately.Hence,the correlation function $H(t, f)$ can be separated into the multiplication of a time-domain and frequency-domain correlation.

Since in this paper a signal transmission over the wide-sense-stationary uncorrelated scattering channel (WSS-USC) is considered, after applying two dimension isotropic scattering model [6], it is possible to determine an autocorrelation function of the $q$thmultipath component as

$$R_{q,q}(t) = E(g_q(t) \times g_q^*(t + t)) =$$
$$= E_q \times R_t(t)$$

(3)

In (3) term Eq denotes the average power of the qth path, while $R_t(t)$ is the time domain correlation from Jakes model, […]. This term is equal to

$$R_t(t) = J_0(2pf_D t)$$

where $J_0(x)$ is the zeroth-order Bessel function of the first kind. Parameter f_D is the maximum Doppler frequency shift, which is related to the vehicle speed and the carrier frequency f_c, i.e.

$$f_D = \frac{vf_c}{c}$$

where c is the light speed.

Also, it is possible to determine a correlation function for the pth and the qth component as

$$R_{p,q}(t) = E[g_p(t) \times g_q^*(t+t)] = E_q \cdot d(p,q) \cdot J_0(2pf_D)$$

where $d(p,q)$ is the d - function and other parameters are previously defined.

IV EFFECT OF TIME-SELECTIVE FADING

For wireless communications, where portable and mobile applications are of particular interest, the function $h(t,t)$ cannot be assumed to be static.

Complex baseband representation of the transmitted signal (at the output of OFDM modulator), when IFFT is imlemented , is

$$x(n) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} x_s(i) \times e^{j(2p/N)in}$$

(4)

The input signal at the receiver is

$$r(t) = y(t) + z(t)$$

This signal is sampled at time instants $t = nT_s$ and hence, can be expressed as:

$$r_s(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} H(n,k) \times x_s(k) \times e^{j(2p/N)(k+e)} + Z(n)$$

(5)

where n= 0,1,2,…N-1, $H(n, k)$ time-varying frequency response and $Z(n)$ is the complex white Gaussian noise.

The sampled received signal $r_s(n)$ is processed via FFT and the corresponding output can be written as

$$\tilde{X}_s(k) = \frac{1}{N} \sum_{n=0}^{N-1} r_s(n) \times e^{-j(2p/N)k \times n}$$

(6)

where $k = 0,1,2,\ldots,N-1$.

After substituting previous equations into (6), the output signal is

$$\tilde{X}_s(k) = \frac{1}{N} \sum_{m=0}^{N-1} \left[\left(\sum_{n=0}^{N-1} H(n,m) \times e^{j(2p/N)(m+e-k)n} \right) \times \times x_s(m) \right] + \tilde{Z}(k)$$

(7)

where $\hat{Z}(k)$ denotes the FFT of the samples of AWGN.

The inter-carrier-interference (ICI) for kth and mth path can be defined as

$$ICI(k,m) = \frac{1}{N} \sum_{n=0}^{N-1} H(n,m) \times e^{j(2p/N)(m+e-k)n}$$

(8)

Now it is possiblle to express the demodulated signal $\tilde{X}(k)$ in terms of ICI as follows:

$$\tilde{X}(k) = \sum_{m=0}^{N-1} (ICI_{k,m} \times x(m)) + \tilde{Z}(k)$$

According to previous equations there are three cases of interest, whether the channel is stationary or mobile,i.e. it is necessary to see how various parameters have an influence on ICI.

If the channel is stationary and there is no carrier offset ($e = 0$), then there is no inter-carrier-interference

In case of mobile radio channel, there are two cases:

if there is no carrier frequency offset ($e = 0$), *ICI* exists, since it is a result of time-varyng features of the channel in OFDM systems. If there is a carrier offset then it is important to determine ICI in terms of combined effect of carrier offset and time selective fading .

In order to evaluate ICI it is necessary to determine an average signal power for the demodulated signal (after demodulation via FFT), defined in (7), using the following equation

$$E[|\tilde{X}_s(k)|^2] = E\left\{ \left| \sum_{m=0}^{N-1} (ICI(k,m) \times x_s(m)) + \tilde{Z}(k) \right|^2 \right\}$$

(9)

It is assumed that the symbols in different subchannels are independent of each other, with the same average power E_s and zero mean.

After the demodulation, desired signal power can be expressed as:

$$S = E_s \times E[|ICI(k,k)|^2]$$

(10)

In order to determine a signal-to-interference-ratio (SIR) it is necessary to define an ICI term, denoted as I

$$I = E_s \times \sum_{\substack{n=0 \\ n \neq k}}^{N-1} [|ICI(k,n)|^2]$$

(11)

At the end signal-to-interference ratio *SIR* can be determined according to the following expression:

$$SIR = \frac{E[|I_{k,k}|^2]}{\sum_{\substack{m=0 \\ m \neq k}}^{N-1} E[|I_{k,m}|^2]}$$

where $ICI(k,m) = I_{k,m}$

$$ICI(k,k)=I_{k,k}$$

or finally as:

$$SIR=\frac{N-2\cdot\sum_{p=0}^{N-1}(N-p)\times J_0(2pf_D\times pt_s)e^{j(2p/N)e\times p}}{\sum_{\substack{m=0\\m\neq k}}^{N-1}(N-2\cdot\sum_{p=0}^{N-1}(N-p)\times J_0(2pf_D\times pt_s)e^{j(2p/N)(m+e-k)\times p}}$$

(12)

In the sequel, the maximum Doppler frequency versus the maximum system degradation will be evaluated by modeling ICI as an additional "fading" noise. Best-case upper bounds will be determined according to the equation for the total fading noise power

$$\sigma_{fad}^2\approx\frac{\pi^2}{6}(\,f_D T_u\,)$$

(13)

where $1/T_u$ is the subcarrier bandwidth. The OFDM receiver is divided into an inner and outer receiver.

V NUMERICAL RESULTS

For the presented analysis, there are three cases of interest. Numerical results were obtained according to equations (12) and (13).

In the first case it is assumed that a mobile channel is stationary i.e. there is no movement in the channel and f_D=0.

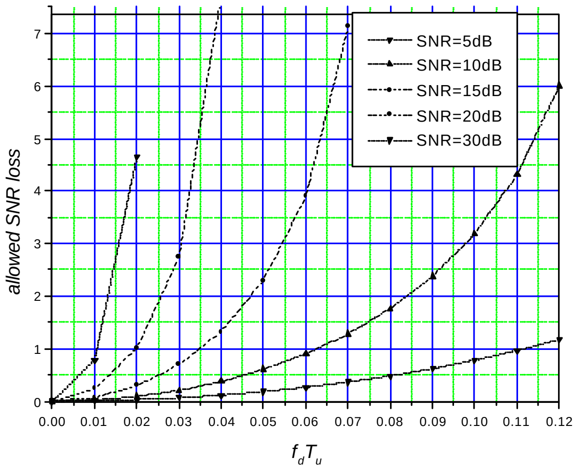

Fig. 1. Signal-to-interference ratio versus frequency offset

In case of a mobile channel $f_D\neq 0$ i.e. a Doppler spread is presented in the channel, the effect of ICI is significant even without a carrier offset. Fig.1. represents the effect of both carrier offset and time selective fading.

The shown results are obtained versus parameter *a* that represents a symbol duration to coherence time ratio for 256-OFDM. According to Fig.2. it is possible to determine symbol duration, as well the vehicle velocity necessary to obtain a desired signal to interference ratio SIR. For a SIR > 20 dB symbol duration must be less than 3 % of the channel coherence time.

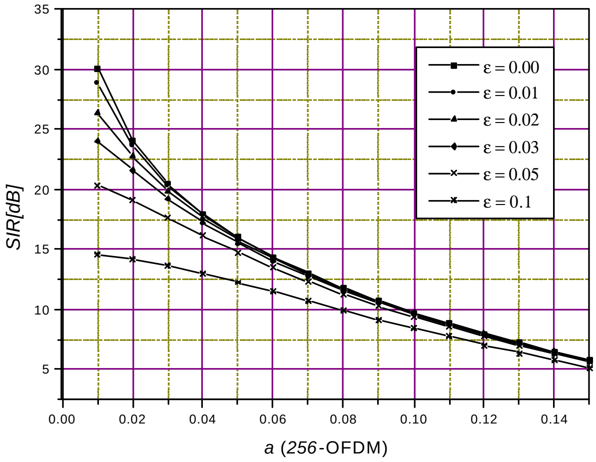

Fig. 2. Signal-to-interference ratio versus parameter *a* for 256-OFDM

Figure 3. represents the best upper case bound for the allowed Doppler frequency for a given SNR loss in [dB].

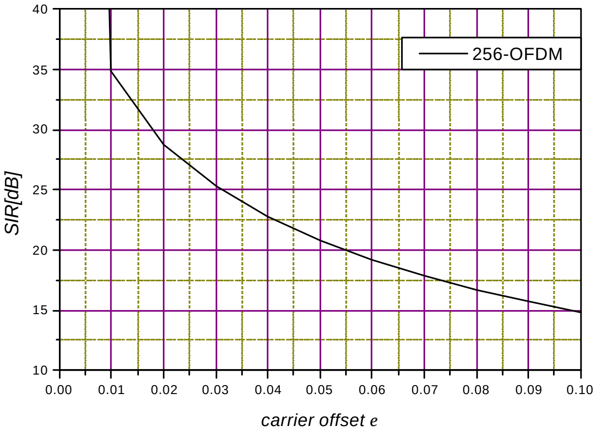

Fig. 3. Maximum allowed Doppler frequency

VI CONCLUSION

In this paper the influence of time-varying features of the channel on OFDM system performance was under investigation. It was assumed that the a channel was influenced by the flat frequency fading and that the system performances were only affected by time selective fading. Performances were evaluated for three different cases. Signal to interference ratio was determined and symbol duration was evaluated for a given SIR. For a SIR > 20 dB symbol duration must be less than 3 % of the channel coherence time.Also, the bound of Doppler tolerance was determined .

REFERENCES:

[1] R.W. Chang, *“Synthesis of band-limited orthogonal signals for multichannel data transmission”*, Bell Syst. Tech. J., vol.45, pp.1775-1796, Dec. 1966.

[2] T.Pollet, M.Van Bladel and M.Moeneclaey, *“BER Sensitivity of OFDM Systems to Carrier Frequency Offset and Wiener Phase Noise”*, IEEE Trans. Commun., vol. 43, pp. 191-193, April 1995

[3] L.J.Cimini, *“Analysis and Simulation of a Digital Mobile Channel Using Orthogonal Frequency Division Multiplexing”*, IEEE Trans. Commun., vol. COM-33, pp. 665-675, July 1985

[4] P.Moose, “A Technique for Orthogonal Frequency Division Multiplexing Frequency Offset Correction”, *IEEE Trans. Commun., vol. 42,* pp. 2908-2914, Oct. 1994

[5] R. Steele, Mobile Radio Communications, New York, IEEE Press 1992.

[6] R.H.Clarke, *"A statistical Theory for Mobile Radio Reception"*, Bell Syst. Tech. J., vol. 47, pp. 957-1000, July 1968.

[7] Y.Li, L.Cimini and N.Sollenberger, *“Robust Channel Estimation for OFDM Syst with Rapid Dispersive Fading Channels”*, IEEE Trans. Commun., vol. 46, pp. 902-915, July 1998

[8] M.Speth, C. Corado and S. Fletcher, *“Optimum Receiver Design for Wireless Broad-Band Systems Using OFDM”*, IEEE Trans.Commun., vol. 47, pp. 1668-1677, Nov. 1999

Sadržaj – U ovom radu je raymatran uticaj vremenski promenljivih osobina kanala na performanse OFDM sistema. Pretpostavljeno je da se u kanalu javlja frekvencijski ravanm feding i da na performanse sistema utièe samo vremenski promenljivi feding. Performanse su izraèunate za tri razlièita sluèaja. Odreðen je odnos signal/smetnja, a trajanje simbola je izraèunato za dati SIR. Za SIR > 20 dB trajanje simbola mora da bude manje od 3 % vremena koherencije kanala. Takoðe je odreðena i granièna vrednost Doplerove tolerancije.

UTICAJ VREMENSKI PROMENLJIVOG FEDINGA NA PERFORMANSE MOBILNIH OFDM SISTEMA,

Nenad Miloševiæ, Ivana Arsiæ, Bojan Dimitrijeviæ