BER Performance Simulation of Generalized MC DS-CDMA System with Time-Limited Blackman Chip Waveform

Ibrahim DEVELI [1], *Kenan KOCKAYA* [2]

[1]Department of Electrical & Electronics Engineering, Faculty of Engineering, Erciyes University, 38039, Kayseri, Turkey
[2]Department of Technical Programs, Divrigi Vocational High School, Cumhuriyet University, Sivas, Turkey

develi@erciyes.edu.tr, ckkockaya@cumhuriyet.edu.tr

Abstract. *Multiple access interference encountered in multicarrier direct sequence-code division multiple access (MC DS-CDMA) is the most important difficulty that depends mainly on the correlation properties of the spreading sequences as well as the shape of the chip waveforms employed. In this paper, bit error rate (BER) performance of the generalized MC DS-CDMA system that employs time-limited Blackman chip waveform is presented for Nakagami-m fading channels. Simulation results show that the use of Blackman chip waveform can improve the BER performance of the generalized MC DS-CDMA system, as compared to the performances achieved by using time-limited chip waveforms in the literature.*

Keywords

BER performance simulation, generalized MC DS-CDMA system, Blackman chip waveform.

1. Introduction

Multicarrier direct sequence-code division multiple access (MC DS-CDMA) is a novel radio access scheme that is preferred widespread for wireless personal communication systems [5, 6, 8, 21, 24]. Despite advantages, the performance of the MC DS-CDMA system is affected significantly by the interference among users which is called as multiple access interference (MAI). This interference is basically dependent on the correlation properties of the spreading sequences used and the chip waveform preferred. Bit error rate (BER) and service quality of MC DS-CDMA systems depend on what proportion this interference can be removed.

The error performance in a single user communication realized over an additive white Gaussian noise (AWGN) channel depends mainly on signal energy instead of a special chip waveform. In contrast, the appropriate design of a chip waveform plays an important role on the performance of a DS-CDMA system and by this way the performance can be improved. The reason for this improvement is that the statistical properties of MAI depend on the real shape of the chip waveform used. Most of the studies carried out in the field of MC DS-CDMA communication systems have focused on the use of rectangular chip waveform [4, 14, 18, 19, 20]. However, a number of works with the aim of finding new and different chip waveforms instead of rectangular chip waveform have been presented in the literature [1, 2, 3, 7, 11, 12, 13]. In general, a chip waveform is either band-limited or time-limited. Even though the chip waveforms are band-limited in practice, time-limited chip waveforms that are defined in one chip duration have been usually considered in the subject of MC DS-CDMA systems.

In a recent paper [22], Yang and Hanzo have proposed a class of generalized MC DS-CDMA schemes with rectangular chip waveform, and evaluated its performance over multipath Nakagami-*m* fading channels. In [25], the same authors have extended their performance investigation of the generalized MC DS-CDMA by considering two additional types of chip waveforms, namely, the half-sine and the raised-cosine chip waveforms, in addition to the previously used rectangular chip waveform. In their work, they have concluded that for a given subcarrier spacing between two adjacent subcarriers, there exist a corresponding best choice of the chip waveform. The impact of time-limited chip waveforms on the performance of MC DS-CDMA systems has been presented in [17]. The authors have demonstrated that the BER performance of MC DS-CDMA systems can be improved by using the half-sine, the raised-cosine or the Blackman chip waveforms for both an AWGN channel and a Rayleigh fading channel.

In this paper, we extend the BER performance evaluation presented in [25], by considering the time-limited Blackman chip waveform for transmissions over multipath Nakagami-*m* fading channels. Simulation results show that the use of Blackman chip waveform can improve the BER performance of the generalized MC DS-CDMA system, as compared to the performances achieved by using the rectangular, the half-sine and the raised-cosine waveforms [9, 10].

2. Description of the MC DS-CDMA System

In this section, a brief description on the performance expressions proposed in [22] for the generalized MC DS-CDMA system is presented. At the transmitting point of the generalized MC DS-CDMA system, the binary data stream having bit duration of T_b is serial-to-parallel converted to U number of parallel substreams. Therefore, the symbol duration is $T_S = UT_b$. After serial-to-parallel conversion, the uth substream modulates a subcarrier frequency f_u using binary phase shift keying (BPSK) for u = 1, 2, ..., U. Then, the U subcarrier-modulated substreams are added in order to produce the complex modulated signal. Finally, spectral spreading is applied on the complex signal by the multiplication of this signal with a spreading sequence. The processing gain, N_e, of the subcarrier signal can be written as [22, Eq. (6)]

$$N_e = UN_1 - \frac{(U-1)\lambda}{2} \tag{1}$$

where U is the number of subcarriers; N_1 is the spreading gain of a corresponding single-carrier DS-CDMA system and λ is the normalized subcarrier spacing. In this study, it is assumed that the channel between the kth transmitter and the corresponding receiver is a multipath Nakagami-m fading channel [15]. The total number of diversity paths, L_p, is given as [22, Eq. (8)]

$$L_p \approx \left\lfloor \frac{2N_e(L_1-1)}{2N_e+(U-1)\lambda} \right\rfloor + 1 \tag{2}$$

where L_1 is the number of resolvable paths of the corresponding single-carrier DS-CDMA system. The average bit error rate (BER) for the generalized MC DS-CDMA system is written as [22, Eq. (47)]

$$P_b = \frac{1}{\pi}\int_0^{\pi/2} \prod_{l=0}^{L-1} \left(\frac{m\sin^2\theta}{\gamma_c e^{-\eta l} + m\sin^2\theta} \right)^m d\theta \tag{3}$$

where l = 0, 1, ..., L–1, L ($1 \le L \le L_p$) is the number of diversity branches used by receiver; m is the Nakagami-m fading parameter and η is the rate of average power decay. γ_c in (3) can be given by [22, Eq. (41)]

$$\gamma_c = \left[\left(\frac{\Omega_0 E_b}{N_0} \right)^{-1} + \frac{2(KL_p-1)(1-e^{-\eta L_p})}{L_p(1-e^{-\eta})} \left(I_0 + (U-1)\bar{I}_M \right) \right]^{-1} \tag{4}$$

where K is the total number of the asynchronous users in the system, Ω_0 is the average signal strength corresponding to the first resolvable path and I_0 is the interference variance that should be defined for a specific chip waveform employed. $\bar{I}_M$ in (4) is the average of the MAI term $I_2^{(k)}$ due to path l_p.

3. Outline of the Derivation

This section presents a brief outline for the derivation of the $\bar{I}_M$ and the I_0 expressions in (4) when a Blackman function is considered as a chip waveform. In [25], it has been shown that for a given α_{vl} value, $I_2^{(k)}$ can be approximated as a Gaussian random variable having zero mean and variance given by

$$\mathrm{Var}\left[I_2^{(k)}\right] = \Omega_{ul_p}^{(k)} \alpha_{vl}^2 \zeta_2^{(k)} \tag{5}$$

where $\Omega_{ul_p}^{(k)} = E\left\{ \left[\alpha_{ul_p}^{(k)}\right]^2 \right\}$, ($\alpha_{ul_p}^{(k)}$ represents the Nakagami-m distributed channel fading amplitude), and [25, Eq. (6)]

$$\zeta_2^{(k)} = \frac{1}{T_s^2}\left\{ E_{\tau,\varphi}\left[R_k^2(\tau,\varphi,u,v)\right] + E_{\tau,\varphi}\left[\hat{R}_k^2(\tau,\varphi,u,v)\right] \right\} \tag{6}$$

where T_s shows the symbol duration of the MC DS-CDMA signal. τ and φ represent the delay time and phase angle, respectively. $E_{\tau,\varphi}[R_k^2(\tau, \varphi, u, v)]$ and $E_{\tau,\varphi}[\hat{R}_k^2(\tau, \varphi, u, v)]$ represent the second central moments of the extended partial autocorrelation functions $R_k(\tau, \varphi, u, v)$ and $\hat{R}_k(\tau, \varphi, u, v)$ of the chip waveforms. The mathematical expression of the Blackman chip waveform is given as [16];

$$\psi(t) = c\left[k_1 - k_2\cos\left(\frac{2\pi t}{T_c}\right) + k_3\cos\left(\frac{4\pi t}{T_c}\right) \right] p_{T_c}(t) \tag{7}$$

where

$$p_{T_c}(t) = \begin{cases} 1, & 0 \le t \le T_c \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

The values of k_n, $n \in \{1, 2, 3\}$, employed are $k_1 = 0.42$, $k_2 = 0.5$, and $k_3 = 0.08$. Using these values that were obtained from expansion of Bessel function, c can be written as

$$c = \left(k_1^2 + \frac{k_2^2}{2} + \frac{k_3^2}{2} \right)^{-1} \tag{9}$$

In this step, we must provide the expressions of $E_{\tau,\varphi}[R_k^2(\tau, \varphi, u, v)]$ and $E_{\tau,\varphi}[\hat{R}_k^2(\tau, \varphi, u, v)]$ for the Blackman chip waveform considered in this paper. With the help of MathCAD software's symbolic mathematics, the following results are obtained

$$E_{\tau,\varphi}\left[R_k^2(\tau,\varphi,u,v)\right] = E_{\tau,\varphi}\left[\hat{R}_k^2(\tau,\varphi,u,v)\right] = \frac{T_s^2 c^4 k_1^4}{64\pi^2} \times \chi(u,v) \tag{10}$$

where

$$\begin{aligned}\chi(u,v)=\Bigg[\Bigg(&\frac{9}{\zeta^2}+\frac{5.68}{[N_e+\zeta]^2}+\frac{5.68}{[N_e-\zeta]^2}+\frac{1}{[2N_e+\zeta]^2}\\
&+\frac{1}{[2N_e-\zeta]^2}-\frac{11.9}{\zeta[N_e+\zeta]}+\frac{11.9}{\zeta[N_e-\zeta]}+\frac{1.42}{\zeta[2N_e+\zeta]}\\
&-\frac{1.42}{\zeta[2N_e-\zeta]}-\frac{5.68}{N_e^2-\zeta^2}-\frac{3.36}{[N_e+\zeta][2N_e+\zeta]}\\
&-\frac{3.36}{[N_e-\zeta][2N_e-\zeta]}\Bigg)-\Bigg(\frac{9}{\zeta^2}+\frac{2.84}{[N_e+\zeta]^2}+\frac{2.84}{[N_e-\zeta]^2}\\
&-\frac{11.9}{\zeta[N_e+\zeta]}+\frac{11.9}{\zeta[N_e-\zeta]}+\frac{1.42}{\zeta[2N_e+\zeta]}-\frac{1.42}{\zeta[2N_e-\zeta]}\\
&-\frac{11.36}{N_e^2-\zeta^2}+\frac{3.36}{[N_e+\zeta][2N_e-\zeta]}+\frac{3.36}{[N_e-\zeta][2N_e+\zeta]}\\
&-\frac{2}{[4N_e^2-\zeta^2]}\Bigg)\times\mathrm{sinc}\left(\frac{2\pi\zeta}{N_e}\right)-\Bigg(\frac{4}{\zeta^2}+\frac{5.68}{[N_e+\zeta]^2}-\frac{11.9}{\zeta[N_e+\zeta]}\\
&+\frac{3.38}{\zeta[N_e-\zeta]}+\frac{5.68}{\zeta[2N_e+\zeta]}-\frac{5.68}{N_e^2-\zeta^2}\\
&-\frac{3.36}{[N_e+\zeta][2N_e+\zeta]}+\frac{3.36}{[N_e-\zeta][2N_e+\zeta]}\Bigg)\times\mathrm{sinc}\left(\frac{2\pi[N_e+\zeta]}{N_e}\right)\\
&-\Bigg(\frac{4}{\zeta^2}+\frac{5.68}{[N_e-\zeta]^2}+\frac{11.9}{\zeta[N_e-\zeta]}-\frac{3.38}{\zeta[N_e+\zeta]}-\frac{5.68}{\zeta[2N_e-\zeta]}\\
&-\frac{5.68}{N_e^2-\zeta^2}+\frac{3.36}{[N_e+\zeta][2N_e-\zeta]}-\frac{3.36}{[N_e-\zeta][2N_e-\zeta]}\Bigg)\\
&\times\mathrm{sinc}\left(\frac{2\pi[N_e-\zeta]}{N_e}\right)-\Bigg(\frac{1}{2\zeta^2}+\frac{2.84}{[N_e+\zeta]^2}+\frac{1}{2[2N_e+\zeta]^2}-\frac{3.38}{\zeta[N_e+\zeta]}\\
&+\frac{1.42}{\zeta[2N_e+\zeta]}-\frac{3.36}{[N_e+\zeta][2N_e-\zeta]}\Bigg)\times\mathrm{sinc}\left(\frac{2\pi[2N_e+\zeta]}{N_e}\right)\\
&-\Bigg(\frac{1}{2\zeta^2}+\frac{2.84}{[N_e-\zeta]^2}+\frac{1}{2[2N_e-\zeta]^2}+\frac{2.84}{\zeta[N_e-\zeta]}-\frac{1.42}{\zeta[2N_e-\zeta]}\\
&-\frac{3.32}{[N_e-\zeta][2N_e-\zeta]}\Bigg)\times\mathrm{sinc}\left(\frac{2\pi[2N_e-\zeta]}{N_e}\right)\Bigg]\Bigg]\end{aligned} \tag{11}$$

ζ in (11) is $\zeta = \lambda(u - v)$ and it represents the normalized spacing between uth and vth subcarriers. Now, $\zeta_2^{(k)}$ given by (6) can be obtained by using the above defined expressions. Based on the relationship between $\bar{I}_M$ and $\zeta_2^{(k)}$ [23, Eq. (27)], $\bar{I}_M$ for the Blackman chip waveform is derived as

$$\bar{I}_M = \frac{0.34N_e}{32\pi^2} \times \chi(u,v). \tag{12}$$

If $\zeta = 0$, then I_0 can be written as

$$I_0 = \frac{3.43}{24N_e} + \frac{118.27}{64N_e\pi^2}. \tag{13}$$

4. Simulation Results

The BER performance of the generalized MC DS-CDMA system using time-limited Blackman chip waveform for transmission over Nakagami-*m* fading channels is presented in this section. The performance results belonging to the rectangular, the half-sine and the raised-cosine chip waveforms are also included into the simulation studies to illustrate the improvement carried out by using the Blackman chip waveform. It is well known that the MATLAB is powerful software that one could do numerical calculations and implement simulations. Therefore, the BER performance of the system employing time-limited Blackman chip waveform is simulated in the MATLAB environment. The system parameters kept constant in the simulations are: The number of resolvable paths of the corresponding single-carrier DS-CDMA system is $L_1 = 32$ and the spreading gain is $N_1 = 128$. The number of simultaneous users is $K = 10$. The signal to noise ratio per bit is set to $E_b/N_0 = 15$ dB. The rate of average power decay is considered as $\eta = 0.2$. Two different number of subcarriers are used; $U = 8$ and $U = 32$. Finally, it is assumed that the receiver combines all of the resolvable paths of the channel ($L = L_p$).

The BER performance of the generalized MC DS-CDMA system is shown in Fig. 1 as a function of the normalized subcarrier spacing, when the Blackman chip waveform is employed. It can be seen that for both Nakagami-*m* fading parameter ($m = 1$ and $m = 3$), the Blackman chip waveform performs the best performance especially for the low values of λ, while the BER performances achieved by the other chip waveforms are nearly the same.

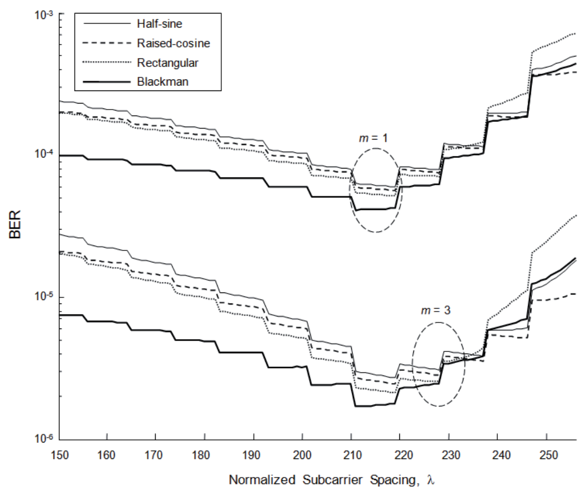

Fig. 1. BER performance of the generalized MC DS-CDMA system using Blackman chip waveform over a Nakagami-*m* fading channel for $m = 1$ and $m = 3$: ($U = 8$, $N_1 = 128$, $L_1 = 32$, $K = 10$, $\eta = 0.2$, $E_b/N_0 = 15$ dB and $L = L_p$).

Fig. 2 depicts the BER performance of the generalized MC DS-CDMA system with Blackman chip waveform versus the normalized subcarrier spacing for $U = 32$. As in the case of Fig. 1, it can be seen that the BER performance produced by using the Blackman chip waveform is better than the other performances obtained by using the rectangular, the half-sine, and the raised-cosine chip waveforms, for both $m = 1$ and $m = 3$.

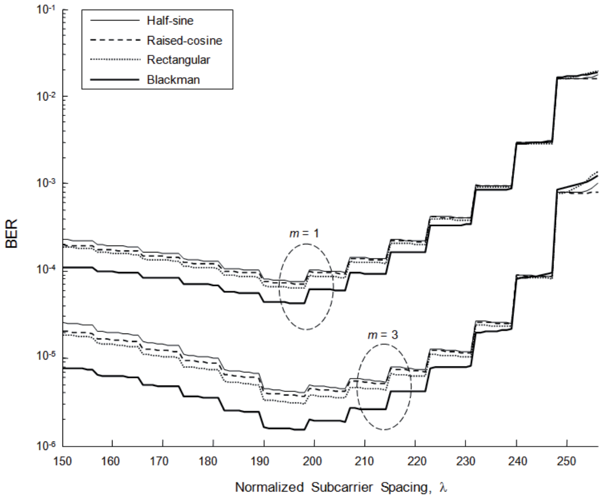

Fig. 2. BER performance of the generalized MC DS-CDMA system using Blackman chip waveform over a Nakagami-*m* fading channel for $m = 1$ and $m = 3$: ($U = 32$, $N = 128$, $L_1 = 32$, $K = 10$, $\eta = 0.2$, $E_b/N_0 = 15$ dB and $L = L_p$).

Because of the importance of the optimum spacing λ_{opt}, which enable to minimize the MAI inflicted upon each of the subcarrier signals; it will be useful to give a comparison on the BERs at this specific spacing. Tab. 1 shows the BER values obtained for each chip waveform examined in this study about the optimum spacing when $m = 3$. As shown in Tab. 1, the lowest BER at λ_{opt} is obtained with the use of Blackman chip waveform [9, 10].

Type of Chip Waveform	λ_{opt}		BER (x 10^{-6})	
	U=8	U=32	U=8	U=32
Rectangular	219	198	2.1126	3.0202
Half-Sine	219	198	2.6988	3.9954
Raised-Cosine	219	198	2.4504	3.6283
Blackman	219	198	1.8456	1.5223

Tab. 1. BER performance of the generalized MC DS-CDMA system using various chip waveforms at λ_{opt} for $m = 3$.

5. Conclusion and Future Work

In this paper, the BER performance of the generalized MC DS-CDMA system using time-limited Blackman chip waveform is presented for transmissions over Nakagami-*m* fading channels. Simulation results show that the use of Blackman chip waveform can improve the BER performance of the generalized MC DS-CDMA system, as compared to the performances achieved by using different time-limited chip waveforms such as the rectangular, the half-sine and the raised-cosine. A possible extension of this paper is to examine the contribution of various chip waveforms presented in the literature, such as the Lanczos chip waveform, to the BER performance of the generalized MC DS-CDMA system. This subject is currently under study.

Acknowledgements

The authors would like to thank the anonymous reviewers for their valuable suggestions and comments. This study is supported by Turkish Scientific and Technical Research Council-TUBITAK (Project Number: EEEAG 107E175).

References

[1] ANJARIA, R., WYRWAS, R. The effect of chip waveform on the performance of CDMA systems in multipath, fading, noisy channels. In *Proceedings of IEEE 42nd Vehicular Technology Conference*. USA, 1992, p. 672 - 675.

[2] DALLAS, P. I., PAVLIDOU, F. N. Innovative chip waveforms in microcellular DS/CDMA packet mobile radio. *IEEE Transactions on Communications,* 1996, vol. 44, no. 11, p. 1413 - 1416.

[3] GERANIOTIS, E. A., PURSLEY, M. B. Performance of coherent direct-sequence spread-spectrum communications over specular multipath-fading channels. *IEEE Transactions on Communications,* 1985, vol. 33, no. 6, p. 502 - 508.

[4] GLANCE, B., GREENSTEIN, L. J. Frequency-selective fading effects in digital mobile radio with diversity combining. *IEEE Transactions on Communications,* 1983, vol. 31, no. 9, p. 1085 to 1094.

[5] HARA, S., PRASAD, R. Overview of multicarrier CDMA. *IEEE Communications Magazine*, 1997, vol. 35, no. 12, p. 126 - 133.

[6] HARA, S., PRASAD, R. Design and performance of multicarrier CDMA system in frequency-selective Rayleigh fading channels. *IEEE Transactions on Vehicular Technology,* 1999, vol. 48, no. 5, p. 1584 - 1595.

[7] KIM, Y. W., KIM, Y. V., KIM J. H. et al. A comparison of system performance using two different chip pulses in multiple-chip-rate DS/CDMA systems. *IEEE Transactions on Communications,* 2001, vol. 49, no. 11, p. 1988 - 1996.

[8] KIM, D. K., HWANG, S. H. Capacity analysis of an uplink synchronized multicarrier DS-CDMA system. *IEEE Communications Letters,* 2002, vol. 6, no. 3, p. 99 - 101.

[9] KOCKAYA, K. Investigation of the variation of optimum subcarrier spacing for generalized MC DS-CDMA system with different chip waveforms. *M.Sc. Thesis, Department of Electrical and Electronics Engineering, Graduate School of Natural and Applied Sciences*, Erciyes University, 2008.

[10] KOCKAYA, K., DEVELI, I. BER performance of generalized multicarrier DS-CDMA system with Blackman chip waveforms over Nakagami-m fading channels (in Turkish). In *Proceedings of IEEE 16th Signal Processing, Communication and Applications Conference*. Didim (Turkey), 2008, CD-ROM.

[11] KOK, B. K., DO, M. A. Effects of spreading chip waveform pulse-shaping on the performance of DS-CDMA indoor radio personal communication systems in a frequency-selective Rician fading channel. In *Proceedings of IEEE International Symposium on Consumer Electronics*. Singapore, 1997, p. 198 - 201.

[12] LANDOLSI, M. A., STARK, W. E. DS-CDMA chip waveform design for minimal interference under bandwidth, phase, and envelope constraints. *IEEE Transactions on Communications,* 1999, vol. 47, no. 11, p. 1737 - 1746.

[13] LEHNERT, J. S. Chip waveform selection in offset-quaternary direct-sequence spread-spectrum multiple access communications. *M.Sc. Thesis, Univ. Illinois*, Urbana, 1981.

[14] MISSER, H. S., WIJFFELS, C. A. F., PRASAD, R. Throughput analysis of CDMA with DPSK modulation and diversity in indoor Rician fading radio channels. *Electronics Letters,* 1991, vol. 27, no. 7, p. 601 - 603.

[15] NAKAGAMI, M. *The m-Distribution–a General Formula of Intensity Distribution of Rapid Fading, Statistical Methods of Radio Wave Propagation.* New York: Pergamon, 1960.

[16] NGUYEN, H. H., SHWEDYK, E. On error probabilities of DS-CDMA systems with arbitrary chip waveforms. *IEEE Communications Letters,* 2001, vol. 5, no. 3, p. 78 - 80.

[17] NGUYEN, H. H. Performance of multicarrier DS-CDMA systems with time-limited chip waveforms. *Canadian Journal on Electrical and Computer Engineering,* 2004, vol. 29, no. 1-2, p. 23 - 29.

[18] OCHSNER, H. Direct-sequence spread-spectrum receiver for communication on frequency-selective fading channels. *IEEE Journal on Selected Areas in Communications,* 1987, vol. 5, no. 2, p. 188 - 193.

[19] PURSLEY, M. B. Performance evaluation for phase-coded spread-spectrum multiple-access communication-Part I: System analysis. *IEEE Transactions on Communications,* 1977, vol. 25, no. 8, p. 795 - 799.

[20] PURSLEY, M. B., ROEFS, H. F. A. Numerical evaluation of correlation parameters for optimal phases of binary shift-register sequences. *IEEE Transactions on Communications,* 1979, vol. 27, no. 10, p. 1597 - 1604.

[21] VANDENDORPE, L. Multitone spread spectrum multiple access communications system in a multipath Rician channel. *IEEE Transactions on Vehicular Technology,* 1995, vol. 44, no. 2, p. 327 to 337.

[22] YANG, L. L., HANZO, L. Performance of generalized multicarrier DS-CDMA over Nakagami-*m* fading channels. *IEEE Transactions on Communications,* 2002, vol. 50, no. 6, p. 956 - 966.

[23] YANG, L. L., HANZO, L. Generalized multicarrier DS-CDMA using various chip waveforms. In *Proceedings of IEEE Wireless Communications and Networking Conference*. USA, 2003, p. 790 to 794.

[24] YANG, L. L., HANZO, L. Multicarrier DS-CDMA: a multiple access scheme for ubiquitous broadband wireless communications. *IEEE Communications Magazine*, 2003, vol. 41, no. 10, p. 116 to 124.

[25] YANG, L. L., HANZO, L. Performance of generalized multicarrier DS-CDMA using various chip waveforms. *IEEE Transactions on Communications,* 2003, vol. 51, no. 5, p. 748 - 752.

About Authors ...

Ibrahim DEVELI was born in Bielefeld, Germany on June 10, 1973. He received the B.S., M.S. and Ph.D. degrees in electronics engineering from Erciyes University, Turkey, in 1995, 1997 and 2003, respectively. From May 2003 to June 2009, he was an Assistant Professor with the Department of Electrical and Electronics Engineering, Erciyes University. Currently, he is an Associate Professor at the same department. He teaches courses in wireless communications and his current research interests are in spread spectrum communications, multiuser communications, wireless networks, radio-over-fiber transmission, radio communication, millimeter waves, multiple access interference rejection in DS-CDMA systems, and applications of neural networks to multiuser communication systems. Dr. Develi is currently serving as an Associate Editor for the *EURASIP Journal on Wireless Communications and Networking*.

Kenan KOCKAYA was born in Sivas, Turkey on September 09, 1979. He received the B.S. degree in electronics and communication engineering from Süleyman Demirel University, Isparta, Turkey, and the M.S. degree in electrical and electronics engineering from Erciyes University, Kayseri, Turkey, in 2001 and 2008, respectively. Currently, he is a lecturer in the department of technical programs, Divriği Vocational High School, Cumhuriyet University. His research interest areas are multicarrier systems, spread spectrum communications and performance evaluation of MC DS-CDMA systems with various chip waveforms.