Jointing UWB Techniques with Multi-Carrier Spread Spectrum Systems in Fading Channels

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Abstract: - The performance analysis of UWB techniques with MC-SS (multicarrier spread spectrum) system working in multipath fading channel is investigated in this paper. The model of the multipath fading is characterized by Nakagami-*m* statistic distribution. We establish and derive the model for MC-CDMA systems working in correlated Nakagami-*m* fading channel. The average BER (bit error rate) is calculated and compared to the special case of the published results. Basically, some studied results from this paper can be implied to approve the system performance for the UWB system combining with MC-CDMA systems in wireless communication systems. Especially, it is worthwhile noting that the fading parameter of the Nakagami-*m* distributed significantly dominated the system performance of the UWB system accompany with MC-SS signaling under fading environments.

Keywords: - UWB, multicarrier spread spectrum, multipath, Nakagami-*m* fading

I. Introduction

The impulse wireless radio system, called as UWB (ultra-wideband) systems, which transmit data without sinusoidal modulating signal instead of sub-nanosecond pulses, have recently raised growing interesting in the development of novel techniques. UWB systems, which joint bandwidth in excess 1 GHz with very low PSDs (power spectral densities) but without inducing significant extra interference to incumbent subscribers, are emerged as a solution for the TG3a (IEEE 802.15a) standard which is to provide a low complexity, low power consumption, low cost and high data rate among WPAN (Wireless Personal Area Networking) devices. Describing specifically, the modulating sub-nanosecond pulses do obtain a 10 dB bandwidth performance which exceeds 500 MHz or on the order of one to several Gigahertz and is traditionally 20% of their center frequency. It is known that, for example, the UWB signals with the large bandwidth can combine appropriate with spreading techniques and provide with a low probability if intercept and detection as well as robustness to jamming. The reasons of mentioned previous is the UWB signals occupy the large bandwidth and mainly account for both the drawback and advantages conjunction with UWB radio systems. For the purpose of minimizing interference to these systems, the operations of UWB system have to be strict and cause some limitations, i. g., transmission range, implementation of power control, and the achievable data rate. However, in order to offset the fact of the limitations, UWB system could be developed to coexist with wideband and narrowband systems that were already allocated for the dedicated frequency spectrum, such as SS-CDMA (spread-spectrum coded-division multiple-access) or DS-CDMA (direct-sequence CDMA) systems. The UWB channels are considered characterized as frequency selective while the waveform of UWB system propagates over fading channel, because of their extremely high bandwidth reported in [1]. Besides, in order to achieve higher data rates with lower power consumption, or to support multiple users, the DS-SS (direct sequence spread spectrum) has been proposed for arrive at this target. There are several researchers has proposed some reports about this issue. In [2] the author Siwiak introduced a new technology about UWB approach with DSC-UWB. The system performance of the direct sequence UWB system over multipath fading environments was evaluated in [3]. The performance of MC-CDMA systems was investigated in the presence of narrowband interference for future UWB communication in [4] by Wang and Milstein. The researchers Win and Scholtz in [5] outlined some attractive features of TH-SS (time hopping spread-spectrum) multiple-access system, and estimated the multiple-access capability for both analog and digital data modulation formats under ideal channel.

In this paper, we aim in analyzing the system performance of combining the multi-carrier spread-spectrum (MC-SS) techniques with the UWB system over the correlated-Nakagami-*m* fading channel. There is not only some closed-form formulas of the BER (bit-error rate) derived, but the numerical results also conduct is. The phenomena of correlation between multipath branches are considered in the system performance. The paper is organized as follows, the system models is presented in the section II, and in section III the analysis of system performance of UWB system with MC-CDMA techniques and the numerical results discussion are illustrated in section IV. A simple conclusion is drawn in section V.

II. System Models

2.1. Transmitter Model

A typical UWB based on TH-PPM (time hopping-pulse position modulation), which is the most popular and suitable modulation technique for UWB systems [1]. The signal of the *k*th user at the output of the transmitter is given as

$$S_{T_x}^{(k)}(t) = \sum_{i=-\infty}^{+\infty} P_{Tx}(t - iT_F - c_i^{(k)}T_h - \delta\alpha_{\lfloor i/N_s \rfloor}^{(k)}) \tag{1}$$

where P_{Tx} is the transmitted pulse waveform, T_F denotes the pulse repetition time and the transmitted pulse waveform P_{Tx} is viewed as a monocycle. Due to the techniques of multiple-access is applied in this report, *k* presents the user number, the time shift $\{c_i^{(k)}\}$ is assigned as a set of time-hopping, thus the $\{c_i^{(k)}T_h\}$ is for the *i*th monocycle in the pulse train, where T_h presents the duration of location time delay bins. The symbol rate, $(1/N_S T_F)$, shown in (1) is applied to determine the number of monocycles that are modulated into binary symbol, δ is the time shift, and the $\alpha^{(k)}$ is the transmitted information of the *k*th user.

2.2. Channel and Receiver Models

Based on the utilization of TH-PPM schemes for the UWB system, the BER of coherent BPSK modulation with AWGN has been calculated in [1], and rewritten as

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E}{\mathbb{N}}\frac{1-\gamma(t)}{2}}\right) \tag{2}$$

where $\gamma(t)$ is defined as the autocorrelation function of received pulse signal and the $E/\mathbb{N}$ represents the SNR (signal-to-noise ratio) of the frame. Specifically speaking, the system BER for evaluating the communication system with BPSK modulation can be expressed as

$$BER = \frac{1}{2} erfc\left(\sqrt{\frac{E}{\mathbb{N}}\frac{T_i}{T_i + T_g}}\right) \tag{3}$$

where $erfc(\cdot)$ represents the complementary error function, T_g is the guard interval, T_i indicates the bit symbol time without guard time. Furthermore, consider that as a channel is with frequency-selective fading, the channel impulse response then is modeled as a filter and can be written as

$$h(t) = \sum_{\ell=0}^{L-1} h_\ell \delta(t - \tau_\ell) \tag{4}$$

where $h_\ell = \alpha_\ell \exp(j\phi_\ell)$, h_ℓ, $\ell = 0, \cdots, L-1$ are mutually uncorrelated. The phase ϕ_ℓ is uniformly distribution over (0, 2 π), and the amplitude $\alpha_\ell = |h_\ell|$ is assumed characterized as Nagakami-*m* distributed, denoted by $\alpha_\ell \sim \mathrm{M}(\alpha_\ell; m_\ell, \Omega_\ell)$ [6], where

$$\mathrm{M}(\upsilon; m, \Omega) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m \upsilon^{2m-1} \exp\left(-\frac{m}{\Omega}\upsilon^2\right) \tag{5}$$

where $\Gamma(\cdot)$ is the Gamma function, $\Omega_\ell = E(|h_\ell|^2)$ denotes the average power of the received signal, and m_ℓ, $\ell = 0, \cdots, L-1$ is the fading parameters, with $m_\ell \geq 1/2$, which represents the fading severity. The smaller values of m_ℓ, the much more fading happens in the channel environments. Moreover, assume that the fading parameters of all taps are identical, i.e., $m_i = m_j$ for $i \neq j$, $i, j = 0, \cdots, L-1$, and exponential MIP (multipath intensity profile), i.e., $\Omega_\ell = \Omega_0 e^{-\ell\delta}$, where Ω_0 is the average power of the first channel path, $\delta \geq 0$ indicates the rate of average power decay, however, $\delta = 0$ corresponding to the condition of constant MIP. The *N*-point $(N \geq L)$ DFT (discrete Fourier transformation) of the channel impulse response at *n*th frequency bin is defined as

$$H_n = \frac{1}{\sqrt{N}} \sum_{\ell=0}^{L-1} h_\ell \exp\left(-j\frac{2\pi n\ell}{N}\right), \quad 0 \leq n \leq N-1. \tag{6}$$

As the approximation of $\beta_n = |H_n|$ is adopted in the system performance analysis, it has been shown that the fading intensity is following

Nagakami-*m* distribution with fading parameter m_f, and the mean power, Ω_f, i.e., $\beta_n \sim \mathrm{M}(\beta_n; m_f, \Omega_f)$, where m_f and Ω_f are given by [6]

$$m_f = \frac{1}{(\frac{1}{m}-1)\frac{d(L,2\delta)}{d^2(L,\delta)}+1}, \qquad (7)$$

$$\Omega_f = \frac{d(L,\delta)}{N}\Omega_0 \qquad (8)$$

, respectively, where $d(L,\delta) = 1 - e^{-L\delta}/1 - e^{-\delta}$, while $\delta = 0$, and then $m_f = L_m/L_m - m + 1$, and $\Omega_f = L\Omega_0/N$. It is worthwhile noting that the accuracy of the approximation becomes better when the number of multipath, *L*, increases. After the model of the channel fading is well modeled and established. The received signal $\gamma(t)$ at the output of the system is able to be expressed as

$$\gamma(t) = \omega(t) + \sqrt{\frac{2E_b}{NT_b}}\sum_{q=-\infty}^{\infty}\sum_{k=0}^{K-1} b_k(q)u_{T_b}(t - qT_b - \tau_k)\, x \\ \times \sum_{n=0}^{N-1}\beta_{k,n}c_{k,n}\cos(2\pi f_n t + \theta_{k,n}) \qquad (9)$$

where $H_{k,n} = \beta_{k,n}e^{j\theta_{k,n}}$ represents the subchannel fading with the attenuation $\beta_{k,n}$, which is defined in (6), and $\theta_{k,n}$ is the phase of the *n*th subcarrier of the *k*th user. The channel impulse response taps, $\{\alpha_{k,\ell}\}_{k=0}^{K-1}$, are assumed i.i.d (identically independently distributed) for different users with the same index ℓ, i.e., $\{\alpha_{k,\ell}\}_{k=0}^{K-1} \sim M(\alpha_{k,\ell}; m, \Omega_\ell)$, and $\{\beta_{k,n}\}_{k=0}^{K-1} \sim M(\beta_{k,n}; m_f, \Omega_f)$, τ_k is the time misalignment of user k with respect to the reference user at the receiver which is i.i.d for different k and uniformly distributed in $[qT_b, (q+1)T_b]$, as well as $\omega(t)$ represents the AWGN having a two-side power spectral density of $N_0/2$.

III. System Performance Analysis

Without loss of generality, when consider the *0*th user as the reference user is operating on each subcarrier with in flat fading channel, which equipped with the channel fading and phase shift variables, i.e., $\beta_{k,n}$ and $\theta_{k,n}$, are constant over one bit duration. The decision variable U_0 of the *0*th data bit of the *0*th user after the coherent demodulation is given by

$$U_{0,MC} = \frac{1}{T_b}\int_0^{T_b}\gamma(t)\sum_{n=0}^{N-1}c_{0,n}g_{0,n}\cos(2\pi f_n t)dt \qquad (10)$$

The weighting factor, $g_{0,n}$, of the *0*th user for an MRC (maximal ratio combining) diversity is employed for detection, i.e., let

$$g_{0,n} = H_{0,n}^* = \beta_{0,n}e^{-j\theta_{0,n}} \qquad (11)$$

Then, by multiplying each subcarrier by the weighting factor $g_{0,n}$, and after despreading the signal of the k th user, the decision variable $U_{0,MC}$ can be expressed as

$$U_{0,MC} = D + J_{MAI} + J_N \qquad (12)$$

where the first tem in previous equation, D, denotes the desired signal term of the referenced user is given by (assuming the case of $b_0(0) = +1$)

$$D = \sqrt{\frac{E_b}{2NT_b}}\sum_{n=0}^{N-1}\beta_{0,n}^2 \qquad (13)$$

, the second term, J_{MAI}, in the (12) represents the MAI (multiple-access interference), and the last term, J_N, is the background noise component. Assuming that the number of multicarriers N is large enough, the chips of the spreading codes and the input data symbol are modeled as random variables, which is conditioned on $\beta_{0,n}$, hence, the term J_{MAI} is able to be well approximated by zero mean Gaussian and with variance expressed as [6]

$$\sigma_{J_{MAI}}^2 = \frac{E_b(K-1)\Omega_f}{4NT_b}\sum_{n=0}^{N-1}\beta_{0,n}^2 \qquad (14)$$

where Ω_f is given as in (8). Utilizing the CLT (central limit theorem), J_N is also approximated by zero mean Gaussian and with variance yields as

$$\sigma_{J_N}^2 = \frac{N_0}{4T_b}\sum_{n=0}^{N-1}\beta_{0,n}^2 \qquad (15)$$

Once the desired value and all the variance of the interference of the referenced user are computed, the instantaneous SINR can then be obtained as

$$\gamma_M = \frac{D^2}{\sigma_{J_{MAI}}^2 + \sigma_{J_N}^2} = \frac{\frac{2}{N}\sum_{n=0}^{N-1}\beta_{0,n}^2}{(K-1)\frac{\Omega_f}{N} + \frac{N_0}{E_b}} \qquad (16)$$

where E_b/N_0 is the SNR per bit. Since $\{h_\ell\}_{\ell=0}^{L-1}$ are mutually uncorrelated for different ℓ, the correlation of H_n and $H_{n'}$ is expressed as

$$\rho_{nn'} = E[H_n H_{n'}^*] = \frac{\Omega_0}{N}\sum_{\ell=0}^{L-1} e^{j2\pi(n'-n)\ell/N} e^{-\ell\delta} = \frac{\Omega_0}{N}\frac{1-e^{-\delta L/N}e^{j2\pi(n'-n)L/N}}{1-e^{-\delta/N}e^{j2\pi(n'-n/N)}} \quad (17)$$

It can be shown that in the case of $\delta = 0$, in order to reach at the case of without correlation, i.e., $\rho_{nn'} = 0$, the relationship

$$n - n' = \frac{cN}{L} \quad (18)$$

has to be satisfied, where nonzero integer $1 \le C \le L-1$. Among all subcarriers, for a fixed sub-carrier *n*, only $L-1$ other subcarriers are uncorrelated to subcarrier *n*. It is well known that if $\sqrt{\mu}$ is Nakagami-*m* distribution, where μ is a random variable and is characterized as Gamma distribution. Thus, the pdf of γ can be denoted as the function of $g(\gamma;m,\Omega)$, i.e.,

$$g(\gamma;m,\Omega) = \left(\frac{m}{\Omega}\right)^m \frac{\gamma^{m-1}}{\Gamma(m)}\exp(-\frac{m}{\Omega}\gamma) \quad (19)$$

By using of the symbol of S_M^C expressing the summation of all the fading components at the system output, i.e., $S_M^C = \sum_{n=0}^{N-1}\beta_{0,n}^2 \big/ N$, since $\{\alpha_{0,\ell}\}_{\ell=0}^{L-1}$ are mutually uncorrelated, the results can be shown as $S_M^C \sim g(S_M^C; m_M^C, \Omega_M^C)$, where

$$m_M^C = \frac{E^2[S_M^C]}{\mathrm{var}[S_M^C]} = \frac{(\sum_{\ell=0}^{L-1} e^{-\delta\ell})^2}{\sum_{\ell=0}^{L-1}\frac{e^{-2\delta\ell}}{m}} = \frac{d^2(L,\delta)}{d(L,2\delta)}m \quad (20)$$

, and

$$\Omega_M^C = \frac{d(L,\delta)}{N}\Omega_0 \quad (21)$$

Following the procedure of obtaining the average system BER for an coherent BPSK signal, the evaluation of BER for MC-CDMA with MRC receiver can be calculated by the formula shown in (21) [7]

$$BER = \int_0^\infty Q\left(\sqrt{\gamma_m}\right) g(x;m,\Omega_f)dx \quad (22)$$

By utilizing of an alternative expression of the Gaussian Q function, i.e.,

$$Q(x) = \frac{1}{\pi}\int_0^{\pi/2}\exp(-\frac{x^2}{2\sin^2\theta})d\theta \quad (23)$$

, and by substituting (16) and (19) into (22), the result of the average system BER of MC-CDMA system with MRC diversity combining UWB signaling can be obtained as

$$BER = \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left(\frac{m}{\Omega_f}\right)^m \times \left(\frac{\frac{1}{\frac{(K-1)d(l,\delta)}{N^2}\Omega_0 + \frac{N_0}{E_b}}\frac{Ti}{Ti+Tg}}{\sin^2\theta} + \frac{m}{\Omega_f}\right)^{-m} d\theta \quad (24)$$

where $d(l,\delta) = \frac{1-\exp(-l*\delta)}{1-\exp(-\delta)}$ (25)

, and $\Omega_f = \frac{1}{N}d(l,\delta)\Omega_0$, when $0 < \delta < 1,\ \Omega_0 = 1$.

IV. Numerical Results Discussions

In this section the system performance is illustrated by implementing with the aid of computer software package. Some of the parameters will be taken into account for the purpose of accuracy validation and comparison, e.g., the number of received resolvable multipath, the user number, the fading parameter, and the subcarrier of the MC-CDMA system. The bit duration is considered identical to that of a frame time. In Fig. 1 the system performance presented in Figure 2 illustrated the effect of the different number of subscribers, k =1, 2, 3, 4, and 5. It is reasonable to note that the less of the users, the superior of the system performance is. This phenomenon is caused by the interference occurs between the subscribers. How is the resolvable multipath, *L*, provides the degradation of the system performance shown in Fig. 3, in which the path number is assigned as 1, 2, and 5. Generally speaking it is well known that the little number of the paths will deteriorate the system performance.

V. Conclusions

We investigate the system performance of the UWB system combines with MC-SS system, in which the MC-CDMA system was proposed for the role of the scenario in the paper. Moreover, the correlated resolvable multipath was characterized as the correlated-Nakagami-*m* fading statistic. Some of the usually parameters are taken into account in the numerical analysis for the purpose of accuracy validation and comparison. The most important thing, worthwhile noting is the fading parameter always dominates the system performance for considering the Nakagami-*m* distributed as the fading model. This fact copes with several results from the past reports.

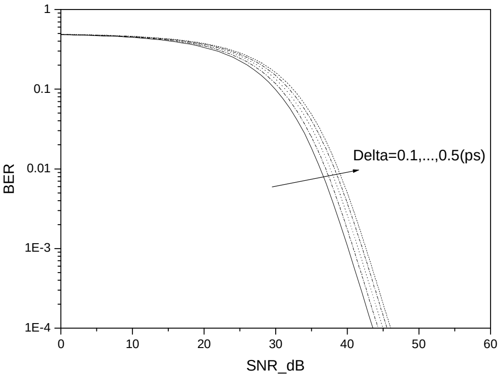

Fig. 1 The plots of BER vs SNR (dB) with different parameters of time shift values δ.

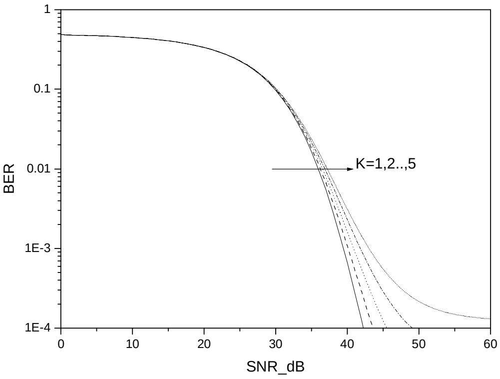

Fig. 2 The plots of BER vs SNR (dB) with different parameters of user number *k*.

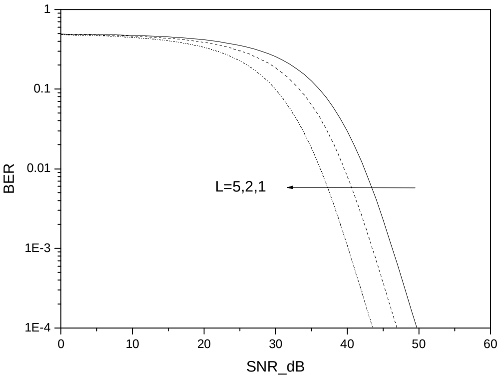

Fig. 3 The plots of BER vs SNR (dB) with different parameters of path number *L*.

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