On the Impact of Exponent Multipath and Branch Correlation on MC-CDMA System in Frequency-Selective Fading Environments

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Abstract—The impact of existence with exponent multipath MIP (multipath intensity profile) for an MC-CDMA (multi-carrier coded-division multiple access) system, which is assumed working over the frequency selective fading environments in this paper. We derived the average BER (bit error rate) formulas for MC-CDMA system with MRC (maximal ratio combining) diversity were with an alternative method for the complementary error function. The consideration included not only the correlated subcarriers and independent subcarriers were addressed in the numerical analysis, but the parameter of user capacity is also analyzed.

Keywords—MC-CDMA systems, exponent MIP, MRC diversity, Nakagami-*m* fading

Ⅰ.Introduction

In order to reduce ISI (inter-symbol interference) effect and overcoming the channel fading in a transmission channel, multi-carrier modulation scheme has been adopted for high speed transmission applications. A number of multi-carrier modulation techniques have been proposed during the pass decade [1]. To support a wide area of services and high data rate by using a variety of techniques capable of achieving the highest possible spectrum efficiency is the main objective for future generations of wideband wireless communication systems. The CDMA (coded-division multiple-access) scheme has been applied as an attractive multiple access technology in both 2G (second-generation) and 3G (third- generation) wireless radio systems. In general, the multicarrier DS systems have already been proposed and can be categorized into two types: a parallel transmission-scheme of narrowband DS waveforms in the frequency domain, and a combination of OFDM (orthogonal frequency division multiplexing) and CDMA [1]. The available frequency spectrum of carrier wave is divided into M equal band of subcarriers in the former systems. These subcarriers are used to carry a narrowband DS waveform and the number of subcarriers is usually much less than the processing gain. In the latter system, each chip modulates a different carrier conveying a narrowband waveform rather than a DS waveform, and the number of carriers should be equal to the processing gain.

On other hand, due to the advantages of spectrum efficient, interference immune, high date rate, and insensitivity to frequency selective channel, etc. Such that multiple access system bases on direct sequence CDMA (coded-division multiple-access) have drawn recent interest in the application of wireless radio systems [1]. Especially, multi-carrier CDMA (MC-CDMA) appears to be a considerable candidate for future mobile radio communication system. The MC-CDMA system based on the spread spectrum techniques. There are a lot of previous researches have been published for investigation about the issues of MC-CDMA system. Besides, the BER (bit error rate) analysis of MC-CDMA based on considering different kinds of assumptions, so far, have been dedicated in numerous previously researches [1, 2, 3]. In [2] the authors analyzed the BER (bit error rate) performance of uplink MC-CDMA system over frequency selective Nakagami-*m* fading with MRC and EGC receptions. The performance evaluation of MC-CDMA over multipath fading channels was studied in [3]. The results presented in [4] are for uplink channel using MRC (maximal ratio combining) with the assumed frequency offsets condition in correlated fading. The performance of MC-CDMA in non-independent Rayleigh fading was studied in [5]. In [6], which by use of the method of CF (characteristic function) and residue theorem to calculate the performance for downlink MC-CDMA system. Both of the envelopes and phases correlation are considered in [7] to evaluate the performance of a MC-CDMA system operates in Rayleigh fading channel. The literature in [8] illustrated the error probability for MC-CDMA systems assumed that the transmission channel is in Nakagami-*m*

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fading, and the postdetection of EGC (equal gain combining) is considered.

In this paper, some expressions of BER performance for uplink MC-CDMA system working in correlated fading channels is evaluated. The general correlation of channels with Nakagami-*m* fading distribution is assumed. An average BER formula closed-form is obtained via the sum of Gamma variates to avoid the difficulty of explicitly obtaining the pdf for the SNR (signal-to-noise ratio) at the MRC output. The results analyze and show that how does the channel correlation affects the system performance of a MC-CDMA systems.

The rest of this paper is organized as follows: section II gives a description of the MC-CDMA system model. The correlated-Nakagami-*m* fading channel model is given in section III. In section IV describes the receiver model of MC-CDMA system. The performance of MC-CDMA operating in uncorrelated and correlated fading cannel is carried out in section V. There are numerically results shown in section VI. Finally, section VII draws briefly conclusions.

II. System Models

We considered an uplink MC-CDMA system model for the study. Assuming that exist *K* simultaneous users are with *N* subcarriers within a signal cell. Any effect of correlation among users is going to be ignored by assuming the number of users is uniformed of distribution. As shown in Fig.1, a signal data symbol is replicated into *N* parallel copies. The signature sequence chip with a spreading code of length *L* is used to BPSK (binary phase shift keying) modulated each of the *N* subscriers of the *k*-th user. Where the subcarrier has frequency F/T_b Hz, and where *F* is an integer number. [1,3]. The technical described above is same as to the performance of OFDM (Orthogonal Frequency Division Multiplexing) on a direct sequence spread-spectrum signal when set $F=1$. The larger values of F, the more transmit bandwidth increase. The transmitted signal the resulting transmitted baseband signal $S_k(t)$ corresponding to the *M* data bit size can be expressed as

$$S_k(t)=\sqrt{\frac{2P}{N}}\sum_{m=0}^{M-1}\sum_{n=0}^{L-1}a_k[n]b_k[m]P_T(t)\,\mathrm{Re}[e^{j\omega_n t}] \qquad (1)$$

where $a_k[n]\in\{-1,1\};b_k[m]\in\{-1,1\}$ the sequencer $a_k[0],...,a_k[L-1]$ and $b_k[0],...,b_k[M-1]$ represent the signature sequence and the data bit of the *k*-th user, respectively. *P* is the power of data bit, *M* denotes the number of data bit, *N* denotes the number of subcarriers, The $P_T(t)$ is defined as an unit amplitude pulse that is non-zero in the interval of $[0,T_b]$, and $\mathrm{Re}[\cdot]$ denotes the real part of a complex number, $\omega_n=2\pi(f_c+nF/T_b)$ is the angular frequency of the *n*-th subcarrier.

III. Channel Model

A frequency-selective channel with $1/T_b \ll BW_c \ll F/T_b$ is addressed in this paper, where BW_c is the coherence bandwidth. This channel model means that each modulated subcarrier does not experience significant dispersion and with transmission bandwidth of $1/T_b$, i.e. $T_b \gg T_d$, where $1/T_d$ is the Doppler shift typically in the range of 0.3~6.1 Hz [1] in the indoor environment, and the amplitude and phase remain constant even the symbol duration T_b. In addition to, the channel of interest has the transfer function of the continuous-time fading channel assumed for the *k*-th user can be represented as

$$H_k[f_c+i\frac{F}{T_b}]=\beta_{k,i}e^{j\theta_{k,i}} \qquad (2)$$

where $\beta_{k,i}$ and $\theta_{k,i}$ are the random amplitude and phase of the channel of the *k*-th user at frequency $f_c+i(F/T_b)$. In order to follow the real world case, the random amplitude, $\beta_{k,i}$ are assumed to be a set of *N* correlated not necessarily identically distributed in one of our scenarios.

The equal fading severities are considered for all of the channels, namely $m_\ell=m,\ \ell=1,\dots,L$. The pdf of the fading amplitude for the *k*-th user *with* *i*-th channel, $\beta_{k,\ell}$, are assumed as r.v. (random variable) with the Nakagami-*m* distribution, and given as [10]

$$P(\beta)=\frac{2\beta^{2m-1}}{\Gamma(m)}\cdot(\frac{m}{\Omega})^m\cdot exp(-\frac{m\beta^2}{\Omega}),\quad \beta\ge 0 \qquad (3)$$

where $\Gamma(\cdot)$ is the gamma function defined by $\Gamma(x)=\int_0^\infty t^{x-1}e^{-t}dt$, $\Omega=E[\beta^2]$ denoting expectation, the parameter *m* of the amplitude distribution characterizes the severity of the fading, and it is defined as

$$m=\frac{\Omega^2}{E[(\beta^2-\Omega)^2]}\ge 0.5 \qquad (4)$$

It is well known that $m=0.5$ (one-sided Gaussian fading) corresponds to worst case fading condition, $m=1$ and $m=\infty$ correspond to Rayleigh fading (purely diffusive scattering) and the non-fading condition, respectively. As what follows, we consider these two cases.

Firstly, if the propagation channels are assumed as i.i.d (identically independent distributed), then by use of the variable changing, the variable γ is assigned as the fading power of the channel, and let $\gamma = \beta^2$, then the pdf of γ is given follows as a gamma distribution, can be obtained by the processing of random stochastic as

$$P_r(r) = \frac{r^{m-1} e^{-r/\Omega}}{\Gamma(m)\Omega^m} \quad (5)$$

Let $[\gamma_\ell],\ \ell = 0,\ldots,L-1$ be a set of N correlated identically distributed, and all the figure parameters and the average power are assumed equivalent, that is, $m_i = m_j = m$, and $\Omega_i = \Omega_j = \Omega$, where $i \neq j,$ for $i, j = 0,\ldots,L-1$. The power at the output of the MRC is a function of the sum of the squares of signal strengths, and is given as $R = \sum_{\ell=0}^{L-1}\gamma_\ell$. Hence following the results extended from the [9] by M. S. Alouini, A. Abdi, and M. Kavehthe [7]. The pdf of $R = \sum_{\ell=0}^{L-1}\gamma_\ell$ can be expressed as

$$P_R(r) = \prod_{\ell=0}^{L-1}(\frac{\lambda_1}{\lambda_\ell})\sum_{q=0}^{\infty}\frac{\mu_q \gamma^{mL+q-1} e^{-\gamma/\lambda_1}}{\lambda_1^{mL+q}\Gamma(mL+q)} \quad (6)$$

where the coefficients δ_q can be obtained recursively by the following formula

$$\begin{cases} \delta_0 = 1 \\ \delta_{q+1} = \dfrac{m}{q+1}\displaystyle\sum_{\ell=1}^{q+1}\left[\sum_{j=1}^{L}\left(1-\frac{\lambda_1}{\lambda_j}\right)^{\ell}\right]\delta_{q+1-\ell} \end{cases}, \quad q = 0,\ 1,\ 2,.... \quad (7)$$

where $\lambda_1 = min\{\lambda_\ell\}$, and $\lambda_\ell,\ \ell = 0,\ldots,L-1$ are the eigenvalues of the matrix $\underline{Z} = \underline{X}\underline{Y}$, where $\underline{X}$ is the $L \times L$ diagonal matrix with the entries of average power $\Omega_i,\ i = 0,\ldots,L-1$, when the subcarrier paths are correlated, the entries of Ω_i can be obtained by taking the minimum value of $\Omega_\ell = \gamma_\ell / m_\ell$. The matrix $\underline{Y}$ is the $L \times L$ positive definite matrix defined by

$$\underline{Y} = \begin{bmatrix} 1 & \rho_{01}^{1/2} & \cdots & \rho_{0(L-1)}^{1/2} \\ \rho_{10}^{1/2} & 1 & \cdots & \rho_{1(L-1)}^{1/2} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{(L-1)1}^{1/2} & \cdots & \cdots & 1 \end{bmatrix}_{L\times L} \quad (8)$$

where ρ_{lm} denotes the correlation coefficient between γ_ℓ and γ_m , $\ell \neq m$, $\ell,\ m = 0,1,\ldots,L-1$, and $\rho_{\ell m}$ can be expressed as

$$\rho_{\ell m} = \frac{Cov(\gamma_\ell,\ \gamma_m)}{[Var(\gamma_\ell)\cdot Var(\gamma_m)]^{1/2}} = \rho_{m\ell},\ 0 \le \rho_{m\ell} \le 1 \quad (9)$$

where $Var(\cdot)$ and $Cov(\cdot)$ are the variance and the covariance operators, respectively.

IV. MC-CDMA Receiver Model

A slowly varying fading channel is considered in this paper, that is, the channel parameters are unchanged over one bit duration T_b . For K active transmitters, the received signal $r(t)$ can be written as

$$r(t) = \sqrt{\frac{2P}{N}}\sum_{k=0}^{K-1}\sum_{m=0}^{M-1}\sum_{n=0}^{L-1}\beta_{m,n}a_k[n]b_k[m] \times P_T(t - mT_b - \tau_k)cos(\omega_n t + \theta_{m,n}) + n(t) \quad (10)$$

where $n(t)$ is the AWGN (additive white Gaussian noise) with a double-sided power spectral density of $N_0/2$. We can evaluate, the local-mean power, $P_{k,n}$, which is given as

$$P_{k,n} = E[\beta_{k,n}^2]\frac{\rho}{N} \quad (11)$$

The total-mean power of the k-th user is defined to be $P_k = N \cdot P_{k,n}$, if the local-mean power of the subcarriers is assumed equal. Assuming that acquisition has been accomplished for the user of interesting ($k = 0$). In addition, the system operates synchronously with each user having the same clock is assumed, and the MRC diversity reception technique is considered in this paper. For the reason of using MRC, it is assumed that perfect phase correction can be obtained, i.e., $\hat{\theta}_{0,i} = \theta_{0i}$. Demodulating each subcarrier includes applying a phase correction, $\hat{\theta}_{0,i}$, and a gain correction factor $d_{0,n} = \beta_{0,n} \cdot a_0[n]$ is multiplied by the n-th subcarrier signal as shown in Fig. 2.

All the signals at the output of the correlators are combined with the MRC diversity scheme, and the results can be written as

$$\gamma = \sum_{\ell=0}^{L-1}\gamma_\ell \quad (12)$$

where γ_ℓ is the SNR at every branch. The branch number is assumed that equal to the subcarrier number, that is , L=N, in this paper. With all the assumptions for MRC combining, the decision variable D_0 of the m-th data bit reference user, and given by

$$D_0 = \frac{1}{T_b}\int_{mT_b}^{(m+1)T_b} r(t)\cdot\sum_{\ell=0}^{L-1}a_0[\ell]\cdot d_{0,\ell}\cdot \mathrm{Re}[e^{(\omega_\ell t+\theta_{0,0})}]dt = \mathrm{U_S} + I_{MAI} + \eta_0 \quad (13)$$

where $r(t)$ is the received signal shown in (10), $d_{0,i}$ is the gain factor for MRC diversity. The first term in second equivalent last equation represents the desired signal, can be expressed as

$$U_S = \sqrt{\frac{P}{2N}}\sum_{\ell=0}^{L-1}\beta_{0,\ell}^2 \cdot a_0[m] \quad (14)$$

, and the second term, I_{MAI} , is the MAI (multiple access interference) contributed from all other users which can be written as

$$I_{MAI} = \sqrt{\frac{P}{2N}}\cdot\sum_{k=1}^{K-1}\sum_{n=0}^{L-1}a_k[m]\cdot b_k[m]\cdot a_0[m]\cdot\beta_{k,m}\cdot\beta_{0,n}\cdot cos(\theta_{k,n}^{'}) \quad (15)$$

where $\theta_{k,n}^{'} = \theta_{0,n} - \theta_{k,n}$ and $\theta_{k,n}$ are i.i.d uniformly distributed over $[0, 2\pi)$, η_0 is the AWGN term.

V. Performance Analysis

A generalized average BER for the *k*-th user using coherent BPSK (binary phase shift keying) modulation scheme is derived in this section. For coherent demodulation in the presence of AWGN, the probability of error conditioned on the instantaneously SNR can be expressed as [11]

$$P_e(s) = 0.5Q\left(\sqrt{SNR}\right) \tag{16}$$

where the Gaussian Q is defined by $Q(x) = \int_x^\infty 1/2\pi\, e^{\left(-t^2/2\right)} dt$, and the received instantaneously SNR , which conditioned on $\gamma_{0,n} = \beta_{0,n}^2$, at output of the receiver is calculated as

$$\frac{U_s^2}{\sigma_T^2} = \frac{\frac{P}{2N}\sum_{n=0}^{N-1}\beta_{0,n}^2}{\sigma_{I_{MAI}}^2 + \sigma_\eta^2} \tag{17}$$

where $\sigma_{I_{MAI}}^2$ is the variance of I_{MAI} , which is shown in (14). In the limiting case of large *N* and by the methods of central limit theory (CLT), the MAI can be approximated by a Gaussian r.v. with zero mean and the variance, $\sigma_{I_{MAI}}^2$, can be determined as

$$\sigma_{I_{MAI}}^2 = E[I_{MAI}^2] = \frac{P}{2}(k-1)\cdot E[\beta_{k,n}^2]\cdot E[cos^2\overline{\theta}_{k,n}] = \frac{P}{4}(k-1)\Omega_{k,n} \tag{18}$$

where $\Omega_{k,n} = E[\beta_{k,n}^2]$, $E[cos^2\overline{\theta}_{k,n}] = 1/2$. On the other hand, the background noise term η_0 is a random variable with zero mean and the variance can be calculated as

$$\sigma_{\eta_0}^2 = E[{\eta_0}^2] = \frac{NN_0}{4T_b} \tag{19}$$

By substituting (17) and (18) into (16), which can be obtained as

$$\frac{U_s^2}{\sigma_T^2} = \frac{\frac{1}{2N}\cdot S}{\sigma_0} \tag{20}$$

where $S = \sum_{n=0}^{N-1}\beta_{0,n}^2 / \Omega_{k,n}$ (21)

, and $\sigma_0 = \frac{NN_0}{4PT_b\Omega_{k,n}} + \frac{k-1}{4} = \frac{N}{4\gamma_0} + \frac{k-1}{4}$ (22)

where $\gamma_0 = PT_b\Omega_{k,n}/N_0 = E_b\Omega_{k,n}/N_0$ is the *SNR* of each bit, and $E_b = PT_b$ denotes the bit energy.

It is known that the decision variable in (13) has a Gaussian distribution conditioned on the uncorrelated and correlated channel power $\beta_{0,n}^2$, respectively, and the AWGN, η_0 , and the MAI, η_{MAI} are mutually independent. Therefore, the probability of error by means of BPSK modulation conditioned on the instantaneously SNR has been given in (16) can be evaluated as follows.

If the conditions of correlated channels are considered as the impact factors for MC-CDMA system, then the average bit error probability for the case can be calculated by averaging (6) and (16), and yield as

$$\begin{aligned}
P_e &= E\left[P_e\left(\beta_{0\ell}\right)\right] = \int_0^\infty P_e\left(\beta_{0\ell}\right) P_{\gamma_M}\left(\gamma_M\right) d\beta_{0\ell} \\
&= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\int_0^\infty \prod_{\ell=1}^{L}\left(\frac{\lambda_1}{\lambda_\ell}\right)^\alpha \sum_{k=0}^{\infty}\frac{\delta_k U(y)}{\lambda_1^{\alpha L+k}\Gamma(\alpha L+k)} y^{L\alpha+k-1}\exp\left(-\frac{B\left(1+\frac{1}{\lambda_1}\right)}{2\sin^2\theta}y\right) \\
&= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\prod_{\ell=1}^{L}\left(\frac{\lambda_1}{\lambda_\ell}\right)^\alpha \sum_{k=0}^{\infty}\frac{\delta_k U(y)}{\lambda_1^{\alpha L+k}\Gamma(\alpha L+k)} d\theta\left[\int_0^\infty y^{L\alpha+k-1}\exp\left(-\frac{B\left(1+\frac{1}{\lambda_1}\right)}{2\sin^2\theta}y\right)\right]
\end{aligned} \tag{23}$$

where $B = \left[(k-1)d(L,S)/N^2\right]\cdot\Omega_f + N_0/E_b$ .Next, by using of the integral equivalent formula $\int_0^\infty e^{-\mu\gamma}\gamma^{m-1}d\gamma = 1/\mu^m\,\Gamma(m)$. The average BER can be simplified and expressed as

$$\begin{aligned}
P_e &= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\prod_{\ell=1}^{L}\left(\frac{\lambda_1}{\lambda_i}\right)^m \sum_{\upsilon=0}^{\infty}\left[1+\frac{1}{\sin^2\theta}\left(\frac{K-1}{N}+\frac{1}{\left(\frac{E_b}{N_o}\right)\Omega_f}\right)^{-1}\right]^{-(mL+v)} \delta_\upsilon d\theta \\
\delta_{\upsilon+1} &= \frac{m}{\upsilon+1}\sum_{\ell=0}^{\upsilon+1}\left(\sum_{j=1}^{N}\left(1-\frac{\lambda_1}{\lambda_j}\right)^\ell\right)\delta_{\upsilon+1-\ell}, \upsilon = 0,1,2,....
\end{aligned} \tag{24}$$

where δ_υ is given in (7), λ_1 and σ_0 are shown in (6) and (22), respectively, the symbol ${}_2F_1(\cdot,\cdot;\cdot;\cdot)$ denotes the confluent hyper geometric function [13], and $\Omega_f = \left[d(L,\xi)/N\right]\Omega_0$, which represent that the exponential MIP (multipath intensity profile) is adopted in this derivation, and the $d(L,\xi) = 1-e^{-L\xi}/1-e^{-\xi}$.

VI. Numerical Results

Some of the numerical results for validation of the derived formulas are shown in this section. The system performance BER versus d/λ of each bit of MC-CDMA system working in fading channels are shown in Fig. 3, in which the user number is set *K=10*, the fading parameter is *m=2* and the intensity decay and the SNR of each bit are set $\xi = 0.5$ and *SNR=15dB*, respectively. It is clearly that the much higher value of subcarrier number *N*, the much better for the system performance is. This is the reason that the higher value of d/λ represents the less of correlation between branches. There is another point definitely to say that the system performance will become superior if the branch number is increase gradually. In addition, the system performance evaluated the results of

BER versus SNR is shown in Fig. 4, in which the system parameters are set as, $K=10$, $m=2$, $d/\lambda=0.7$, and the intensity decay values $\xi=0.1$, 0.5, and 0.9. From the results shown in Fig. 4, it is obviously to declare that the branch number do same as the affect similar to the results shown in Fig. 3. However, the system performance is still major decided by the parameter of subcarrier number. From the other view point of the system performance is shown in Fig. 5 where the different fading parameters with $m=2$, and $m=3$ are presented. The results illustrated in Fig. 5 clearly said that the determination of the base station is one of the most important factors which will turn the system performance of the MC-CDMA system to “RIGHT” side. In order to prove the accuracy of our derived formulas mentioned above, in Fig. 6 the user capacity (K) versus BER is also presented. It is reasonable to describe that the system performance become degraded after the number of active user increased. This fact prove validates the accuracy of the investigation in this paper.

VII. Conclusion

In this paper the SNR and the user number versus system performance error rate for MC-CDMA operating in correlated Nakagami-*m* fading channels has evaluated. The system parameters with the subcarrier number, correlation coefficients, the branch number, and the exponential MIP are considered for determination the system performance of an MC-CDMA system. The results explicit illustrated that the phenomena of channel correlation and the multipath fading do dominate the performance of MC-CDMA communication systems. However, the most important factors should be the fading parameter of the fading model, and the subcarrier number. Hence it is worthy not only to pay much attention in the consideration of correlation coefficient for channel fading while designing the MC-CDMA systems, but the chosen of subcarrier number and the environment of the base station are important..

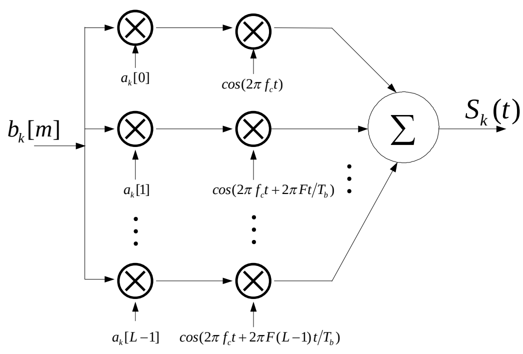

Fig. 1 The transmitter model of the MC-CDMA system

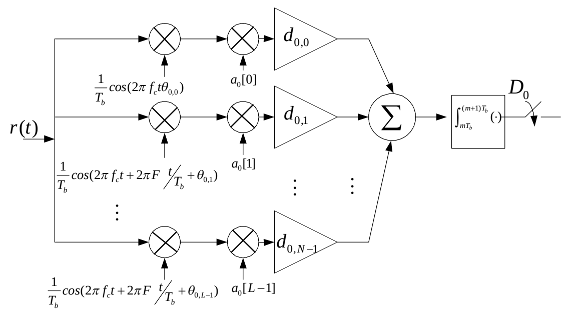

Fig. 2 The receiver model of the MC-CDMA system

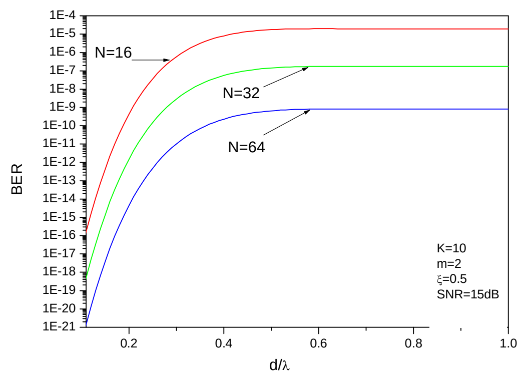

Fig. 3 d/λ vs BER with different N values

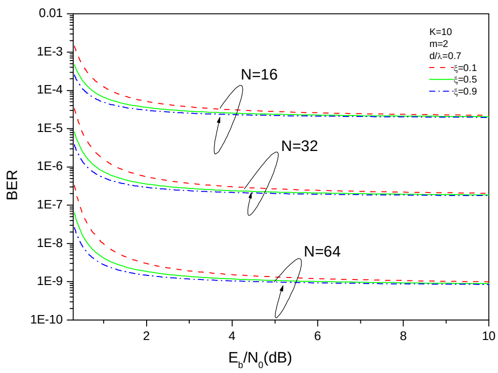

Fig. 4 SNR vs BER with different subcarrier number, *N*, MIP values, and $m = 2$

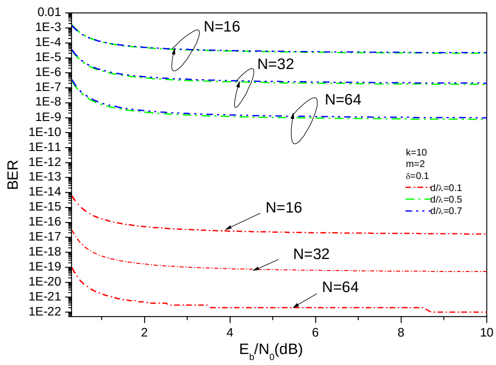

Fig. 5 SNR vs BER with different subcarrier number, *N*, MIP values, and $m = 3$

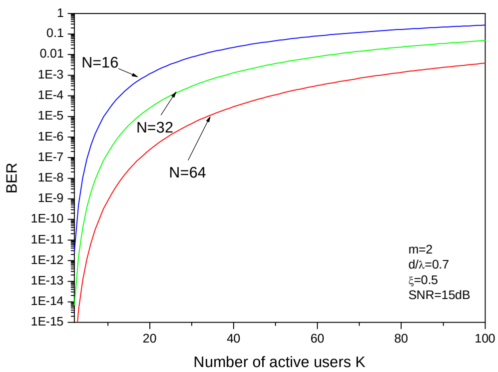

Fig. 6 User capacity, *K*, vs BER

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