Derivation of New Expression of SNIR for Multi Code Multi Carrier CDMA Systems

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Abstract. This paper analyze a new process of transmission combining multiple access technique, CDMA, to multi code and multi carrier techniques, denoted as Multi Code Multi Carrier CDMA or MC-MC-CDMA. This method, very advantageous, seems to be very attractive for fourth generation (4G) wireless system. Its potential is then shown in the present paper, by analyzing and comparing the performance of the system with those of Multi Code CDMA and MC-CDMA systems. Results indicate that this system outperforms both the two other systems.

Keywords: CDMA, Multi Code Multi Carrier CDMA, SNIR, interferences.

1 Introduction

The progress in wireless communication entails a demand for higher data rates and good spectral efficiency. Future generation systems will have to accommodate with these requirements. So, a new system denoted MC-MC-CDMA have been suggested based on the combination of MC-CDMA and Multi Code CDMA. There has been came research in trying to combine the advantages of both systems to get a more powerful system; MC-CDMA is attracted because of its higher capacity and its powerful method of combating channel fading [1],[2],[3],[4] and using Multi Code-CDMA can provide multi-rate services [5],[6],[7].

The MC-MC-CDMA were introduced by [8]. In these systems a high data rate stream is split into a number of parallel low rate streams and then the low rate streams are spread by different sequences and added together. The resulting data is then split into a number of parallel low rate streams and each sub stream modulates a different subcarrier before transmission. In [9], an M-ary symbol selects one of M code sequences for transmission. Each chip of the code sequence is copied onto P branches and for the user-specific sequence it is then multiplied with the corresponding branch i.e. the p^{th} chip of the user-specific sequence is multiplied with the p^{th} branch of the copier. Each of these branches then modulates one of the P orthogonal subcarriers and the results are summed.

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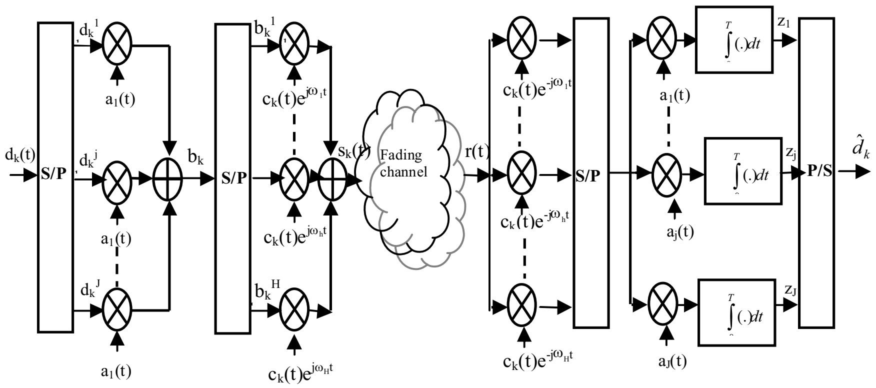

Fig. 1. Transmitter/Receiver system model for MC-MC-CDMA

In this article, the analytical framework of MC-MC-CDMA system described in [8] is employed when we derived the expression of Signal-to-Noise plus Interferences ratio (SNIR) to evaluate the performance of the system. The results show that our system is very effective to eliminate, simultaneously, the effects of multipath interference, multi-carrier, multi-user and the interference between symbols.

2 System Model

The transmitter and receiver are shown in Fig. 1. At the transmitter side, the data bit stream of the kth user $d_k(t) = d_k^I(t) - jd_k^Q(t)$, where $d_k^I(t)$ and $d_k^Q(t)$ are the inphase and quadrature component, respectively, is serial-to-parallel (S/P) converted into J substreams which is coded by an orthogonal signal $a_j(t)$.The resulting signal $b_k(t)$, called superstream, is S/P converted again, spread by $c_k(t)$ and modulated with H orthogonal carriers.The bit stream, with duration T is given by [8]

$$d_k(t) = \sum_i d_k^i \prod_{\frac{T}{HJ}} (t - i\frac{T}{HJ}) . \tag{1}$$

where d_k^i is ith value of the kth bit stream.

The code set a_j for the jth substream is given by

$$a_j(t) = \sum_{i=0}^{N_a-1} a_j^i \prod_{T_a} (t - iT_a) , \ T_a = \frac{T}{H.N_a} . \tag{2}$$

where T_a is the chip duration of the code, N_a is its length and a_j^i is the ith value of the code $a_j \in \{\pm 1\}$.

The superstream $b_k(t)$ with duration $\frac{T}{H}$ is

$$b_k(t) = \sum_{j=1}^{J} a_j(t) d_{kj}(t) . \tag{3}$$

After S/P conversion, the superstreams are spreading by the pseuso-random Noise (PN) sequence, $c_k(t)$, which is defined

$$c_k(t) = \sum_{i=0}^{N_c-1} c_k^i \Pi_{T_c}(t - iT_c) , \ T_c = \frac{T}{N_c} . \tag{4}$$

c_k^i is the ith bit value of the PN code and N_c is its length. Notice that the spreading code on all the subcarriers is the same for one particular user.

The transmitting signal of the kth user can be expressed as

$$s_k(t) = \sum_{h=1}^{H} \sqrt{2P_k} \, \mathrm{Re}[b_k(t) c_k(t) e^{j\omega_h t}] . \tag{5}$$

where P_k is the power of user k distributed among the carriers; if we assume perfect power control, then all users have the same power $P_1=P_2 =\ldots= P_k=P$. ω_h is the angular carrier frequency.

The channel is considered as conventional multipath channel with equivalent transfer function, h(t) given by

$$h(t) = \sum_{l=0}^{L-1} A_{kl} \, e^{j\phi_{kl}} \delta(t - \tau_{kl}) \ . \tag{6}$$

where L is the number of propagation path ; A_{kl} is the path gain of lth path of the kth user; τ_{kl} is the path time delay uniformly distributed over [0, T] ; Φ_{kl} is the l phase uniformly distributed over [0, 2п]. It is assumed that the channel path gain A_{kl} has a Nakagami distribution.

The received signal, r(t), for all K users is given by

$$r(t) = \sqrt{2P} \sum_{k=1}^{K} \sum_{h=1}^{H} \sum_{j=1}^{J} \sum_{l=1}^{L} \left\{ A_{kl} a_j(t-\tau_{kl}) c_k(t-\tau_{kl}) \times \mathrm{Re}[d_{kjh}(t-\tau_{kl}) e^{j(\omega_h(t-\tau_{kl})+\phi_{kl})}] \right\} + n(t). \tag{7}$$

where d_{kjh} is the data symbol of jth substream of hth superstream and n(t) is the additive white gaussien noise (AWGN).

At the receiver part, the received signal is first demodulated by locally generated carrier, despread by the PN sequence and then P/S converted; his output is then despread again by each orthogonal code for multicode component in order to recover substream before correlation. Finally, the substreams are recovered from the correlated data.

For convenience and yet no loss of generality, we assume that the signal for the first user, first carrier, first orthogonal code via the first path is considered as the reference. The signal received [8] can be written as

$$\begin{aligned}
r(t) = \sqrt{2P}\Big\{&A_{11}a_1(t)c_1(t)\times[d^I_{111}(t)\cos(\omega_1 t)+d^Q_{111}\sin(\omega_1(t)]+\sum_{l=2}^{L}A_{1l}a_1(t-\tau_{1l})c_1(t-\tau_{1l}) \\
&\times[d^I_{111}(t-\tau_{1l})\cos(\omega_1(t-\tau_{1l})+\phi_{1l})+d^Q_{111}(t-\tau_{1l})\sin(\omega_1(t-\tau_{1l})+\phi_{1l})] \\
&+\sum_{j=2}^{J}\sum_{l=1}^{L}A_{1l}a_j(t-\tau_{1l})c_1(t-\tau_{1l})[d^I_{1j1}(t-\tau_{1l})\cos(\omega_1(t-\tau_{1l})+\phi_{1l}) \\
&+d^Q_{1j1}(t-\tau_{1l})\sin(\omega_1(t-\tau_{1l})+\phi_{1l})]+\sum_{h=2}^{H}\sum_{j=1}^{J}\sum_{l=1}^{L}A_{1l}a_j(t-\tau_{1l})c_1(t-\tau_{1l}) \\
&\times[d^I_{1jh}(t-\tau_{1l})\cos(\omega_h(t-\tau_{1l})+\phi_{1l})+d^Q_{1jh}(t-\tau_{1l})\sin(\omega_h(t-\tau_{1l})+\phi_{1l})] \\
&+\sum_{k=2}^{K}\sum_{h=1}^{H}\sum_{j=1}^{J}\sum_{l=1}^{L}A_{kl}a_j(t-\tau_{kl})c_k(t-\tau_{kl})[d^I_{kjh}(t-\tau_{kl})\cos(\omega_h(t-\tau_{kl})+\phi_{kl}) \\
&+d^Q_{kh}(t-\tau_{kl})\sin(\omega_h(t-\tau_{kl})+\phi_{kl})]\Big\} \\
&+n(t).
\end{aligned} \tag{8}$$

Thus, r(t) can be written according six components as follows

$$r(t)=r_{DS}(t)+r_{MPI}(t)+r_{ISSI}(t)+r_{ICI}(t)+r_{MUI}(t)+n(t). \tag{9}$$

Where $r_{DS}(t)$ is the desired signal, corresponding k=h=j=l=1;

$r_{MPI}(t)$ is the MultiPath Interferences caused by the propagation of the desired signal, k=h=j=1; via all path except the first path.

$r_{ISSI}(t)$ is the Inter SubStream Interferences caused by other substream except the first substream, j=1.

r_{ICI} (t) is the Inter Carriers Interferences caused by all other carriers other than the desired, h=1 for the first user.

$r_{MUI}(t)$ is the MultiUser Interferences, caused by all other users except the first user, k=1.

Assuming synchronous detection ($\tau_{11}=\phi_{11}=0$); the output for the correlator for k=h=j=l=1 is given by

$$z_1(t)=\int_0^T r(t)a_1(t)c_1(t)[\cos(\omega_1 t)-j\sin(\omega_1 t)]\,dt \tag{10}$$

By substiting (8) to (10), we obtained

$$z_{DS}(t)=\sqrt{\frac{P}{2}}TA_{11}[d^I_{111}(t)-jd^Q_{111}(t)] \tag{11}$$

$$z_{MPI}(t)=\sqrt{\frac{P}{2}}\sum_{l=2}^{L}A_{1l}\int_0^T a_1(t-\tau_{1l})a_1(t)c_1(t-\tau_{1l})c_1(t)\times\{d_{111}^I(t-\tau_{1l})$$
$$\cos(\theta_{1l})+d_{111}^Q(t-\tau_{1l})\sin(\theta_{1l})+jd_{111}^I(t-\tau_{1l})\sin(\theta_{1l})-jd_{111}^Q(t-\tau_{1l})\cos(\theta_{1l})\}dt. \quad (12)$$

$$z_{ISSI}(t)=\sqrt{\frac{P}{2}}\sum_{j=2}^{J}\sum_{l=1}^{L}A_{1l}\int_0^T a_j(t-\tau_{1l})a_1(t)c_1(t-\tau_{1l})c_1(t)$$
$$\times\{d_{111}^I(t-\tau_{1l})\cos(\theta_{1l})+d_{111}^Q(t-\tau_{1l})\sin(\theta_{1l})+jd_{111}^I(t-\tau_{1l})\sin(\theta_{1l})-jd_{111}^Q(t-\tau_{1l})\cos(\theta_{1l})\}dt. \quad (13)$$

$$z_{ICI}(t)=\sqrt{\frac{P}{2}}\sum_{h=2}^{H}\sum_{j=1}^{J}\sum_{l=1}^{L}A_{1l}\int_0^T a_j(t-\tau_{1l})a_1(t)c_1(t-\tau_{1l})c_1(t)$$
$$\times\{\cos(\theta_{1l})[d_{1jh}^I(t-\tau_{1l})\cos(\omega_h-\omega_1)t+d_{1jh}^Q(t-\tau_{1l})\sin(\omega_h-\omega_1)t]$$
$$+\sin(\theta_{1l})[d_{1jh}^Q(t-\tau_{1l})\cos(\omega_h-\omega_1)t-d_{1jh}^I(t-\tau_{1l})\sin(\omega_h-\omega_1)t]$$
$$+j\cos(\theta_{1l})[d_{1jh}^Q(t-\tau_{1l})\cos(\omega_h-\omega_1)t-d_{1jh}^I(t-\tau_{1l})\sin(\omega_h-\omega_1)t]$$
$$+j\sin(\theta_{1l})[d_{1jh}^I(t-\tau_{1l})\cos(\omega_h-\omega_1)t+d_{1jh}^Q(t-\tau_{1l})\sin(\omega_h-\omega_1)t]\}dt. \quad (14)$$

$$z_{MUI}(t)=\sqrt{\frac{P}{2}}\sum_{k=2}^{K}\sum_{h=1}^{H}\sum_{j=1}^{J}\sum_{l=1}^{L}A_{kl}\int_0^T a_j(t-\tau_{kl})a_1(t)c_k(t-\tau_{kl})c_1(t)$$
$$\times\{\cos(\theta_{kl})[d_{kjh}^I(t-\tau_{kl})\cos(\omega_h-\omega_1)t+d_{kjh}^Q(t-\tau_{kl})\sin(\omega_h-\omega_1)t]$$
$$+\sin(\theta_{kl})[d_{kjh}^Q(t-\tau_{kl})\cos(\omega_h-\omega_1)t-d_{kjh}^I(t-\tau_{kl})\sin(\omega_h-\omega_1)t]$$
$$+j\cos(\theta_{kl})[d_{kjh}^Q(t-\tau_{kl})\cos(\omega_h-\omega_1)t-d_{kjh}^I(t-\tau_{kl})\sin(\omega_h-\omega_1)t]$$
$$+j\sin(\theta_{kl})[d_{kjh}^I(t-\tau_{kl})\cos(\omega_h-\omega_1)t+d_{kjh}^Q(t-\tau_{kl})\sin(\omega_h-\omega_1)t]\}dt. \quad (15)$$

$$z_n(t)=\int_0^T n(t)a_1(t)c_1(t)[\cos(\omega_1 t)-j\sin(\omega_1 t)]dt. \quad (16)$$

To simplify the expressions (12) to (16), we assume BPSK modulation and we define the functions

$$G_{jv,hu}^{k}(xy)=\sum_{l=0}^{L}A_{kl}g^{y}(\theta_{kl})R_{jv,hu}^{x}(\tau_{kl})$$
$$\hat{G}_{jv,hu}^{k}(xy)=\sum_{l=0}^{L}A_{kl}g^{y}(\theta_{kl})\hat{R}_{jv,hu}^{x}(\tau_{kl}) \quad (17)$$

$R_{jv,hu}^{x}(\tau_{kl})$ and $\hat{R}_{jv,hu}^{x}(\tau_{kl})$ are correlation function where *j*, *v* are the jth and vth multicode, and h, u are the hth and uth frequency, respectively.
x can be sinus or cosinus function of correlation function ; y can be sinus or cosinus function of function g having phase θ_{kl}.

The interferences component can be rewritten as

$$z_{MPI}(t)=\sqrt{\frac{P}{2}}[G_{11,11}^{\prime 1}(cc)+\hat{G}_{11,11}^{\prime 1}(cc)] \quad (18)$$

G' and $\hat{G}'$ are same expressions with G and $\hat{G}$ but with path from 2 to L.

$$z_{ISSI}(t)=\sqrt{\frac{P}{2}}\sum_{j=2}^{J}[G^1_{jl,11}(cc)+\hat{G}^1_{jl,11}(cc)] \tag{19}$$

$$z_{ICI}(t)=\sqrt{\frac{P}{2}}\sum_{h=2}^{H}\sum_{j=1}^{J}[G^1_{jl,hl}(cc)+\hat{G}^1_{jl,hl}(cc)]-\sqrt{\frac{P}{2}}\sum_{h=2}^{H}\sum_{j=1}^{J}[G^1_{jl,hl}(ss)+\hat{G}^1_{jl,hl}(ss)] \tag{20}$$

$$z_{MUI}(t)=\sqrt{\frac{P}{2}}\sum_{k=2}^{K}\sum_{h=1}^{H}\sum_{j=1}^{J}[G^k_{jl,hl}(cc)+\hat{G}^k_{jl,hl}(cc)]-\sqrt{\frac{P}{2}}\sum_{k=2}^{K}\sum_{h=1}^{H}\sum_{j=1}^{J}[G^k_{jl,hl}(ss)+\hat{G}^k_{jl,hl}(ss)] \tag{21}$$

3 Performance Analysis

To evaluate the performance of the system, we calculate the Signal-to-Noise plus Interferences ratio (SNIR), which is the ratio of signal power to noise plus interference variance; thus, we need to find variance of all the interferences and noise terms, then we assume that all terms are zero means, statistically independent random variables.

The signal power is

$$S=(z_{DS})^2=\frac{P}{2}(A_{11})^2T^2. \tag{22}$$

The noise variance is

$$\sigma_n^2=E\left[z_n^2\right]=\frac{N_0T}{4}. \tag{23}$$

For the other variance, we have

$$\sigma^2_{MPI}=\frac{P}{2}E\,[\{G'^1_{11,11}(cc)+\hat{G}'^1_{11,11}(cc)\}^2]$$

$$\sigma^2_{MPI}=\frac{P}{2}\left[\frac{N_1T_C{}^2}{3}\right]\sum_{l=2}^{L}\mathrm{var}\,A_{1l}. \tag{24}$$

Where N_1 is the number of chip per bit of input data $d_k(t)$ before the first S/P conversion ; thus : $N_1=\frac{N_a}{J}=\frac{N_c}{JH}$ and $T=N_cT_c=JHN_1T_c$, The *MPI* variance becomes

$$\sigma_{MPI}^2 = \frac{P}{2}\left[\frac{T^2}{3JHN_c}\right]\sum_{l=2}^{L} \operatorname{var} A_{1l} .$$

For *ISSI* variance, we have J-1 substream, then

$$\sigma_{ISSI}^2 = \frac{P}{2}(J-1)\frac{T^2}{3JHN_c}\sum_{l=1}^{L} \operatorname{var} A_{1l} . \tag{25}$$

The *ICI* variance is equal to

$$\sigma_{ICI}^2 = \frac{JPT^2}{2}\sum_{h=2}^{H} \frac{F^c(h) - F^s(h)}{4\pi^2 J^2 (h-1)^2 N_1}\sum_{l=1}^{L} \operatorname{var} A_{1l} . \tag{26}$$

With

$$\begin{aligned} F^c(h) = N_c\Big\{ & \frac{1}{N_c} - \frac{1}{2N_c}\cos 4\pi\frac{J(h-1)}{T} gT_c + \frac{1}{\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T} gT_c \cos 2\pi\frac{J(h-1)}{T}(g+1)T_c \\ & - \frac{1}{2\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T} gT_c c\cos 2\pi\frac{J(h-1)}{T} gT_c + \frac{1}{N_c} - \frac{1}{2N_c}\cos 4\pi\frac{J(h-1)}{T}(g+1)T_c \\ & + \frac{1}{2\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T}(g+1)T_c \cos 2\pi\frac{J(h-1)}{T}(g+1)T_c \\ & - \frac{1}{\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T}(g+1)T_c \cos 2\pi\frac{J(h-1)}{T} gT_c \Big\}. \end{aligned} \tag{27}$$

$$\begin{aligned} F^s(h) = N_c\Big\{ & \frac{1}{N_c} + \frac{1}{2N_c}\cos 4\pi\frac{J(h-1)}{T} gT_c + \frac{1}{4\pi J(h-1)}\sin 4\pi\frac{J(h-1)}{T}(g+1)T_c \\ & - \frac{1}{\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T}(g+1)T_c \cos 2\pi\frac{J(h-1)}{T} gT_c + \frac{1}{2\pi J(h-1)}\sin 2\pi\frac{J(h-1)}{T} gT_c c\cos 2\pi\frac{J(h-1)}{T} gT_c \\ & + \frac{1}{N_c} + \frac{1}{2N_c}\cos 4\pi\frac{J(h-1)}{T}(g+1)T_c - \frac{1}{\pi J(h-1)}\cos 2\pi\frac{J(h-1)}{T}(g+1)T_c \sin 2\pi\frac{J(h-1)}{T}(g+1)T_c \\ & + \frac{1}{\pi J(h-1)}\cos 2\pi\frac{J(h-1)}{T}(g+1)T_c \sin 2\pi\frac{J(h-1)}{T} gT_c \Big\}. \end{aligned} \tag{28}$$

The variance of multi user is given by

$$\sigma_{MUI}^2 = \frac{PT^2}{2}J(K-1)\left\{\frac{T^2}{3JHN_c} + \sum_{h=1}^{H}\frac{F^c(h) - F^s(h)}{4\pi^2 J^2 (h-1)^2 N_1}\right\} \times \sum_{l=1}^{L} \operatorname{var} A_{kl} \tag{29}$$

The variances of interferences depend of variance of the gain A_{kl}; Assuming $var[A_{11}] = \Omega$ and $\sum_{l=1}^{L} var\, A_{kl} = \Omega Q(L, \delta)$, with $Q(L, \delta) = \frac{1-e^{-L\delta}}{1-e^{-\delta}}$.

Therefore, the totally variance can written as

$$\sigma_T^2 = \frac{PT^2}{2}\left\{\frac{1}{3JHN_c}\Omega(Q(L, \delta)-1) + \frac{J-1}{3JHN_c}\Omega Q(L, \delta) + \left\{\sum_{h=2}^{H}\frac{J[F^c(h)-F^s(h)]}{4\pi^2 J^2 (h-1)^2 N_1}\right\}\Omega Q(L, \delta)\right.$$
$$\left. + \left\{\frac{J(K-1)}{3JHN_c} + \sum_{h=1}^{H}\frac{J(K-1)\left[F^c(h)-F^s(h)\right]}{4\pi^2 J^2 (h-1)^2 N_1}\right\}\times \Omega Q(L, \delta) + \frac{1}{2\frac{E_b}{N_0}}\right\} \tag{30}$$

where E_b=PT.

Finally, the SNIR is

$$\gamma = \frac{\frac{p}{2} {A_{11}}^2 T^2}{\sigma_T^2} \tag{31}$$

4 Result of Simulation

Having derived the output SNIR, the performance of the system is presented in this section. We used parameters listed in table1.

Table 1. Simulation parameters

Parameter	Value
Nakagami parameter	m=1
Number of user	K=20
Number of multipath	L=3
Number of substreams	J=8
Number of carriers	H=8
Local mean power	Ω=10dB
Multipath decay factor	$\delta=5\text{x}10^{-7}$

Fig. 2 illustrates SNIR performance for BPSK and QPSK modulation schema, versus the Signal-to-noise ratio. It is seen that the BPSK performance better than the QPSK, but QPSK can transmit two more information than BPSK.

Fig. 3 shows SNIR performance as a function of the SNR for several values of number of users K for BPSK and QPSK modulations; It is clear from those two figures that, as many users are transmitting signal simultaneously, the SNIR decreases; this appears clearly in Figure 4; Hence, the higher the number of users, the higher the multiuser interference caused by the unwanted user and consequently the performance become worse.

A plot of the SNIR performance of the different system MC-MC-CDMA, MC-CDMA and MultiCode CDMA is shown in Figure 5; the figure clearly shows that the MC-MC-CDMA system has the highest SNIR performance of all the systems compared. Indeed, our system eliminates, simultaneously, the effects of multipath interference, multi-carrier, multi-user and the interference between symbols.

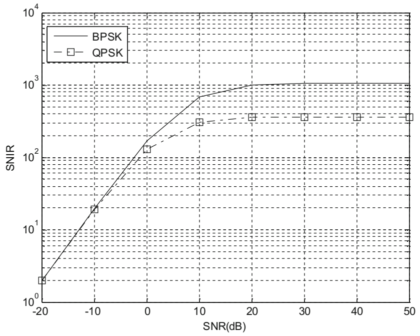

Fig. 2. SNIR for BPSK and QPSK modulations

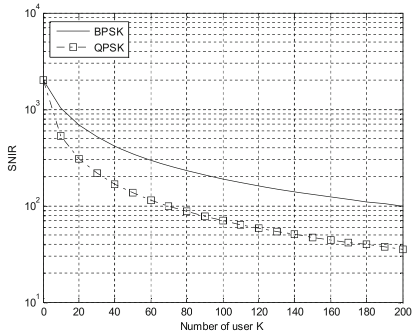

Fig. 3. Effect of number of users, *K*, on the SNIR, SNR=10dB

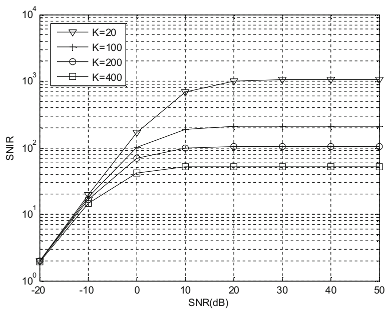

Fig. 4. Effect of number of users, *K*, in the SNIR

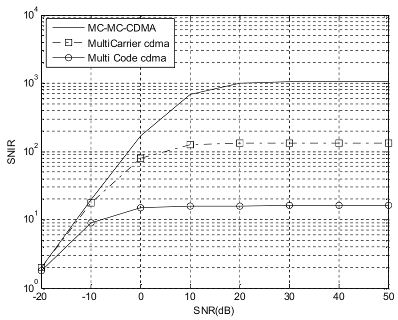

Fig. 5. SNIR performance for different CDMA based systems

5 Conclusion

On the basis of principle of multi-carrier CDMA and multi code CDMA technology, a novel MC-MC-CDMA schema is developed in this paper. We have analyzed the performance of this system in term of SNIR; It was shown that MC-MC-CDMA outperforms the MC-CDMA and Multi code-CDMA systems. Our system is very effective in reducing the interferences, and improving the quality of the wireless link.

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