A New Overloading Scheme for DS-CDMA System

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Abstract

In this paper a new overloading scheme for DS-CDMA system is analyzed, which allows to accommodate a higher number of users than the spreading factor N. In this scheme, orthogonal codes are assigned to first N users synchronously and additional users are assigned pseudo-random (PN) codes asynchronously. It is shown that with this hybrid scheme, the BER performance of first N users is considerably better than Sari et al. and Vanhaverbeke et al., at any SNR. Also additional PN-users performance is better. This results in a considerable capacity enhancement.

1. Introduction

Orthogonal-waveform multiple access (OWMA) techniques can accommodate N users without any mutual interference on a channel whose bandwidth is N times that required by one user in the single-user case. OWMA includes the well-known frequency-division multiple access (FDMA), time-division multiple access (TDMA), orthogonal code-division multiple access (OCDMA), as well as orthogonal frequency-division multiple access (OFDMA). However, N is a strict limit to the number of users in these techniques. Overloading is a technique to increase the number of users above N in OWMA systems. Overloading seems to be appealing for the operators, where capacity can be increased by enhancing the base station without modifying the handsets and without violating the transmission standard [1].

In hybrid scheme for overloaded DS-CDMA, two different types of codes are assigned to the users of two different sets. An important aim of these schemes is to accommodate a higher number of users than the spreading factor N. In [2], the idea has been to assign synchronously orthogonal spreading sequences to the first N users and pseudo-random (PN) spreading sequences to all additional users. The proposed technique can thus accommodate N users without any mutual interference and some additional users at the expense of some SNR loss. Further an iterative multistage detection scheme has been proposed to remove the interference among the users of two sets. In another study [3], each of the available orthogonal spreading sequences of length N is assigned to one of the first N users which employ a common PN scrambling sequence. When the number of users K exceeds N, say K=N+M with M<N, the M additional users reuse M of these orthogonal codes but in combination with another PN scrambling sequence. Both sets are synchronous to each other. Thus there should be no intraset interference and only interference is the mutual interference.

In this work we propose a new overloading scheme for DS-CDMA, where both the sets use different sequences and follow different transmission scheme. The set-1 users are assigned orthogonal codes (WH-users) and they are synchronous to each other. On the other hand set-2 users are assigned PN (PN-users) codes asynchronously, that is they do not have to transmit synchronously at the same time. It is shown that, with the same number of set-2 users M, and given SNR, the BER performance of this scheme is considerably better for set1-users as compared to [2] and [3] at the matched filter output. Also set-2 users performance is better than other two schemes and hence the capacity of the system is enhanced.

2. System model

In hybrid spreading sequence scheme, the first N users are assigned mutually orthogonal codes that operate in a synchronous manner. The set-2 users, which are in excess of N, are assigned PN codes asynchronously.

The spreading codes of set-1, k_1-th user (where k_1 =1, 2,…, N) is given as

$$a_{1,k_1}(t) = \sum_{j=1}^{N} w_{1,k_1}^{j} \prod_{T_c}(t - jT_c) \qquad (1)$$

and for set-2, k_2-th user (where k_2 =1,2,…,M) the spreading sequence is given as

$$a_{2,k_2}(t) = \sum_{j=1}^{N} p_{2,k_2}^{j} \prod(t - jT_c) \qquad (2)$$

where $\prod_{T_c}()$ is the unit gate function with height 1 when $0 \le t \le T_c$, and zero otherwise, where T_c is the chip period. $w_{1,k_1}^{j}, p_{2,k_2}^{j} \in \{-1,+1\}$ are the j-th chip of orthogonal and PN spreading sequence of users in set-1 and set-2 respectively. In the random signature sequence model w_{1,k_1}^{j} and p_{2,k_2}^{j} (for j =0,1,2,…..,N-1) are independent and identically distributed random variables taking values +1 and-1 with equal probability.

The transmitted signal for set-1, k_1-th user is given as [4]

$$s_{1,k_1}(t) = Ab_{1,k_1}(t)a_{1,k_1}(t)\cos(\omega_0 t + \theta_{1,k_1}) \qquad (3)$$

and for set-2, k_2 -th user

$$s_{2,k_2}(t) = Ab_{2,k_2}(t)a_{2,k_2}(t)\cos(\omega_0 t + \theta_{2,k_2}) \qquad (4)$$

where

$$b_{g,k_g}(t) = \sum_{l=-\infty}^{\infty} b^l_{g,k_g} \prod_{T_b}(t - lT_b) \qquad (5)$$

is the data signal and data sequence $b^l{}_{g,k_g} \in \{-1,+1\}$ for g=1,2 (denotes set1 and set2) are identical independent distributed (i.i.d.) and equiprobable random variables, A is the amplitude of transmitted signal, ω_0 is the carrier frequency, and θ_{g,k_g} the phase of the transmitted signal. There are N chips of duration T_c for each data pulse of duration T_b .

3. System analysis

For the following discussion, perfect chip, symbol, and carrier synchronization are assumed. We have also considered perfect power control and fading effect is ignored. The received signal, r(t), follows

$$r(t) = n(t) + \sum_{k_1=1}^{N} s_{1,k_1}(t - \tau_{1,k_1}) + \sum_{k_2=1}^{M} s_{2,k_2}(t - \tau_{2,k_2}) \qquad (6)$$

where

$$s_{1,k_1}(t - \tau_{1,k_1}) = A\sum_{k_1=1}^{N} b_{1,k_1}(t - \tau_{1,k_1})a_{1,k_1}(t - \tau_{1,k_1})\cos(\omega_0 t + \phi_{1,k_1})$$

and

$$s_{2,k_2}(t - \tau_{2,k_2}) = A\sum_{k_2=1}^{M} b_{2,k_2}(t - \tau_{2,k_2})a_{2,k_2}(t - \tau_{2,k_2})\cos(\omega_0 t + \phi_{2,k_2})$$

where n(t) is a zero-mean white Gaussian noise process with two-sided spectral density $N_0 / 2$. Received amplitude, A= $\sqrt{2P}$ where P is the received signal power. The difference in propagation and message start times are incorporated into τ_{g,k_g} and ϕ_{g,k_g} represents the phase parameter in the carrier. The delay and phase parameters, τ_{g,k_g} and ϕ_{g,k_g} are i.i.d. uniform random variables in the interval [0, T_b] and [0,2 π] respectively . Note that all set1-users are synchronous, $\tau_{1,k_1} = \tau_{1,1}$. ϕ_{g,k_g} is shown to be

$$\phi_{g,k_g} = \begin{cases} (\theta_{1,k_1} - \omega_0\tau_{1,k_1}) \bmod 2\pi \\ (\theta_{2,k_2} - \omega_0\tau_{2,k_2}) \bmod 2\pi \end{cases} \qquad (7)$$

The output of the correlation receiver matched to $s_{g,k_g}(t)$ is

$$Z_{g,k_g} = \int_0^{T_b} r(t) s_{g,k_g}(t)\cos\omega_0 t dt \qquad (8)$$

The decision statistics of set1-users for the 1st user is given by

$$Z_{1,1} = \tilde{N} + D_{1,1} + I_{1,2} \qquad (9)$$

and for set2-user

$$Z_{2,1} = \tilde{N} + D_{2,1} + I_{2,1} + I_{2,2} \qquad (10)$$

where $\tilde{N}$ is the noise caused by n(t), $D_{1,1}, D_{2,2}$ is the desired signal, I is the Multiple Access Interference (MAI). The variance of $\tilde{N}$ is given as

$$\text{Var}[\tilde{N}] = \text{NoTb}/4 \qquad (11)$$

The mean value of the desired signal $D_{1,1}, D_{2,2}$ is shown to be

$$\text{E}[D_{g,1}] = \frac{A}{2} b^{[0]}_{g,1}.T_{b,} \text{ for g =1,2} \qquad (12)$$

where $b^{[0]}_{g,1}$ represents the zeroth bit of $b_{g,1}(t)$.

The MAI of set1-users on 1st set2-user is given by

$$I_{2,1} = \sum_{k_1=1}^{N} \sqrt{P/2}[b_{1,k_1,-1}R_{k_1,1}(\tau_{k_1}) + b_{1,k_1,0}\hat{R}_{k_1,1}(\tau_{k_1})]\cos(\phi_{1,k_1}) \qquad (13)$$

where $b_{1,k_1,-1}$ and $b_{1,k_1,0}$ are two consecutive bits of k_1 -th set1-user. $R_{k_1,1}(\tau_{k_1})$ and $\hat{R}_{k_1,1}(\tau_{k_2})$ are the continuous-time partial crosscorrelation function.

The variance of the MUI is given by [4]

$$Var[I_{2,1}] = \frac{A^2T_b^2}{24N^3}\sum_{k_1=1}^{N-1} r_{k_1,1} \qquad (14)$$

where, $r_{k_1,1} = 2\mu_{k_1,1}(0) + \mu_{k_1,1}(1)$ (15)

$\mu_{k_1,1}$ is the cross-correlation parameter defined by

$$\mu_{k_1,1} = \sum_{l=1-N}^{N-1} C_{k_1,1}(l)C_{k_1,1}(l+n) \qquad (16)$$

where $C_{k_1,1}$ is the discrete aperiodic cross-correlation parameter for the k-th set-1 user and desired user sequence.

Now the mutual interference of (M-1) set2-users is given by

$$Var[I_{2,2}] = \frac{A^2T_b^2}{24N^3}\sum_{k_2=2}^{M} r_{k_2,1} \qquad (17)$$

Similarly finding the interference on set1-users from set2-users, the variance of the interference is given as

$$Var[I_{1,2}] = \frac{A^2T_b^2}{24N^3}\sum_{k_2=1}^{M} r_{k_2,1} \qquad (18)$$

From the equation (17) and (18), we find that interference power on set1-users and mutual interference of set2-users are almost same.

The signal-to-noise ratio (SNR) for set1-users is given by

$$SNR_1 = \frac{\left(E[D_{1,1}]\right)^2}{Var[\tilde{N}] + Var[I_{1,2}]} \tag{19}$$

and for set2-users it is given as

$$SNR_2 = \frac{\left(E[D_{2,1}]\right)^2}{Var[\tilde{N}] + Var[I_{2,1} + I_{2,2}]} \tag{20}$$

Since BPSK signaling is used for both the sets, the BER for each set becomes

$$BER_g = Q\left(\sqrt{SNR_g}\right), \quad \text{for g = 1, 2} \tag{21}$$

4. BER analysis

Although the chip sequence is usually deterministic and periodic (the sequence appears random within a period), analysis is sometimes simplified by assuming that the signature sequence is completely random; that is, the sequences are generated from a random process producing outcomes uniform on the set {-1,+1} [5]. We consider that the decision statistics of receiver 1 from equation (8) and (9) is normalized with respect to the chip sequence T_c, with all signals received at power P=2.

If the interfering signals are not chip and phase synchronous with the desired user signal then the MAI variance (assuming that the useful signal power is normalized by1) from single interferer is 1/3N, considering Gaussian distribution for MAI [5].Since the MAI components from various interfering transmitters are uncorrelated, the variance adds, and the total MAI variance from K-1 interfering users is given by $\left(\frac{K-1}{3N}\right)$.

In the proposed scheme the set-1users are synchronously assigned orthogonal codes while the set-2 users are assigned PN codes asynchronously. So there will be no intraset interference for set-1 users. Also both sets of users are asynchronous to each other as shown in equation (6). Now the normalized interference power on set1-users from M set2- users is $\frac{M}{3N}$.

Now following Gaussian approximation for BER calculation, the average BER for set1-users is given by

$$P_e^1 = Q\left[\frac{1}{\sqrt{N_0/2E_b + M/3N}}\right] \tag{22}$$

For set-2 users, there are interference form N set-1 users as well as interference from (M-1) set-2 users. The interference power of set1- users on set-2 is N/3N = 1/3. There are (M-1) intraset interferer in set-2 and the normalized interference power for set-2 users is (M-1)/3N. So the total interference power is given by (M+N-1)/3N. The average BER for set-2 users is given as

$$P_e^2 = Q\left[\frac{1}{\sqrt{\frac{N_0}{2E_b} + \frac{M+N-1}{3N}}}\right] \tag{23}$$

The BER performance of set-2 users is poor as compared to Set1-users due to increased interference power. The set2-users are subjected to interference from N set1-users as well as inraset interference form (M-1) set2-users.

5. Results and discussion

Following the similar approach as in the previous section, the MAI variance for the two sets have been shown in the Table 1 for the schemes proposed in [2] and [3] as well as the proposed scheme. In the scheme [1] and [2], set-1 and set-2 users are synchronous with respect to each other. The BER plot for set-1 users at different values of SNR has been plotted in Fig. 1 for all the schemes. The number of set2-users is 12 that is overloading is 19%. The BER performance of the proposed scheme is considerably better than other two schemes.

In Fig. 2, variation of BER at different values of SNR for all the three schemes is plotted. The amount of overloading, that is, extra set2-users is 19%. Here, the BER performance of the proposed scheme is better than the other two schemes and so is the system capacity. It can be observed that the BER performance of all the three schemes is very poor as compared to the single user bound. So multiuser detection scheme is required to enhance the system performance and the system capacity. Interference cancellation receivers like iterative multistage detection are proposed in [1] and [2]. Also for set1-users, BER degradation is considerably less as compared to set2-users. This is due to the fact that set1-users experience less interference power as compared to set2-users [Table 1] due to its orthogonal codes.

Table 1: Comparison of the overloading schemes

	[Sari H 1999] [2]	[Van F 2000] [3]	[Proposed]
Set-1 users	Orthogonal Synchronous	Orthogonal Synchronous	Orthogonal Synchronous
Set-2 users	PN Synchronous	Orthogonal Synchronous	PN Asynchronous
Interference Power on set-1 users	M/N	M/N	M/3N

Interference Power on set-2 users	1+(M-1)/N	1	1/3+(M-1)/3N

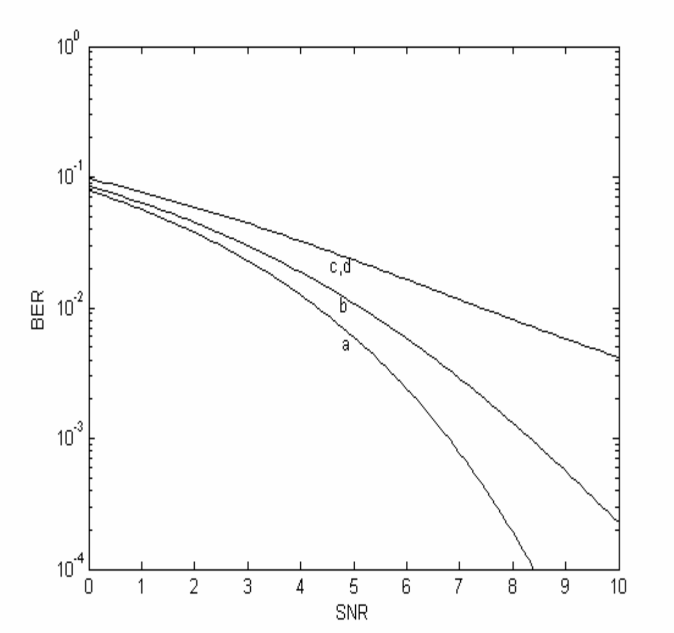

Figure 1: BER performance comparison of set1-users, with N=64, M=12, Overloading=19%
a: single user bound; b: Proposed scheme; c: [3]; d: [2]

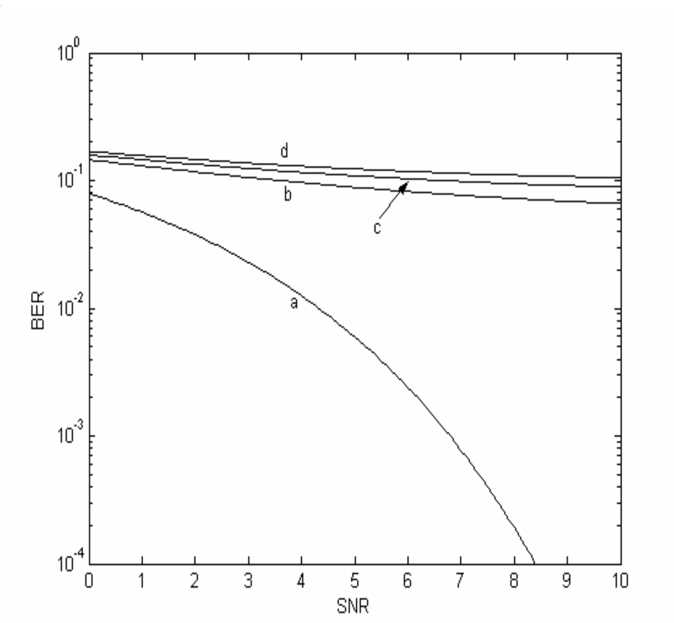

Figure 2: BER performance comparison of set2-users, with N=64, M=12, Overloading=19%
a: single user bound ; b: proposed scheme; c: [3] ; d: [2]

6. Conclusions

The DS-CDMA using PN spreading sequence has soft capacity limit, as the amount of interference grows linearly with the number of simultaneous users. On the other hand the number of users in OCDMA scheme has hard capacity limited, which depends on the number of orthogonal sequences .Overloading scheme has been proposed in [2] and [3] to increase the system capacity. In the present work, a new overloading scheme has been proposed which uses hybrid sequence and transmission mode to achieve better performance and system capacity

7. Acknowledgements

The first author is sponsored by Birla Institute of Technology Mesra, Ranchi to carry out his research work at IIT Kharagpur.

8. References

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