EFFICIENCY IMPROVEMENT OF ADVANCED $\tau$-CDMA SYSTEM WITH NONCOHERENT DETECTION

Zorica Nikolić, Predrag Petrović, Igor Jovanović, Bojan Dimitrijević, Nenad Milošević
Elektronski fakultet, Niš
IRITEL, Beograd

I INTRODUCTION

Direct sequence spread spectrum (DSSS) systems are widely used in many applications. Mobile communication systems of the third generation (3G) are based on DSSS systems and code division multiple access (CDMA).

Coherent detection of these signals offers better performances, but if coherency is not feasible then noncoherent solution is the only option. The effect of barrage and partial-band noise jamming on frequency-hopped, M-ary frequency-shift keyed (FH/MFSK) noncoherent receivers, when one or more symbols per hop are transmitted, has been examined for channels with no fading and for Rayleigh fading channels in [9] and [10], respectively. The effect of partial-band noise jamming on fast frequency-hopped (FFH) binary frequency-shift keyed (BFSK) noncoherent receivers with diversity has been examined for channels with no fading [11], as has the effect of partial-band noise jamming on FFH/MFSK for Ricean fading channels [12]. The performance degradation resulting from both band and independent multitone jamming of FH/MFSK, where the jamming tones are assumed to correspond to some or all of the possible FH M-ary signaling tones and when thermal and other wideband noise is negligible, is examined in [13]-[15]. The effect of tone interference on noncoherent MFSK when AWGN is not neglected is examined for channels with no fading in [16], and the effect of independent multitone jamming on coherent FH/BFSK when AWGN is not neglected is examined for channels with no fading in [17].

In this paper we introduce a new concept of multiple access called $amM\tau$-CDMA. The concept is based on a modification of Direct Sequence Spread Spectrum (DSSS) system where transmitted waveform includes multiple amplitude and delay replicas of DSSS signal. The notation $amM\tau$-CDMA will be used for DS signal that includes $m$ delayed replicas of different amplitudes ($a$) sent in a limited delay window of $M$ chip intervals. The position of the delay window is hopped (Delay Hopping) in the range of the code length $N$. The results demonstrate that under the large range of the signal, channel and interference parameters this system offers better performance.

II SYSTEM MODEL

For a standard CDMA concept the simplest form of the overall received signal can be represented as

$$r(t) = \sum_{k} b_{k'}(t)s_{k'}(t - \tau_{k}) \cos(\omega t + \theta_{k}) + i(t) + n(t)$$

(1)

where for the $k'$-th user $b_{k'}$ and $s_{k'}$ are data (bits) and PN sequence respectively, $i(t)$ is the total interference, and $n(t)$ is Gaussian noise. The standard receiver uses coherent despreading and demodulation and will be referred to as coherent CDMA (c-CDMA). Extension to include I and Q signal component is straightforward. If a correlator (composed of a multiply plus integrate) is used for signal despreading then we will refer to this structure as correlator receiver (CR). If a PN matched filter is used at the receiver and if the sequence period $T_{s} = N\tau_{s}$ equals bit period $T_{b}$, then at the output of the filter, one correlation pulse generated by the useful signal will appear per bit interval. The correlation pulse will appear each time at the chip interval when the input sequence coincides with the filter coefficients. This will be referred to as PN matched filter receiver (PNMFR).

If now instead of sequence $s_{k'}$ a delayed version (cyclic shift) of the same sequence is used $s_{k'}'$ the position of the correlation pulse will depend on the sequence shift $\tau = \mu_{k}(k) = kT_{s}$. Eq.(1) now becomes

$$r(t) = \sum_{k} b_{k'}(t)s'_{k}(t - \mu_{k}(k)T_{s} - \tau_{k}) \cos(\omega t + \theta_{k})$$

(2)

If $\mu_{k}(k) = kT_{s}$, $k = 0,1,...,M - 1$, is one out of $M = 2^{n}$ different adjacent cyclic shifts then $n = \log_{2}M$ additional bits can be transmitted within one symbol interval. Capacity of a standard coherent CDMA system is roughly [6]

$$K \cong G / y_{b}$$

(3)

where $G$ is the system processing gain and $y_{b}$ is signal to noise ratio needed for a given quality of transmission. In our case $G = N$. In accordance with the above explanation capacity of the new CDMA system is additionally increased by a factor $K' \cong (G\log_{2}M) / y_{b}' = (N\log_{2}M) / y_{b}'$
where \( y'_b \) is signal to noise ratio needed for the same BER. Parameter \( y'_b \) will depend on the type of demodulator and is the main subject of this paper.

Let's now consider the case if we send two different delayed replicas simultaneously. If two delayed signal replicas with different amplitudes \( A_i, (i = 1, 2) \) are used the number of combinations is now larger and can be expressed as \( M_2(a) = M(M-1) \). If \( m \) replicas each of different amplitude are sent we have

\[
M_n(a) = M(M-1)(M-2)\cdots(M-m+1)
\]

and the number of bits transmitted is

\[
n_m(a) = \sum_{i=0}^{m-1} \log(M-i)
\]

If \( M \) is large the previous relation can be approximated as \( n_m(a) \approx m \log M = mn \).

The name for modulation \( amMτ-CDMA \) is self-explanatory. \( M \) is the size of the delay window, \( m \) the number of simultaneously transmitted replicas and \( a \) says that all transmitted replicas are of different amplitudes. Receiver block diagram is shown in Fig. 1, where \( u_{in}^* = s(t-kT_i-\tau) \). The processing block calculates \( U_{in} \) and chooses \( m \) the largest in decreasing order.

**Fig. 1.** The noncoherent receiver block diagram

The interference \( i(t) \) is modelled as a CW interference, an equivalent tone (phasor) with random phase \( \theta \in [0,2\pi] \) and power given by

\[
\sigma^2_i = (K-1)m\alpha^2\bar{A}^2 / G
\]

where \( \alpha \) is the channel attenuation and \( \bar{A}^2 \) is the average amplitude of the interferers.

**III PERFORMANCE ANALYSIS**

As performance measure we will be using the system efficiency improvement factor defined as [7]

\[
E = \left[ (1-P)n \right] / \left[ (1-P_0)n_0 \right]
\]

where parameters with index zero refer to the standard modulation, \( n \) is the number of bits per symbol, \( P \) is the bit error rate and \( 1-P \) is the average number of correctly transmitted bits per symbol.

We will consider case of \( m = 2 \) and arbitrary \( M \).

Signals at the output of detectors are Ricean distributed, with the following pdfs.

\[
p(U_k) = \frac{1}{\sigma_k^2} \exp \left( -\frac{U_k^2 + a_k^2 + 2a_k a_j \cos \theta}{\sigma_k^2} \right) \times
\]

\[
\times I_0 \left( \sqrt{a_k^2 + \frac{2a_k a_j \cos \theta}{\sigma_k^2}} U_k \right)
\]

\[\quad k = 1,2\]

\[
p(U_k) = \frac{1}{\sigma_k^2} \exp \left( -\frac{U_k^2 + a_j^2}{\sigma_k^2} \right) U_k \left( \frac{a_j}{\sigma_k^2} U_k \right)
\]

\[\quad k = 3,4,...,M\]

Probability of a correct decision is

\[
P_c = P(U_1 > U_2, U_1 > U_3,..., U_1 > U_M)\times
\]

\[
P(U_1 > U_2, U_1 > U_3,..., U_1 > U_M) = \int_{-\infty}^{\infty} P(U_1 > U_2,..., U_i > U_M | U_1 = u_1) p(U_1) dU_1
\]

\[
P(U_2 > U_1, U_2 > U_4,..., U_2 > U_M) = \int_{-\infty}^{\infty} P(U_2 > U_3,..., U_2 > U_M | U_2 = u_2) p(U_2) dU_2
\]

\[
P(U_i > U_j | U_i = u_1) = \int_0^{\infty} p(U_2) dU_2 = \int_0^{\infty} \exp \left( -x - a_j^2 + a_j^2 + 2a_j a_j \cos \theta \right) \times
\]

\[
\times I_0 \left( \sqrt{a_j^2 + \frac{2a_j a_j \cos \theta}{\sigma_j^2}} \sqrt{2x} \right) dx
\]

\[
= \int_0^{\infty} \exp \left( -x - a_j^2 + a_j^2 + 2a_j a_j \cos \theta \right) \times
\]

\[
\times I_0 \left( \sqrt{a_j^2 + \frac{2a_j a_j \cos \theta}{\sigma_j^2}} \sqrt{2x} \right) dx
\]
\[ P(U_1 > U_2 \mid U_1, \theta) = \cdots = P(U_1 > U_N \mid U_1, \theta) = \int_0^{U_1} p(U_1) dU_1 = \int_0^{U_1} \frac{U_1}{2\sigma_n^2} \exp \left( -\frac{U_1^2}{2\sigma_n^2} \right) \left( \frac{a_1}{\sigma_n} \right)^{U_1} dU_1 \] (14)

\[ P(U_2 > U_1 \mid U_2, \theta) = \cdots = P(U_2 > U_N \mid U_2, \theta) = \int_0^{U_2} p(U_2) dU_2 = \int_0^{U_2} \frac{U_2}{2\sigma_n^2} \exp \left( -\frac{U_2^2}{2\sigma_n^2} \right) \left( \frac{a_2}{\sigma_n} \right)^{U_2} dU_2 \] (15)

The conditional probability of a correct decision is

\[ P_c(\theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P(U_1 > U_2 \mid U_1, \theta) P(U_1 > U_1 \mid U_2, \theta)^{U_1-2} \times P(U_2 > U_1 \mid U_2, \theta)^{U_2-2} p(U_1) p(U_2) dU_1 dU_2 \] (16)

After averaging over \( \theta \), we get

\[ P_c = \frac{1}{2\pi} \int_0^{2\pi} P_c(\theta) d\theta \] (17)

The error probability now becomes

\[ P_e = 1 - P_c = 1 - F_{necohCDMA}(a_1^2, a_2^2) \] (18)

After averaging over \( a_1, a_2 \), the error probability becomes

\[ P_e = \int_{a_1, a_2} (1 - F_{necohCDMA}(a_1^2, a_2^2)) f(a_1) f(a_2) da_1 da_2 \] (19)

IV NUMERICAL RESULTS

Some examples of numerical results are shown in this section. They illustrate the advantages of the proposed \( amM\tau\)-CDMA system.

Three dimensional figure (Fig.2) represents parameter \( E \) for \( amM\tau\)-CDMA system for \( m = 2, M = 4 \), and \( SNR = 10 \text{ dB} \). The influence of fading was not taken into account due to enormous numerical computations.

Fig. 2. Efficiency improvement of \( amM\tau\)-CDMA system as a function of the number of users and \( A_i^2 \)

Under the assumption that \( A_i^2 + A_j^2 = 1 \), the maximum value for efficiency improvement is obtained if \( A_i^2 \approx 0.75 \). Also, it may be seen that the efficiency improvement is larger than 1 for only a few users.

V CONCLUSION

In this paper we introduce a new concept of multiple access called \( amM\tau\)-CDMA. The concept is based on a modification of Direct Sequence Spread Spectrum (DSSS) system where transmitted waveform includes multiple amplitude and delay replicas of DSSS signal. The notation \( amM\tau\)-CDMA will be used for DS signal that includes \( m \) delayed replicas of different amplitudes \( (a) \) sent in a limited delay window of \( M \) chip intervals. The position of the delay window is hopped (Delay Hopping) in the range of the code length \( N \). The results demonstrate that under the large range of the signal, channel and interference parameters this system offers better performance.

REFERENCES


Abstract: In this paper we introduce a new concept of multiple access called amMr-CDMA. The notation amMr-CDMA will be used for DS signal that includes m delayed replicas of different amplitudes (a) sent in a limited delay window of M chip intervals. The position of the delay window is hopped (Delay Hopping) in the range of the code length N. The results demonstrate that under the large range of the signal, channel and interference parameters this system offers better performance.

POBOLJŠANJE PERFORMANSI τ-CDMA SISTEMA SA NEKOHERENTNOM DETEKCIJOM, Zorica Nikolić, Predrag Petrović, Igor Jovanović, Bojan Dimitrijević, Nenad Milošević