MULTI-USER CANCELLATION DETECTOR FOR UMTS CDMA SATELLITE COMMUNICATIONS

E. Del Re, R. Fantacci, S. Morosi, F. Baiocchi, P. Bagnoli.

Dipartimento di Ingegneria Elettronica
Università di Firenze, Italy

ABSTRACT: this paper deals with a multiuser cancellation detection scheme for DS/CDMA satellite communication systems where the BPSK modulation technique is used in transmission. The proposed receiver, defined as one-shot detector, is intended to be used at the end of an up-link satellite channel and considered in a communication system characterized by lack of synchronism between the users and multipath fading satellite channel. One-shot receiver basic assumption is to divide the users into two different groups according to the received signals power level. The reliable ones are directly detected and cancelled from the whole received signal before making the decision on not reliable users bit sign, without any further processing delay. The proposed scheme performance is evaluated in BER terms by means of simulations, proving that the proposed one-shot satellite receiver exhibits very good behavior for uniform users power distribution and shows reasonable near-far resistance. Moreover, the small computational complexity allows us to suppose a real time implementation for the proposed receiver.

1. INTRODUCTION

The 3rd generation of wireless communication systems is supposed to integrate different services of different traffic at variable bit-rate with optimum resources management: in particular, the distinction between terrestrial and satellite communications is thought to vanish towards a global wireless system.
These objectives have to be granted by the communication system chosen to be the 3rd generation standard and bring leading International Standard Organizations and manufacturer groups to consider CDMA (Code Division Multiple Access) Systems to this purpose. The choice of CDMA is attractive because of its potential capacity increases and other technical factor such as antimultipath fading capabilities. However, this capacity improvement over alternative Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (TDMA) systems is based principally on the ability of CDMA to support universal frequency reuse and variable rate voice encoder which are supposed to exploit voice activity factor (VAF)[2]: in fact, within a single cell environment, the capacity of CDMA systems with conventional receivers is actually less than or equal to orthogonal multiple access techniques. Over the years researchers have sought ways to extend the user capacity of CDMA systems either by exploiting optimum (maximum likelihood, ML) detec-

tion, interference cancellation (IC) methods and other techniques such as decorrelating receiver.
Although optimum multiuser algorithms offer huge potential capacity and significantly improved performance by alleviating the disadvantages associated with the conventional scheme, they unfortunately get too complex to be used in practical systems. This fact spurred research on suboptimal solutions like decorrelating detectors and multistage receivers. In particular, this paper deals with a multiuser cancellation detection scheme for DS/CDMA satellite communication systems in which the BPSK modulation technique is used in transmission: the proposed receiver, defined as one-shot detector, is supposed to be used at the end of up-link satellite channel in the base station.
In literature the IC is generally accomplished by two different methods: successively [3,4,5,6,7] or in parallel way [2,8,9,10,11]. The fundamental disadvantage of successive cancellation scheme is the required delay necessary to fully accomplish the IC for all users in the systems. Since the successive IC proceeds serially, a delay on the order of M computation stages is required to complete the job (M is the user number).
Parallel processing of multiuser interference simultaneously removes from each user the interference produced by the remaining users accessing the channel. As compared with the serial processing scheme, since the IC is performed in parallel for all users, the delay required to complete the operation is at most a few bit time intervals.
It has been observed that successive schemes, in which interference cancellation is performed on users on descending order of received powers, are more effective when received powers are widely variable. On the contrary the parallel schemes, in which interference cancellation is performed simultaneously, are more effective in the case of equal received signal powers.
In satellite communications environment the signals involved are characterized by nearly the same power level: in fact, the free space attenuation is similar for each user since the distance between users and satellite is almost the same and is not related to the users position inside the cell. As a consequence, parallel cancellation seems to be the best performance-complexity trade-off for satellite communications.
If we consider a parallel scheme, it can be demonstrated that interference cancellation on the user k with power P_k is only effective if the interfering signals are powerful enough while weak interfering users cancellation effects are quite bad. As a consequence, a threshold can be chosen according to received signal power in order to perform cancellation.
Hence, this paper main focus is a selective parallel cancellation approach: according to this philosophy the more powerful users are deemed reliable, decoded as in a conventional rake receiver and used to regenerate the signal successively cancelled from the received signal. The others users are decoded only after performing reliable users signals cancellation. Distinction between reliable and not reliable users is done by comparing combined matched filters outputs with a fixed threshold for each user: correlator outputs will be used to distinguish between reliable and not

reliable users and directly perform interference cancellation, as seen in [4,5,6]. In the paper the threshold optimization is accomplished and the receiver performance for different threshold value are reported. The proposed receiver requires knowledge of users delay, attenuation and phase offset and uses the conventional matched filters outputs instead of a separate channel estimates.
The proposed scheme performance is evaluated in B.E.R. terms by means of simulations; the channel model used in these simulations is derived by research recent studies about 2Ghz band link for MEO satellite [12]. This paper is organized as follows: the system and channel model is introduced in Section II while the proposed receiver is described in Section III. Obtained results evaluation is done in section IV before the concluding remarks.

2. SYSTEM AND CHANNEL MODEL

We consider a simple analytical model according to which the received signal *r(t)* can be expressed as follows:

$$r(t)=\sum_{j=1}^{L}\sum_{k=1}^{K}\alpha_k^j\sqrt{2P_k}\,a_k(t-\tau_k^j)b_k(t-\tau_k^j)\cos(\omega_0 t+\phi_k^j)+n(t)$$ where

P_k : power of each chip of user *k*;
$b_k(t)$: bit sequence of the user *k* at bit rate R_b ;
$a_k(t)$: spreading chip sequence of the user *k* at chip rate R_c ;
$n(t)$: Additive White Gaussian Noise (two sided power spectral density equal to $N_0/2$);
$N=T_b/T_c$ where T_b and T_c are bit and chip time respectively;
K: total number of active users;
L: total number of tracked paths, i.e. 6 for the systems considered;
α_k^j : varying amplitude of the path *j* and the user *k* (α_k^1 is Rice distributed, the others show Rayleigh statistics)
τ_k and ϕ_k are time delay and phase of the user *k*, which are assumed to be known, i.e. tracked accurately.
The τ_k and ϕ_k are i.i.d. uniform random variables in $[0,T)$ and $[0,2\pi)$. The satellite channel model considered here has been recently proposed in COST252 [12] and is relative to a MEO satellite link.
The bits and chips are rectangular. Their random values are i.i.d. in $\{\pm 1\}$
At the output of the low pass filter of the in-phase channel, we get:

$$d^I(t)=LPF\{r(t)\cos(\omega_0 t)\}=\sum_{j=1}^{6}\sum_{k=1}^{K}\alpha_k^j\sqrt{2P_k}\cdot$$
$$\cdot a_k(t-\tau_k^j)b_k(t-\tau_k^j)\frac{\cos\phi_k^j}{2}+\frac{n_I(t)}{2}$$

The in-quadrature component can be expressed likewise.

A rake receiver that implements maximum ratio combining alghoritm processes signals $d^I(t)$ and $d^Q(t)$.
For the in-phase channel, the matched filter output for the user *k* and the path *j* will be given by:

$$Z_k^I(j)=\frac{1}{T_b}\cdot\int_{\tau_k^j}^{\tau_k^j+T_b}d^I(t)\alpha_k^j a_k(t-\tau_k^j)\cos(\phi_k^j)dt$$

By adding the in-phase component and in-quadrature components we obtain:

$$Z_k(j)=Z_k^I(j)+Z_k^Q(j)=$$
$$=\frac{1}{2}\cdot(\alpha_k^j)^2 b_k\sqrt{2P_k}+\frac{1}{2}\cdot C_k(j)$$

where

$$C_k(j)=n_{kj}^I+n_{kj}^Q+\sum_{p=1,p\neq k}^{K}\sum_{l=1}^{L}\sqrt{2P_p}$$
$$\cdot\alpha_p^l\cdot\alpha_k^j\cdot I_{k,p}(\tau_{k,p}^{j,l};\phi_{k,p}^{j,l})b_p(t-\tau_p^l)+$$
$$+\sum_{l=1,l\neq j}^{L}\sqrt{2P_k}\cdot\alpha_k^l\cdot\alpha_k^j\cdot I_{k,k}(\tau_{k,k}^{j,l};\phi_{k,k}^{j,l})b_k(t-\tau_k^l)$$

Furthermore, we define that:

$$n_{kj}^I=\frac{1}{T_b}\int_{\tau_k^j}^{\tau_k^j+T_b}n_I(t)\cdot\alpha_k^j\cdot a_k(t-\tau_k^j)\cos(\phi_k^j)dt$$

$$n_{kj}^Q=\frac{1}{T_b}\int_{\tau_k^j}^{\tau_k^j+T_b}n_Q(t)\cdot\alpha_k^j\cdot a_k(t-\tau_k^j)\,\mathrm{sen}(\phi_k^j)dt$$

$$I_{k,p}(\tau_{k,p}^{j,l};\phi_{k,p}^{j,l})=\frac{1}{T_b}\int_{\tau_k^j}^{\tau_k^j+T_b}a_p(t-\tau_p^l)a_k(t-\tau_k^j)\cdot$$
$$\cdot\cos(\phi_p^l-\phi_k^j)dt$$

As can be deduced from Fig. 1, the conventional rake receiver based on Maximum Ratio Combining algorithm at the end of the up-link MEO satellite channel is vulnerable to the multiple access interference (MAI) impairments. As a consequence, this near-far effect gives rise to an irreducible error floor, even for 10 users communication systems.

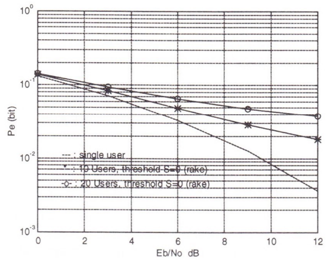

Fig. 1: Rake Receiver Performance in Satellite Environment.

3. ONE-SHOT RECEIVER IN SATELLITE MULTIPATH FADING CHANNEL

In this section, a complete description of the proposed receiver and of the multipath fading environment will be given and an analytical model of the receiver will be defined in order to evaluate its performance. Simulations will validate this model. Furthermore, the threshold optimization will be accomplished by means of simulations. We assume knowledge of the spreading sequences of all the users.
The fundamental idea is to select the strongest users and then cancel their effects from the received signal. Correlator outputs (in absolute values) are combined by means of Maximum Ratio Combining Algorithm and, successively, passed on to a threshold selector that distinguishes between reliable users (over the threshold) and non-reliable users (below the threshold). The former signals are directly detected, as in a conventional receiver. The latter ones are detected only after performing the cancellation of each replica of the most powerful users from the received signal. To perform cancellation correlator outputs are used, without implementing bit decision, to reconstruct the single replicas of the signals to be cancelled.
At the correlator outputs we get $L \cdot K$ variables $Z_k(j)$ (where j is the path and k is the user). For each user, the values $Z_k(j)$ are added for all paths, as in a conventional rake, according to MRC Algorithm. We obtain K variables Z_k, which will be used to distinguish between reliable and not reliable users, and to decide on the reliable ones' bit sign. At the output of the maximum ratio combining RAKE we get the Z_k variable for each user:

$$Z_k = \frac{1}{2}\sum_{j=1}^{L}\sqrt{2P_k}(\alpha_k^j)^2 b_k + \frac{1}{2}\sum_{j=1}^{L}(n_{kj}^I + n_{kj}^Q) +$$
$$\frac{1}{2}\sum_{p=1}^{L}\sum_{j=1, j\neq p}^{L}\sqrt{2P_k}\alpha_k^p\alpha_k^j b_k(t-\tau_k^p)I_{k,k}(\tau_{k,k}^{j,p};\phi_{k,k}^{j,p}) +$$
$$\frac{1}{2}\sum_{l=1}^{L}\sum_{i=1, i\neq k}^{K}\sum_{j=1}^{L}\sqrt{2P_i}\alpha_k^l\alpha_i^j b_i(t-\tau_i^j)I_{i,k}(\tau_{i,k}^{j,l};\phi_{i,k}^{j,l})$$

A threshold S is considered and compared to variable Z_k. We proceed to a straightforward decision when $Z_k \geq S$ or $Z_k \leq -S$: $\hat{b}_k = +1$ for the former case, $\hat{b}_k = -1$ for the latter; if $Z_k \in \left]-S, S\right[$ we do not assign any value to $\hat{b}_k$, and the decision on the bit is taken only after canceling off the over threshold reconstructed signals.
If the user k is reliable, all the replicas of this user will be cancelled from the received signal. Hence, the user k's signal, regenerated for the cancellation process, will be given by:

$$\sum_{j=1}^{L}\frac{1}{\alpha_k^j}\cdot Z_k(j)\cdot a_k(t-\tau_k^j)\cdot\cos(\phi_k^j)$$

for the in-phase component, and

$$\sum_{j=1}^{L}\frac{1}{\alpha_k^j}\cdot Z_k(j)\cdot a_k(t-\tau_k^j)\cdot\mathrm{sen}(\phi_k^j)$$

for the in-quadrature component.
The multiplication of both in-phase and in-quadrature component by the factor $\frac{1}{\alpha_k^j}$ is due to maximum ratio alghoritm used in the rake receiver.
The signal obtained after the reliable users' interference cancellation is passed again on to rake correlators bank. The unreliable users decision variables $\hat{Z}_k$ are obtained by adding the values $\hat{Z}_k(j)$ for each path. The flow chart of cancellation process in a satellite multipath fading environment is shown in Fig 2.w
As can be seen in the following, one-shot multiuser canceller in satellite channel is effective in facing the impairments due to the multiple access interference (MAI) effects.

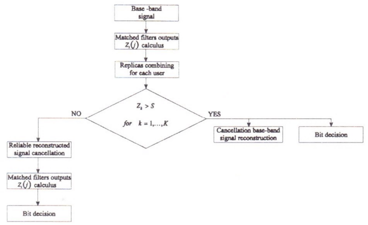

Fig. 2: Multiuser Cancellation Detector Flow Chart.

4. SIMULATIONS RESULTS

In this section the performance of the conventional rake detector and that of the proposed receiver are compared in different interference environments, i.e. in systems whose number of users is equal to 10 and 20. In performing our simulations the following conditions have been assumed:

- Satellite up-link channel for 2 Ghz band;
- Symbol rate for the PSK modulation equal to 78.740 ksymbols/sec;
- Spreading obtained through Gold sequences with processing gain equal to 127;
- Doppler spread equal to 8 Khz.
- User k power P_k equal to 1 $\forall k$ (i.e. free space attenuation is not considered);

The channel model considered is derived from [12]: due to long computation times, the non-stationary multipath fading was modeled in the worst case, i.e. considering not continuos variations. As a consequence extremely high SNR values are not considered in the simulations. In Fig. 3-4 the multiuser canceller performance are compared with conventional rake receiver results, for 10 and 20 users systems respectively, in satellite channel. In both figures the threshold is fixed at 50% of the single user power in the considered channel and the conventional single user rake receiver performance is reported for a comparison. Fig. 5-6 shows how the one-shot receiver performance is influenced by the threshold value. Three curves are shown for different values of SNR. We can observe that the optimum threshold value is almost the same for all SNR considered. This feature is indeed positive towards design and development of the proposed receiver. We can fix the optimum threshold at 40-60% of the single user power in the considered channel. Anyway we can deduce that the one-shot detector shows robustness with respect to eventual estimation error in the determination of the optimum threshold value.

CONCLUDING REMARKS

In this paper a multiuser cancellation detector for DS/CDMA up-link satellite communications has been presented. The proposed receiver has been analyzed in multipath fading channel environment with asynchronous users. The proposed receiver shows performance better than conventional rake receiver scheme with a low complexity increase.

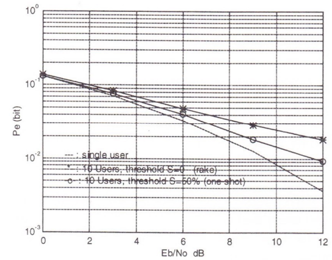

Fig. 3: Multiuser Cancellation Detector Performance in 10 Users Satellite Environment.

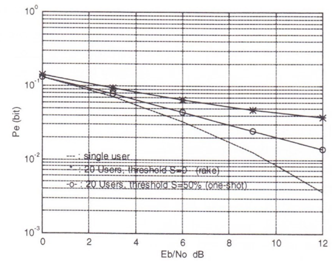

Fig. 4: Multiuser Cancellation Detector Performance in 20 Users Satellite Environment.

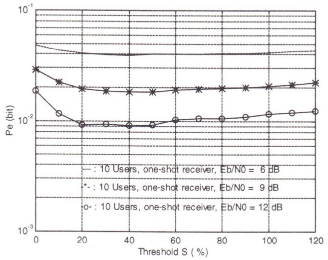

Fig. 5: Multiuser Cancellation Detector Threshold Optimization in 10 Users Satellite Environment.

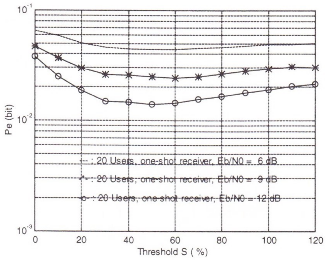

Fig. 6: Multiuser Cancellation Detector Threshold Optimization in 20 Users Satellite Environment.

REFERENCES

[1] Proakis J. G., "Digital Communications", Third Edition, *Mc Graw-Hill,* New York, 1995.

[2] Bueher M., Woerner B.D., "Analysis of Adaptive Multistage Interference Cancellation for CDMA Using an Improved Gaussian Approximation", *Trans. Comm.*, Oct 1996.

[3] Patel P. and Holtzman J. M., "Analysis of a Simple Successive Interference Cancellation Scheme in a DS/CDMA System", *Journal on Selected Areas on Comm.*, June 1994.

[4] Viterbi A.J. , "Very Low Rate Convolutional Codes for Maximal Theoretical Performance of Spread Spectrum Multiple Access Channels", *Journal on Selected Areas on Comm.*, May 1990.

[5] Patel P. and Holtzman J. M., "Analysis of a DS/CDMA Successive Interference Cancellation Scheme Using Correlations", *in Proc. Globecom*, Houston, Tx, 1993.

[6] Teder P., Larsson G., Gudmundson B., Ewerbring M., "CDMA with interference cancellation: a technique for high capacity wireless systems", in *Proc. IEEE Int. Conf. Commun.*, Geneva, Switzerland, 1993.

[7] Dent P., Gudmundson B., Ewerbring M., "CDMA-IC: a novel code division multiple access scheme based on interference cancellation", in *Proc. PIMRC, Boston,* Oct. 1992

[8] Varanasi M. K., Aazhang B., "Multistage detection in asynchronous channels", *IEEE Trans. Commun,* Apr. 1990.

[9] Divsalar D., Simon M. K., Raphaeli D., "Improved Parallel Interference Cancellation for CDMA", *IEEE Trans. Commun.*, Feb. 1998.

[10] Patel P. and Holtzman J. M., "Performance Comparision of a DS/CDMA System Using a Successive Interference Cancellation (IC) Scheme and a Parallel IC Scheme under Fading", *IEEE Magazine,* Jan 1994.

[11] Kohno S. R., Meidan R., Milstein L. B., "Spread-Spectrum Access Methods for Wireless Communications", *IEEE Comm. Magazine*, 1995.

[12] Bischl H., Jahn A., Lutz E., "Wideband Channel Model for UMTS satellite Communications" TD(98)05 Temporary Document inside COSTaction252.