TWO-STATES W-CDMA RECEIVER PERFORMANCE IN A MULTIPATH FADING CHANNEL

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Abstract—**The use of CDMA makes third generation wireless systems interference limited rather than noise limited. The research for new methods to reduce interference and increase efficiency lead us to formulate a signaling method where fast impulsive silence states are mapped on zero-energy symbols. The theoretical formulation of the optimum two-states receiver is reported. The proposed communication scheme has been merged into the 3GPP standard W-CDMA communication system and the performance of the two-states RAKE receiver has been simulated in a multipath fading wireless channel. Comparisons with the traditional one-state RAKE receiver have been also reported in the paper.**

I. INTRODUCTION

Bandwidth represents the last challenge in wireless personal communications. In the third generation communication system, due to the average increase of the radio link bandwidth requirements and the hostile urban radio channel for the interference limited W-CDMA access, the system capacity will meet its physical limitations even in a moderated deployment scenario.

Every technology able to increase the spectral efficiency of the radio link maintaining the compatibility with the approved standards will play a fundamental role for the economical aspects of the UMTS diffusion.

Power consumption at the handheld terminal is another key issue. Mobile phones are requested to operate complex computational tasks at the expense of a reduced duration of the batteries. The techniques able to save energy by optimizing the transmission scheme play a fundamental role in the the design phase.

The idea of a discontinued transmission has been exploited starting from the second generation of personal communication systems with the DTX feature in the GSM standard [1], [2], [3].

Voice activity detectors are designed to exploit the natural pauses in the speech flow to reduce the transmitted power and, consequently, battery life. Transmission silences for voice are modelled as two states Markov chain where the average silences last for seconds [4]. There are however some information sources, like fast variable rate video coders or fast impulsive data sources which are characterized by very short silences, i.e. slotwise or even bitwise.

In the 3GPP standard, due to the complexity constraints at the user equipment, the DTX implementation on the uplink channel is hevily limited. The silence state from the source is mapped on a true suppression of the transmitted signal only if the silence period is longer than a frame, i.e. 10 ms. Thus the power saving only occurs for slow on-off transitions while fast VBR sources result in a continuous trasmission at full rate.

Those considerations lead to the development of the transmission scheme presented in this paper. The basic idea is the extension of the traditional informative symbol set with a *zero energy* symbol. The silence symbols are integrated with the informative ones and delivered to the radio link layer for transmission [4]. The end-to-end signaling between the applications can be avoided and the radio layer does not need to receive any explicit *transmit on/off* commands from higher layers. The proposed reception scheme has also the property of being able to receive common single state transmissions. In this case, the silence symbols thresholds collapse to 0 and the receiver degenerates in a traditional single state receiver.

The advantages of the proposed solution can be summed up in the following list:

- the reduction of the average transmit power from a CDMA terminal, obtained by employing silence symbols, reduces the interference on other users,
- the radio layer need not to be integrated with the silence state management function of the application layer,
- silence symbols allow very short traffic bursts and a great variety of fractional bit-rates without increasing the MAI level.

A theoretical analysis of the performance of the proposed two-states CDMA receiver has been previously published in [5] and [6]. In this paper the proposed communication scheme has been moved into a real 3GPP W-CDMA environment and the performance of the two-states receiver has been taken via computer simulations.

The paper has been organized as follow: in section II the proposed two-states communication strategy is described and the optimum detector is derived. Section III reports the generalized probability of error for a two-states CDMA communication system. The simulated 3GPP W-CDMA environment is also described in the section. Numerical results and conclusions are shown in Section IV and Section V, respectively.

II. TWO-STATES CDMA RECEPTION

With the proposed scheme, the general base-band transmission signal of the kth user is:

$$s_k(t) = \sum_{n=-\infty}^{n=\infty} s_k(t)^{(n)} \qquad (1)$$

$$s_k(t)^{(n)} = A_k m_k^{(n)} b_k^{(n)} g_k^{(n)}(t - nT_s) \qquad (2)$$

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where

$$g_k^{(n)}(t) = \sum_{i=1}^{G} c_k^{(n)}(i) p(t - iT_c)$$

and
T_s is the symbol time,
T_c is the chip time,
$G = T_s/T_c$ is the processing gain,
$A_k = \sqrt{E_k}$ the transmitted amplitude for user k,
$p(t)$ is the complex valued chip waveform due to pulse shaping filter,
$c_k^{(n)}$ is the kth normalized spreading code of user k referred to nth symbol interval,
$m_k^{(n)}$ is the **mask** symbol which assumes one of the two possible values $\{0, 1\}$. It determines the state of the transmitter in the n-th time interval: *Talk* or *Silent*.
$b_k^{(n)}$ is the informative symbol transmitted during the n-th interval, chosen among the symbol alphabet of the chosen modulation (e.g. for a BPSK signaling $b_k^{(n)} \in \{-1, 1\}$). It has no significance when the transmitter is in the *Silent* state.

The received signal $r(t)$ expresses the observable part of the transmission chain. The received signal can be seen as:

$$r(t) = \sum_{k=1}^{K} s_k(t) + n(t) \tag{3}$$

where $n(t)$ is the the white gaussian noise with zero mean and variance σ^2.

The unknown mask and symbol transmitted by the user over the transmission channel can be grouped in the two-state information symbol $q^{(n)}$ defined as:

$$q^{(n)} = m^{(n)} b^{(n)} \tag{4}$$

where we have dropped here the k index for simplicity. The **optimum detector** [7], for a given set of transmitted two-state symbols will choose the symbol $\hat{q}^{(n)}$ corresponding to the largest *posterior probability* based on the observation of $r(t)$ (MAP criterion). Formally:

$$\hat{q}^{(n)} = \arg\max_q P\left(q | r(t)^{(n)}\right) \tag{5}$$

We can assume that the two-states are alternating independently from the informative stream, constituted by M equally probable symbols. This leads to:

$$P\left(q_{talk}\right) = \frac{P\left(talk\right)}{M} \tag{6}$$

$$P\left(q_{silence}\right) = 1 - P\left(talk\right) \tag{7}$$

where $P\left(talk\right)$ is the absolute probability of a talk symbol. The two-state symbol q is thus possibly one of the equally probable M informative symbols or the single "silence" one. The transmission model described above needs a more complex performance characterization with respect to the traditional one. The receiver is characterized by a general *probability of error* which is specialized in:

- probability of false detection of a *silence state*, $P_{e,sil}$
- probability of symbol error conditioned to a talk state, $P_{e,symb}$.

TABLE I
BPSK+ SIGNALING

Symbol	Transmitter state	Informative symbol
q_0	Talk	0
q_1	Talk	1
q_2	Silent	n.a.

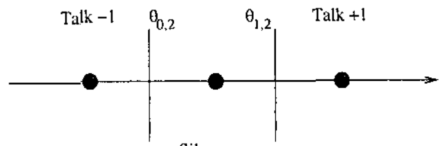

Fig. 1. BPSK+ Decision Regions

In the special case of a BPSK+ (the "plus" symbol indicates the presence of a "silent" state) operating on a AWGN channel, the optimum receiver is defined by the following thresholds:

$$\theta_{0,2} \doteq \frac{\sigma^2}{\sqrt{E}} \ln \frac{P\left(q_2\right)}{P\left(q_0\right)} + \frac{\sqrt{E}}{2} \tag{8}$$

$$\theta_{1,2} \doteq \frac{\sigma^2}{\sqrt{E}} \ln \frac{P\left(q_1\right)}{P\left(q_2\right)} - \frac{\sqrt{E}}{2} \tag{9}$$

Where the symbols are labeled as in table I, and E is the talk symbol energy.

The decision regions for the described receiver, with h being the observable metric, are described by:

$$\begin{cases} h < \theta_{1,2} & \text{the symbol } q_1 \text{ is selected} \\ \theta_{1,2} \leq h < \theta_{0,2} & \text{the symbol } q_2 \text{ is selected} \\ \theta_{0,2} \leq h & \text{the symbol } q_0 \text{ is selected} \end{cases} \tag{10}$$

The decision regions are represented in Fig. 1.

III. Error and False Alarm Probability

After each received symbol, the proposed *two states* reception scheme belongs to one of the possible states derived from the combination of both the transmitter and the receiver ones. This concept is explained in Table II. The columns represents the possible receiver decisions while the rows enumerate the transmitter symbols. The elements inside are called "conditions" of the whole reception system (i.e. transmitter + receiver).

The **False Alarm** condition is met when the Talk/Silence status is misinterpreted. An **Error** occurs when the transmitter is in the Talk state but the symbol is not correctly detected. The **Correct** condition is self explanatory. In order

	Rx q_0	Rx q_1	Rx q_2 (silence)
Tx q_0	Correct	Error	False Alarm
Tx q_1	Error	Correct	False Alarm
Tx q_2	False Alarm	False Alarm	Correct

TABLE II
THE SET OF SYSTEM STATES

to provide the two states receiver with a performance index suitable for a comparison with the traditional reception, we consider the *generalized probability of error* or P_{eg} defined as:

$$P_{eg} = \Pr(\text{Error}|\text{Talk}) \cup \Pr(\text{False Alarm}|\text{Talk}) \quad (11)$$

The cited index takes into account all the potential errors the receiver may commit when the transmitter is in the talk state. It should be noted that the two state system provides more information than the traditional "always on" reception, the additional information is transmitted at the expense of a reduced noise margin for the decision regions. This fact makes the comparison with the traditional system a difficult task.

In this paper the comparison has been carried out via computer simulations and the Bit Error Rate (BER) of the proposed two-states receiver has been evaluated with the same throughput of the traditional one-state receiver. A W-CDMA communication environment has been built up following in the 3GPP standard specifications [8]. The complex envelope of the received DPDCH at symbol time n can be written

$$r^{(n)}(t) = \sum_{k=1}^{K} A_k b_k^{(n)} \sum_{l=1}^{L} h_{k,l}^{(n)} g_k(t - nT_s - \tau_k - \tau_{k,l}) + n(t) \quad (12)$$

where $n(t)$ is the complex AWG (Additive White Gaussian) noise with zero mean and variance σ^2, while the entire received signal is

$$r(t) = \sum_{n=0}^{N_b-1} r^{(n)}(t) \quad (13)$$

where N_b is the number of observed symbols. An *asynchronous* W-CDMA system implies that users delays τ_k are uniformly distributed random variable into interval $[0, T_s)$ $\forall k$. This property is extended to the user paths in a multipath fading channel scenario, so that $\tau_{k,l}$ are uniformly distributed in the interval $[0, T_s)$ $\forall k, l$. This fact comes from the assumption that the transmitted signals pass through separated and independent channels in an asynchronous system. It is assumed here that the channel acts like a linear filter with impulse response $h_k^{(n)}(t)$ and consists of L discrete multipath components.

The matched filter (MF) outputs of all users and multipath components produce sufficient statistics for the detection of data symbols [9]. The sampled output of the matched filter of the kth user lth path on symbol interval n, is

$$y_{k,l}^{(n)} = \int_{nT_s+\tau_k+\tau_{k,l}}^{(n+1)T_s+\tau_k+\tau_{k,l}} r(t) g_k(t - nT_s - \tau_k - \tau_{k,l}) dt \quad (14)$$

A sub-urban multipath fading channel with $L = 4$ independent paths has been simulated. Channel coefficients are supposed to have a Rayleigh distributed amplitude and uniform distributed phase. Classical Jake's Doppler spectrum is assumed with 100Hz Doppler spread. Both DPDCH (data) and DPCCH (control) have been simulated although only data channel is considered in the BER calculation.

It is important to highlight that the two-states optimal threshold has been derived for a single-user AWGN channel, and it does not take into account the presence of the multiple access interference as well as the fading process. Thus, the performance of the two-states CDMA receiver reported in the paper has to be considered as a worse estimate. Results with the optimal two-states threshold for a multipath-multiuser channel will be soon available.

IV. Numerical Results

The dependence of the probability of error from the operating point of the proposed CDMA communication scheme has been analyzed; the same operating condition have been then applied to the conventional single-state receiver and the resulting performances compared to those obtained by the proposed two-states communication scheme in a W-CDMA communication environment following the 3GPP specifications.

The comparison between the proposed two-states RAKE receiver and the conventional one-state receiver has been carried out in the following summarized cases:

1. 4 users @ 960kbs (100% of the system load) with a $P(talk)$ ranging from 0.5 to 0.0625;
2. 8 users @ 240kbs (50% of the system load) with a $P(talk)$ ranging from 0.5 to 0.0625;
3. 8 users @ 480kbs (100% of the system load) with a $P(talk)$ ranging from 0.5 to 0.0625;

A multipath relatively fast fading channel with 4 independent paths shared by the 8 asynchronous users is supposed.

In Figs. 2, 3 and 4 are shown the ternary symbol error rate of the two-states CDMA receiver and the bit error rate for the single-state receiver. The curves are reported for different values of the SNR and different values of $P(talk)$ (for the two-states receiver only). All simulations assumed the same throughput for the two compared communication systems. In the high $P(talk)$ region the performances of the proposed scheme are not significantly different than the traditional single-state receiver. For quasi-continuous sources the presence of a third decision region results in a higher probability of error when the trasmitter is in the talk state. As the probability of a talk symbol decreases, the two-states transmission method performs significantly better the the standard one, since the frequent but short silences reduce the average MAI interference without any signaling overhead.

All these results coupled with the lower power consumption, lead us to conclude that the proposed CDMA communication scheme is able to get practical advantages over the traditional W-CDMA communication systems.

V. Conclusions

In this paper a new CDMA transmission scheme based on a variable energy symbols constellation called "two-states" transmission is presented. Simulations show the convenient use of the proposed signaling method in W-CDMA systems where MAI and power consumption are the dominant limiting factors. Performance evaluation and comparison based on the Symbol error rate of the conventional one-state and two-states RAKE receivers have been reported. The use of the silence symbol saves power at the handheld terminal and reduces MAI on the overall access scheme. Hence, the proposed communication scheme is able to get practical advantages over the traditional single-state communication scheme, especially for fast varying data traffic.

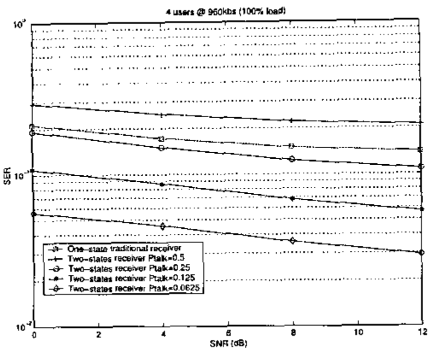

Fig. 2. Symbol Error Rate as a function of the average SNR with 4 asynchronous users @ 960kbs (100% system load) for various $P(talk)$

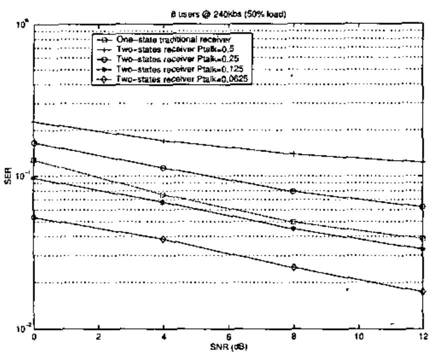

Fig. 3. Symbol Error Rate as a function of the average SNR with 8 asynchronous users @ 240kbs (50% system load) for various $P(talk)$

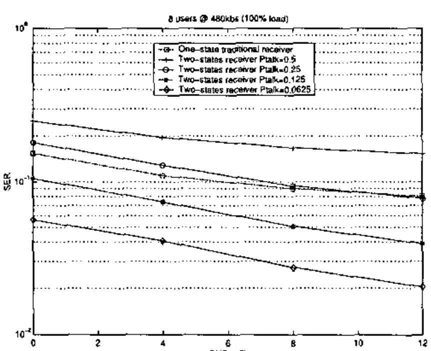

Fig. 4. Symbol Error Rate as a function of the average SNR with 8 asynchronous users @ 480kbs (100% system load) for various $P(talk)$

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