

Return Link 2-D Code Acquisition for DS-CDMA in a High Capacity Multi-user System

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Abstract — Acquisition of the code timing in a direct-sequence code-division multiple-access system with antenna arrays must take place before signal detection and decoding is possible. Code acquisition under severe multiple access interference conditions with time varying codes makes the task even more difficult and has been shown to limit the capacity of the system. This paper details a powerful code acquisition technique for the uplink of direct-sequence code-division multiple-access systems under high loaded situations, where the number of users is greater than the addition of the spreading factor and the number of antenna elements. The method discussed utilises soft data from the multi-user detector to reduce the interference received by the acquisition unit. Numerical performance in terms of the probability of missed detection and the probability of false alarm is shown.

I. INTRODUCTION

The introduction of cellular wireless systems in the 1980s has resulted in a huge demand for personal communication services. This demand has increased the need for efficient systems, which has been partially satisfied by the introduction of second generation digital systems, where some are based on direct-sequence code-division multiple-access (DS-CDMA). New third generation systems, almost all based on DS-CDMA, are now being deployed and will require even more efficient utilisation of the spectrum if the high bandwidth features are to become a reality.

In the Uplink of a DS/CDMA cellular communication system it is well known that the limiting factor on performance is due to interference from other users, i.e. Multiple Access Interference (MAI). To mitigate this effect a large body of research work has been performed to find receiver methods of minimising the MAI, called multi-user detection (MUD) [1]. The most powerful technique to date is based on Iterative multi-user detection [2, 3]. Although these receiver techniques bring large improvements, further gains are sought. Antenna arrays can be included in the iterative MUD scheme and performance has been shown, for example, in [4]. System performance in terms of capacity and cell size improvements was shown in [5]. This paper focuses on acquisition of multi-user DS/CDMA where an antenna array is used by

the receiver.

Efficient timing acquisition in DS-CDMA systems with antenna arrays is necessary to maximise the capacity of a receiver that utilises an antenna array. A technique for single user acquisition was first proposed in [6], a multi-user approach utilising a subspace technique was proposed in [7], however, the authors used a system where the number of users was only equal to the processing gain. The effective processing gain is actually the product of the number of antenna elements with the processing gain of the spreading code. In [8] the authors studied 2-D code acquisition, however they treated the interfering users as noise. As we will show the performance of a system that performs a 2-D acquisition as well as interference cancellation can significantly outperform a system that treats multiple access interference (MAI) as noise. In [9] a 2-D code acquisition approach based on antenna arrays and least mean square (LMS) is presented.

In this paper we show acquisition under loadings much higher than the product of the number antenna elements with the processing gain, therefore removing the capacity limitations caused by code acquisition. The technique described has been patented under [10].

The paper is organised as follows. In Section II we discuss the system model. Section III describes the data directed acquisition approach. An analytical study is detailed in Section ?? before analytical and simulation results are presented in Section IV. Finally conclusions are drawn in Section V.

II. SYSTEM MODEL

We shall employ a model where we assume that $K+1$ users each transmit symbols $d_t^{(k)}$ via QPSK modulation of the length N spreading codes $\underline{s}_{c,t} \in \{(\pm 1 \pm j)/\sqrt{N}\}^N$, where t is the time index and c is a chip index and the underline represents vector notation. Note that our model uses random complex spreading codes which are selected only once for the user of interest but are time varying for the interfering users. In this model we assume no modulation or data encoding for the user of interest (i.e. $d_t^{(1)} = +1$), as would be the case for the preamble of 3GPP [11].

The transmitted baseband signal for all users at time

t and chip interval k is then

$$x_{c,t} = \sum_{k=2}^{K+1} s_{c,t}^{(k)} d_t^{(k)} + s_{c,t}^{(1)} \quad (1)$$

The channel adds zero mean complex white Gaussian noise (AWGN) with variance $\sigma^2 = N_0/2$, where N_0 is the single sided noise power spectral density. The channel output is therefore

$$\begin{aligned} y_{c,t} &= \sum_{k=2}^{K+1} s_{c,t}^{(k)} d_t^{(k)} + s_{c,t}^{(1)} + n_{c,t} \\ &= g_{c,t} + s_{c,t}^{(1)} + n_{c,t} \end{aligned} \quad (2)$$

where the noise term $n_{c,t}$ is normal distributed $N(0, \sigma_n^2)$. The first line shows the user of interest separate from the K interfering users while the second line shows the MAI as $g_{c,t}$. Without loss of generalisation synchronous chip and symbol timing is assumed, therefore square chip pulses are used. As random code MAI is generated the same result would be expected for a symbol asynchronous system. We assume perfect carrier synchronisation and that there is no frequency uncertainty. The results, however, are easily extendable to systems that assume frequency offsets. The system model also assumes no multi-path. The system assumes no time variation during acquisition, such as time drift or change in channel conditions.

The signal received by an E element Uniform Linear Array (ULA) can be described as

$$\begin{aligned} y_{l,c,t} &= \sum_{k=2}^{K+1} s_{l,c,t}^{(k)} d_t^{(k)} + s_{l,c,t}^{(1)} + n_{l,c,t} \\ &= g_{l,c,t} + s_{l,c,t}^{(1)} + n_{l,c,t} \end{aligned} \quad (3)$$

where l is the element number and is a value between 1 and L . Using vector notation to represent the antenna array we have

$$\begin{aligned} \underline{y}_{c,t} &= \sum_{k=2}^{K+1} \underline{e}^{(k)} s_{c,t}^{(k)} d_t^{(k)} + \underline{e}^{(1)} s_{c,t}^{(1)} + \underline{n}_{c,t} \\ &= \underline{e}^{(k)} g_{c,t} + \underline{e}^{(1)} s_{c,t}^{(1)} + \underline{n}_{c,t} \end{aligned} \quad (4)$$

where $\underline{e} = [1, e^{-j l \cos(\theta^{(k)})}, \dots, e^{-j(L-1) \cos(\theta^{(k)})}]^T$ is the steering vector and $\underline{n}_{c,t}$ is a vector of L noise terms.

III. ACQUISITION WITH ITERATIVE MUD UNDER HIGH MULTIPLE ACCESS INTERFERENCE

In conditions where the number of users (K) is larger than the processing gain (N) traditional code acquisition techniques based on correlation techniques fail. This is because the integration time required to detect a path is typically longer than the time that the channel is stationary. The acquisition performance is also interference limited so that regardless of the amount of time

provided for integration, the acquisition performance is limited due to the interference. Acquisition performance suffers from noise and interference from other users. In the uplink of a mobile cellular system the base-station receiver is assumed to use a high performance multi-user receiver. This receiver contains information about the signals from the users that are currently being detected. These signals cause the MAI in the acquisition unit which is looking for new users (users not currently known to the receiver).

Initially the base station is turned on and no terminals are connected, over time callers connect and disconnect. The receiver detects the data for all users connected. The iterative MUD techniques [3, 4] know a very good estimate of the baseband spread signal that it received at its input. If the receiver cancels the input baseband signal against the receiver estimate for every connected user then what is left is system noise, noise from incorrect estimation of signals, and signals from unknown users, or unknown paths of currently tracked users. If the signal estimates from the currently tracked users is “good” then the remaining cancelled signal can be processed by a conventional correlator to find new users or new paths of currently tracked users. The definition of a “good” signal from the receiver is subjective, however, the received signal must be of a high enough signal to noise ratio after interference cancellation such that the frame error rate conditions (QoS conditions) are met. If this was not the case this user would be dropped by the receiver as part of the Radio Resource Controller (RRC).

We now show the formulation of the technique. We assume the received spread signal, $y_{c,t}$, now consists of both signals that are being tracked by the receiver $g_{c,t}$ and one new signal $s_{c,t}^{(1)}$. The decision directed approach then computes

$$\underline{w}_{c,t} = \underline{y}_{c,t} - \underline{\tilde{g}}_{c,t} \quad (5)$$

where $\underline{\tilde{g}}_{c,t}$ is the sum of an estimate of the spread signal sent by users $k = 2 - K$. The iterative multi-user detection technique discussed in [4, 5] is well suited to this decision directed approach as the receiver has available the spread signal estimates as they are needed for the receiver implementation. The added complexity of the implementation is therefore very low. Figure 1 shows the implementation. Essentially the idea is that soft information from the multi-user receiver (which is the receiver’s best guess at the input signals) is subtracted from the input signal. If the receiver’s guess is perfect then the remaining signal only contains noise and signals from new users or paths which are trying to connect to this base station receiver. A beamformer followed by a correlator can then be used to acquire these signals. It is clear that the performance of this system relies heavily on the performance of the receiver. This paper says nothing about the architecture of the beamformer and acquisition unit only that it follows the cancellation of the input signal against the receiver estimate of the input

signal.

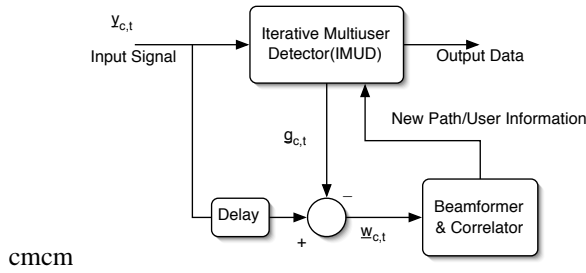


Fig. 1: Decision Directed Acquisition Unit.

Figure 1 also highlights the need for a delay between the input signal and the cancellation process. This is because the IMUD requires a certain amount of time to determine its estimate of the received signal.

Before correlation can be performed beamforming needs to be performed, this is performed by multiplying by the transpose of the steering vector, this is equivalent to a sum of weighted (phase rotated) signals and is

$$w_{c,t} = (\underline{e}^{(i)})^\top \underline{w}_{c,t} \quad (6)$$

where the transpose steering vector is for the i^{th} sector of interest. The space is broken down into sectors, whereby in each sector time correlation is performed before moving to the next sector. Following beamforming the received signal is convolved with the time reversed complex conjugate of the wanted transmitted sequence such that the timing position can be determined. This method is based on the conventional correlation approach. The resultant signal is

$$r_{c,t} = \left| \sum_{c=1}^N w_{c,t} (s_{c,-t}^{(1)})^\top \right| \quad (7)$$

where the absolute value is taken as the phase of the signal is unknown.

IV. NUMERICAL PERFORMANCE RESULTS

In this section we show results from our simulation. The simulation consists of transmitting $T = 2500$ symbols where the codes for the multiple access interference are randomly selected for each symbol interval and for each user. The system is chip and symbol synchronous and all users have the same power. The number of users was $K = 500$ and the processing gain of each spreading code was $N = 100$. The $E_s/N_0 = 7\text{dB}$ and the cancellation factor for the partial cancellation case was set to 0.2, or $\sigma_x^2 = 0.04$. The direction of arrival of the interfering users was normally distributed between 30 and 150 degrees, as would be the case for a 3 sector cellular configuration. The antenna array is assumed to be a ULA with half wavelength spacing of the antenna elements.

In Figure 2 we show the performance of the full interference, no interference (single user) and partial cancellation cases. We compare the performance for a single antenna (solid line) to the results (points) for a ULA with 5 elements. As can be seen the performance of the partial cancellation scheme is substantially better than that of the full loaded system. For example, fixing a $P_{fa} = 10^{-2}$ the single user (no interference) $P_{md} \approx 0.1$ while the partial cancellation result is $P_{md} \approx 0.49$. In comparison to the fully loaded system where $P_{md} = 1$, ie. 100% of detections would be missed. As explained earlier, the scenario where $\sigma_x^2 = 0.04$ represents a realistic cancellation noise factor from the MUD receiver based on a $P_e = 10^{-2}$.

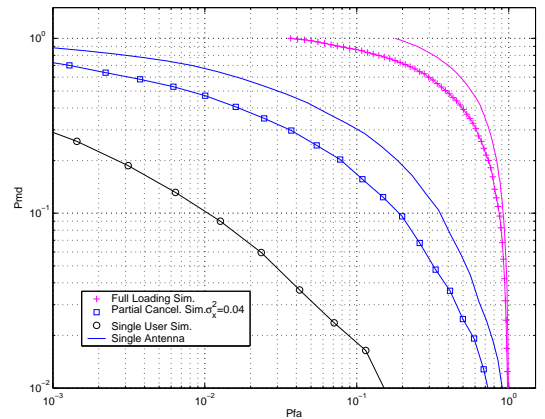


Fig. 2: Performance of the 2-D Acquisition Unit.

This paper does not say anything about the correct design points for P_{fa} and P_{md} as this depends on numerous system issues including the amount of correlation integration time used, channel variation and frequency offset specifications.

V. SUMMARY

In this paper we have investigated an acquisition technique based on the utilisation of an antenna array and soft data directed assistance from the receiver. This has been performed under severe multiple access interference, where the number of users is equivalent to the product of the processing gain with the number of antenna elements.

We derive the system model and the acquisition approach and compare the performance to the case with a single antenna and multiple antennas. We show that although antenna arrays improve performance in a MAI environment, the improvement is not large and it is only with the inclusion of interference cancellation by using information from the receiver that reasonable performance is attainable.

In conclusion this paper demonstrates that for systems utilising antenna arrays and high performance multi-user detection designs that information sharing be-

tween the correlator unit and the receiver is essential to achieve acquisition of new users, or new paths of current users. This technique shows how one can overcome the the capacity limitation due to signal synchronisation.

VI. REFERENCES

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