



Receiver method and apparatus for space-time coded CDMA signals

Field of the invention

The present invention relates to code-division-multiple access (CDMA) wireless communication systems, in which a base station transmits a
5 respective CDMA signal to each of multiple receivers. In particular, the present invention relates to methods and receivers for recovering data from the CDMA signal transmitted by the base station.

Background of Invention

WCDMA is a crucial technology for the third-generation (3G) wireless
10 communication systems. In a WCDMA downlink system shown generally in Fig. 1(a), a base station 1 sends downlink signals (indicated as 3) to multiple receivers 5, a term which is used here to include, but not be limited to, mobile phones. Each receiver 5 is associated with a respective user. Note that usually there are multiple base stations 1 in the entire communications
15 system. Each base station defines a respective cell.

The downlink signals for the multiple mobile phones 5 are spread by respective orthogonal spreading codes. The spread signals for all users are combined together synchronously. The sum is scrambled by a long pseudo-noise code and transmitted. The transmitted signals from one cell are
20 orthogonal to each other. However, due to multipath propagation in practical environments, the orthogonality of the received signals at a mobile receiver 5 is reduced seriously. Thus, the desired user's signal is interfered by other users' signals. Multiple-access interference (MAI) is caused. MAI degrades the receiving performance dreadfully. Some MAI suppression methods have
25 been proposed in the literature [6-10]. These methods are based on known channel information, which can be obtained by channel estimation techniques.

In Singapore patent application no. 200006535-9, the disclosure of which is incorporated herein by reference although the application had not been published by the effective filing date of the present application, the present inventor proposed a receiver for CDMA signals in which data intended for transmission to multiple intended receivers is spread by respective orthogonal spreading codes and scrambled by an aperiodic random scrambling code. The receiver includes a processing branch for each of one or more base stations from which the receiver may pick up CDMA signals. Each processing branch performs both channel equalisation based on a set of weights for that branch, and a decoding operation. The outputs of the branches are combined to produce a combined signal which is used both for determining the data intended for the receiver and in a feedback loop to improve the sets of weights. The receiver is reliable even in the presence of multipath fading and during soft handover, and does not require channel estimation as such.

The system is not, however, suitable for receiving signals according to another recently proposed coding technique: space-time coded signals (a term used here to be synonymous to transmission diversity coding). Such coding schemes are based on transmission diversity to improve the signal quality [1-3]. Space-time coding can obtain great diversity-gain in both space and time domains, so the receiving performance is expected to be better than that of a single transmission antenna case. The overall scheme of a space-time coding transmitter is shown in Fig. 1(b), where the signals to be transmitted to multiple users are input (within the base station) from the left of Fig. 1(b) to a space-time coding unit 7, and used to generate M signals to be transmitted simultaneously by M antennas. Each antenna has a respective channel (generally a multipath channel) to a given mobile receiver 5 associated with a given one of the users. The receiver 5 receives all M signals and attempts to reconstruct the data for the corresponding user.

Summary of the invention

The present invention aims to provide a new and useful receiver for CDMA signals, and a new method for receiving CDMA signals.

5 In general terms, the present invention proposes that the receiver includes a processing branch for each of the multiple transmitted signals produced by a base station employing space-time coding. Each branch includes a corresponding adaptive filter and a decoder which receives the spreading codes for the user associated with the receiver. The outputs of all the
10 branches are transmitted to a space-time decoder where they are used in combination to obtain an estimate of the data intended for the corresponding user.

A receiver according to the invention may be suitable for receiving
15 transmission diversity multiple access code division (CDMA) signals in third generation cellular wireless communication systems. In particular the multiple adaptive filters can provide multiple access interference (MAI) suppression by each functioning as an adaptive multi-branch channel equalizer for a multipath fading channel corresponding to one of the transmitter aerials.

20 The adaptive filters are preferably modified during a learning phase using a feedback based on a comparison of the output of the space-time decoder with known training data. This avoids the need for a channel estimator to be provided for each of the channels. Note that the equalizer branches
25 preferably do not include channel estimation.

Thus the present invention makes it possible to suppress MAI in transmission diversity CDMA downlink signals without any channel estimation, and thus

may provide improved receiving performance as compared with existing downlink MAI suppression methods.

Specifically, in a first aspect the present invention proposes a receiver for a
5 communications system including a base station and a plurality of receivers, the base station being arranged to encode the data intended for each of the receivers using a respective spreading code for that receiver, combine the encoded data for the receivers and re-encode it using space-time coding, and transmit the re-encoded signal through multiple antennas;

10 the receiver including:

reception means for receiving the transmitted signals;

a branch processing means for each of the antennas and arranged to receive the output of the reception means, each branch processing means comprising:

15 (i) a data equaliser based on a respective filter employing a plurality of weights; and

(ii) a decoder for decoding the output of the data equaliser using the spreading code associated with the receiver; and

20 decision means for subjecting the outputs of the branch processing means to space-time decoding to obtain an estimate of the data intended for transmission to the user associated with the receiver.

In a second aspect the invention proposes a method of extracting data intended for a first user from signals transmitted by multiple antennas, the transmitted signals being derived by encoding data to be transmitted to each
25 of a plurality of users using a respective spreading code and re-encoding a

combination of the encoded data using space-time coding, the method including:

receiving the transmitted signals;

transmitting the received signal to each of a plurality of branch
5 processing means, each branch processing means comprising:

(i) a data equaliser based on a respective filter employing a plurality of weights; and

(ii) a decoder for decoding the output of the data equaliser using the spreading code for the first user; and

10 subjecting the outputs of the branch processing means to space-time decoding to derive an estimate of the data intended for the first user.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of
15 illustration only, with reference to the following figures in which:

Fig. 1 is composed of Fig. 1(a) showing a known CDMA downlink system, and Fig. 1(b) showing a known transmission system including a space-time coding unit; and

Fig. 2 shows the structure of a receiver according to the present
20 invention.

Detailed Description of the embodiments

To define the present invention, we firstly define the terminology which is to
25 be used. In this notation the known transmission diversity CDMA system (as shown in Fig. 1) is defined such that:

- 1) The downlink of a cellular communication system is the signal transport from the base station 1 to mobile phone 5;
- 2) The transmitter on the base station side has M transmission antennas, $M \geq 2$ labelled by an integer index m in the range 1 to M . The receiver in the mobile phone 5 has just one antenna.
- 3) The multipath-fading channel from the transmission antenna m in the base station to the receiving antenna of the mobile phone is denoted as $\mathbf{H}_m$, where $\mathbf{H}_m$ is a matrix containing the unknown channel parameters.
- 4) The sum of transmitted signals for all users having receivers 5 in the base station can be denoted as a series of column vectors $\mathbf{S} \in \mathbb{C}^{M \times 1}$. The m -th element, $\bar{s}_m$, of $\mathbf{S}$ denotes the signal waveform at symbol duration $(i-1)M + m$, where i denotes the i th received symbol.
- 5) The signal vector $\mathbf{S}$ is coded using a space-time coder 7 and the coding output consists of M sub-vectors $\mathbf{S}_1$ to $\mathbf{S}_M \in \mathbb{C}^{M \times 1}$. The transmitted signals for all users transmitted by each transmission antenna are orthogonal to each other.
- 6) Multiple access interference (MAI) denotes undesired users' signals interfering with the desired user's signal (i.e. the user operating receiver 5).

The received signal vector at the desired user's receiver 5 can be represented as follows,

$$\mathbf{y}(i) = \sum_{m=1}^M \mathbf{H}_m \mathbf{S}_m(i) \quad (1)$$

where

$$\mathbf{H}_m = \underbrace{[\mathbf{h}_m, \mathbf{h}_m]}_M, \quad \mathbf{h}_m = \begin{bmatrix} h_m(L) \cdots h_m(1) 0 0 \cdots 0 \\ 0 h_m(L) \cdots h_m(1) 0 \cdots 0 \\ \vdots \quad \quad \quad \vdots \\ 0 \cdots 0 0 h_m(L) \cdots h_m(1) \end{bmatrix} \quad (2)$$

and where, $h_m(l)$ is the channel parameter of path l in channel m . There are L

paths in each channel.

For example, when $M = 2$,

$$\mathbf{S}_1 = \begin{bmatrix} \bar{S}_1(2(i-1)+1) \\ \bar{S}_1(2(i-1)+1) \end{bmatrix}, \mathbf{S}_2 = \begin{bmatrix} \bar{S}_2(2(i-1)+2) \\ -\bar{S}_2(2(i-1)+2) \end{bmatrix}, \quad (3)$$

5 where

$$\bar{S}_1(2(i-1)+1) = \sum_k \overline{spm}(2(i-1)+1) \cdot b_k(2(i-1)+1) \cdot \bar{c}_k \quad (4)$$

$$\bar{S}_2(2(i-1)+2) = \sum_k \overline{spm}(2(i-1)+2) \cdot b_k(2(i-1)+2) \cdot \bar{c}_k \quad (5)$$

and where $\overline{spm}(i)$ denotes the scrambling code with N chips of the base station at symbol duration i , $\bar{c}_k(i)$ is the spreading code with N chips for the user k , $b_k(i)$ denotes the i th symbol of the user k , and “.” denotes dot multiplication.

The receiver structure according to the embodiment of the invention is shown in Fig.2. The received signal, containing the data for multiple users, is input from the left of Fig. 2, and is firstly organized as a signal matrix by an input data matrix unit 11.

This signal matrix is simultaneously fed to each of M equalizer branches, labeled by integer index m in the range 1 to M . Each m -th branch comprises a channel equalizer 13 m controlled by a corresponding adaptive algorithm 15 m , and a corresponding descrambling/despreading unit 17 m . Each descrambling/despreading unit 17 m receives the same despreading and descrambling codes (the codes for the user associated with this receiver device 5) in each branch from a unit 19. The despread and descrambled results for each branch are space-time decoded together by a space-time decoding unit 21.

During a learning phase, the detected symbol (M parallel symbols at any one time) from the space-time decoding unit 21 are compared with reference data (training sequence) to obtain M error signals associated with each of M multipath channels. Each error signal will be used by the adaptive algorithm
 5 15m of a corresponding one of branches to adjust the tap weights of the corresponding equalizer 13m. By the above process, each equalizer branch m will equalize one of the M multipath channels which the transmission diversity signal passes through. Since the multipath effect is removed, the MAI is suppressed. Furthermore, due to the diversity gain, the equalizer and
 10 MAI suppression performance will be much better than those of existing downlink MAI suppression methods.

The mathematical representation of the above process is as follows:

First, the received signal vector is

$$15 \quad \mathbf{y}(i) = [y_1((i-1)N+1) \cdots y_1(iN+L-1)]^T \quad (6)$$

where $[\]^T$ denotes transpose.

Using three neighboring receiver signal vectors one can form the following received signal matrix:

$$\mathbf{Y}(i) = \begin{bmatrix} y((i-1)N-G+1) \cdots y((i-1)N-G+N) \\ \vdots \quad \quad \quad \vdots \\ y((i-1)N+1) \quad \cdots \quad y((i-1)N+N) \\ \vdots \quad \quad \quad \vdots \\ y((i-1)N+G+1) \cdots y((i-1)N+G+N) \end{bmatrix}. \quad (7)$$

20 Here G is a constant, and 2G+1 is equal to the length of the equaliser.

We construct the descrambling/depreading vector of user k as

$$\mathbf{C}_k(i) = [\overline{spm}(2(i-1)+1), \overline{spm}(2(i-1)+2)]^T \cdot * [\bar{\mathbf{c}}_k, \bar{\mathbf{c}}_k]^T. \quad (8)$$

Let $\mathbf{w}_m(i)$ be the weight vector for m th equalizer branch at i th symbol duration. When $M=2$, the adaptive algorithm is as follows:

$$\begin{cases} \hat{b}_k(2(i-1)+1) = \mathbf{w}_1(i)^H [\mathbf{Y}(i), \mathbf{Y}(i)] \mathbf{C}_k^*(i) \\ \hat{b}_k(2(i-1)+2) = \mathbf{w}_2(i)^H [\mathbf{Y}(i), -\mathbf{Y}(i)] \mathbf{C}_k^*(i) \end{cases} \quad (9)$$

$$\begin{cases} e_1(i) = d_k(2(i-1)+1) - \hat{b}_k(2(i-1)+1) \\ e_2(i) = d_k(2(i-1)+2) - \hat{b}_k(2(i-1)+2) \end{cases} \quad (10)$$

5

The weights are now updated iteratively. Updating the weights by a steepest descent algorithm gives an update of:

$$\begin{cases} \mathbf{w}_1(i+1) = \mathbf{w}_1(i) + \mu [\mathbf{Y}(i), \mathbf{Y}(i)] \mathbf{C}_k^*(n) e_1^*(n) \\ \mathbf{w}_2(i+1) = \mathbf{w}_2(i) + \mu [\mathbf{Y}(i), -\mathbf{Y}(i)] \mathbf{C}_k^*(n) e_2^*(n) \end{cases} \quad (11)$$

Alternatively, if all the weights are updated by an RLS algorithm, then in each iteration:

10

$$\begin{cases} \mathbf{w}_1(i+1) = \mathbf{w}_1(i) + \mathbf{R}_1^{-1}(i) [\mathbf{Y}(i), \mathbf{Y}(i)] \mathbf{C}_k^*(n) e_1^*(n) \\ \mathbf{w}_2(i+1) = \mathbf{w}_2(i) + \mathbf{R}_2^{-1}(i) [\mathbf{Y}(i), -\mathbf{Y}(i)] \mathbf{C}_k^*(n) e_2^*(n) \\ \mathbf{R}_1^{-1}(i) = \mathbf{R}_1^{-1}(i-1) - \frac{\mathbf{R}_1^{-1}(i-1) [\mathbf{Y}(i-1), \mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1) ([\mathbf{Y}(i-1), \mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1))^H \mathbf{R}_1^{-1}(i-1)}{1 + ([\mathbf{Y}(i-1), \mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1))^H \mathbf{R}_1^{-1}(i-1) [\mathbf{Y}(i-1), \mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1)} \\ \mathbf{R}_2^{-1}(i) = \mathbf{R}_2^{-1}(i-1) - \frac{\mathbf{R}_2^{-1}(i-1) [\mathbf{Y}(i-1), -\mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1) ([\mathbf{Y}(i-1), -\mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1))^H \mathbf{R}_2^{-1}(i-1)}{1 + ([\mathbf{Y}(i-1), -\mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1))^H \mathbf{R}_2^{-1}(i-1) [\mathbf{Y}(i-1), -\mathbf{Y}(i-1)] \mathbf{C}_k^*(i-1)} \\ \mathbf{R}_1^{-1}(0) = \mathbf{R}_2^{-1}(0) = \delta I \end{cases} \quad (12)$$

where μ is the step-size of the adaptive algorithm, I is the identity matrix, δ is a small value constant, $d_k(i)$ is the training data, $\hat{b}_k(n)$ is the estimated symbol and $()^H$ means the Hermitian transpose.

15

This method can efficiently suppress MAI in transmission diversity CDMA downlink signals. Its BER performance is much better than that of existing downlink MAI suppression methods.

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This method can directly be used in a 3G mobile phone system employing base station transmission diversity WCDMA. Moreover, it can be used in a high speed downlink packet access (HSDPA) mobile terminal. HSDPA is an upgraded modification of the current 3G WCDMA standard.

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Claims

1. A receiver for a communications system including a base station and a plurality of receivers, the base station being arranged to encode the data intended for each of the receivers using a respective spreading code for that receiver, combine the encoded data for the receivers and re-encode it using space-time coding, and transmit the re-encoded signal through multiple antennas;

the receiver including:

reception means for receiving the transmitted signals;

- 10 a branch processing means for each of the antennas and arranged to receive the output of the reception means, each branch processing means comprising:

(i) a data equaliser based on a respective filter employing a plurality of weights; and

- 15 (ii) a decoder for decoding the output of the data equaliser using the spreading code associated with the receiver; and

decision means for subjecting the outputs of the branch processing means to space-time decoding to obtain an estimate of the data intended for transmission to the user associated with the receiver.

- 20 2. A receiver according to claim 1 further comprising:

error signal generation means for, during a learning phase, generating error signals from the outputs of the decision means; and

adaptation means for adapting the sets of weights using the error signals.

3. A receiver according to claim 1 or claim 2, for use in a communications system in which the CDMA signal transmitted by the base station is encoded using a scrambling code, said decoders being supplied with the scrambling code.

5 4. A method of extracting data intended for a first user from signals transmitted by multiple antennas, the transmitted signals being derived by encoding data to be transmitted to each of a plurality of users using a respective spreading code and re-encoding a combination of the encoded data using space-time coding, the method including:

10 receiving the transmitted signals;

transmitting the received signal to each of a plurality of branch processing means, each branch processing means comprising:

(i) a data equaliser based on a respective filter employing a plurality of weights; and

15 (ii) a decoder for decoding the output of the data equaliser using the spreading code for the first user; and

subjecting the outputs of the branch processing means to space-time decoding to derive an estimate of the data intended for the first user.

5. A method according to claim 4 including, during a learning phase,
20 generating error signals from a comparison of the outputs of the space-time decoding with training signals, and adapting the sets of weights based on the error signals.