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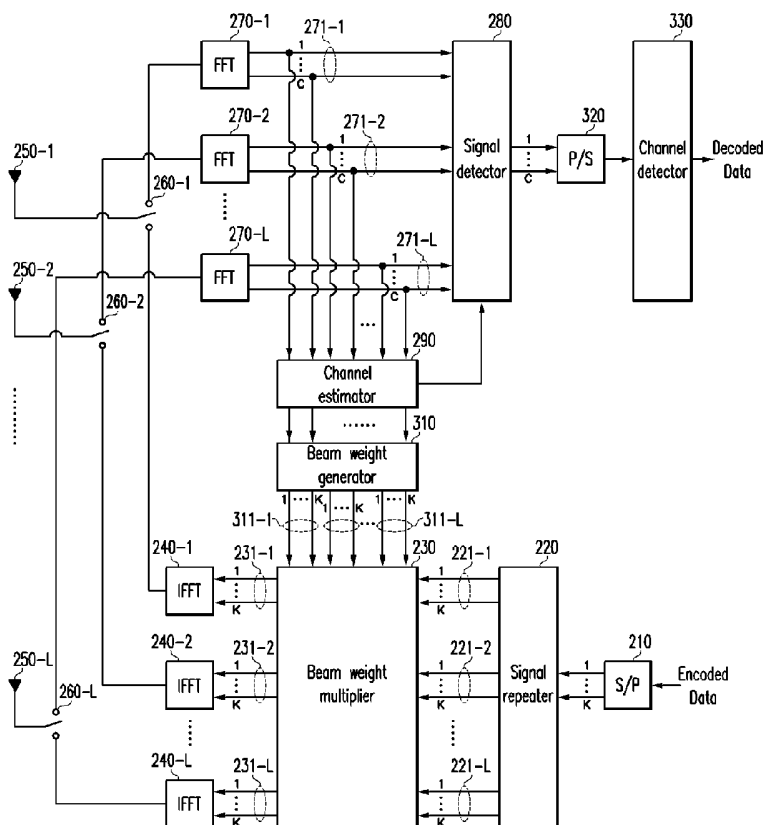
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[Continued on next page]

(54) Title: SMART ANTENNA SYSTEM AND METHOD THEREOF FOR FORMING DOWNLINK EIGENBEAM OF OFDM/TDD



(57) Abstract: A base station transmitting and receiving method and a corresponding base station transmitter and receiver of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD (orthogonal frequency division multiplex/time division duplex), wherein OFDM symbols are received through an uplink via multiple antennas (250) and an FFT (fast Fourier transform) is performed on the received OFDM symbols by the FFT units (270). By means of a channel estimator (290) the channels are estimated and a beam weight generator (310) generates respective beam weights from the channels of the respective pilot tones of the respective subcarriers according to the channel estimation result. A beam weight multiplier (230) forms the downlink beam by multiplying the respective beam weights with the output of the signal repeater (220) and IFFT units (240) generate respective OFDM symbols which are transmitted via multiple antennas (250) through a downlink.

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## Description

# SMART ANTENNA SYSTEM AND METHOD THEREOF FOR FORMING DOWNLINK EIGENBEAM OF OFDM/TDD

### Technical Field

- [1] The present invention relates to a smart antenna system and method thereof for forming downlink eigenbeams of OFDM/TDD. More specifically, the present invention relates to a smart antenna system and method thereof for forming OFDM/TDD-based downlink eigenbeams in an OFDM (orthogonal frequency division multiplex) system in which all subcarriers have spatial covariance and a TDD (time division duplex) system in which the subcarriers have reciprocity.

### Background Art

- [2] In order to perfectly realize the mobile communication system which allows transmission and receiving of all kinds of data with desired peers anytime and anywhere, the 3rd generation mobile communication systems which are operable by global and single standards and provide far better services than the present mobile communication system have been commercialized.
- [3] The next generation mobile communication system transmits and receives currently serviced speech signals, video, and other types of data with a high reliability. Also, as various services are provided, the bandwidths of transmitted and received data will be wider, and demands of the mobile communication networks will be increased further.
- [4] Therefore, the most important technical aim of the next generation mobile communication systems is to propose techniques for transmitting furthermore amounts of data with reliabilities by using as narrow bandwidths as possible.
- [5] However, since the reduction of useable bandwidths and the increase of reliabilities are incompatible, the conventional arts cannot solve the problems of capacity and reliability required by the next generation mobile communication.
- [6] Recently, a new technique for concurrently achieving the increases of capacity and reliability in the communication systems by controlling beam patterns of antennas and suppressing interference and noise has been aggressively studied. The so-called smart antenna technique has been highlighted as the core skill of the next generation mobile communication system.
- [7] The smart antenna technique allows a base station to establish an optimized beam to

a mobile station subscriber, thereby reducing radio interference, increasing communication capacity, and improving communication quality.

[8] For example, a smart antenna system installed in a base station adaptively processes respective speeds of 1) a fixed target such as an office, 2) a target which moves at low speed such as a person or a satellite, and 3) a target which moves at light speed such as a car or a train, and consecutively provides optimized beam patterns to thus provide maximum gains in the target directions, and provides relatively very much fewer gains in other directions to thus suppress the interference. That is, the above-noted smart antenna system increases capacity of the mobile communication system and improves communication reliability.

[9] Therefore, the smart antenna skill is a new technique applicable to the W-CDMA and CDMA2000 which are next generation communication methods for transmitting a huge volume of data with reliability.

[10] Most studies for smart transmit antennas have been focused at the downlink category. In general, it is needed for a base station to know a temporal channel of a downlink in advance in order to apply a closed-loop downlink beam forming technique.

[11] It is needed for the mobile station to feed temporal channel information back to the base station since frequency bandwidths of uplink and downlink channels are different in the FDD (frequency division duplex) mode. In this instance, a large amount of needed feedback information can be a problem for the closed-loop beam forming skill.

[12] A conventional blind beam forming technique is a method for measuring an uplink channel and adaptively forming a downlink beam assuming that radio environments and spatial statistical properties of the uplink and the downlink are similar with each other. The blind beam forming technique requires no feedback information since it uses the channels' reciprocity, but loses a diversity gain since a beam forming vector does not follow changes of the temporal channel.

[13] Temporal channel information of the downlink must be fed back in order to obtain the spatial diversity gain, and since the amount of feedback information is increased as the number of transmit antennas is increased, and since the feedback rate is increased in order to track the changes of the temporal channel, it is very difficult to apply the above-described beam forming technique to the case in which a large number of transmit antennas are provided or a moving body moves fast. Many techniques for alleviating the above-noted problems have recently been proposed.

[14] The Korea Application No. 1999-43679 (filed on October 9, 1999) discloses

"Transmit antenna diversity controlling device and method in mobile communication system," and it relates to a control device and method for adaptively calculating weights in the closed-loop transmit antenna and performing transmit antenna diversity.

[15] In detail, the above-described Korea Application consecutively tracks an optimized weight vector for a predetermined time frame, that is, detects a state of an initial downlink channel to find a weight vector, and finds a further accurate weight vector by using the found weight vector when detecting a state of a subsequent downlink channel, and hence, it applies variable weights to the respective antennas used for the transmit antenna diversity according to the channel states, and calculates the current weight by using the previous weight to thus perform adaptive weight calculation.

[16] The other Korea Application No. 2000-11617 (filed on March 8, 2000) discloses "Blind transmit antenna array device and method using feedback information in mobile communication system," and it aims to use at least two antenna elements and corresponding weight vectors and allow a base station to form appropriate transmission beams toward a specific mobile station, and thereby increase subscriber capacity.

[17] In detail, a base station proposed by the Korea Application No. 2000-11617 comprises a reverse processor for processing reverse signals received through an antenna array; a forward fading information extractor for extracting forward fading information from the received reverse signals; a beam forming controller for generating weight vectors for forming transmission beams by using the forward fading information and the received reverse signals; and a forward processor for forming a transmission message from the transmission beam according to the weight vector, and outputting the transmission message to the antenna array. Also, a mobile station comprises a forward processor for receiving forward signals and processing the same; a forward fading estimator for estimating forward fading information for each path of the received forward signals; a forward fading encoder for combining the estimated forward fading information for each path to encode the same; and a reverse processor for multiplexing the encoded forward fading information together with the transmission message, and feeding them back to the base station.

[18] Therefore, the invention of the Korea Application No. 2000-11617 uses a mixed forward beam forming method for selecting from among a default (predictive) beam forming method and a blind forward beam forming method according to the moving speed of the mobile station when a feedback delay time is less or greater in a mobile communication system with multiple paths, and hence, the invention enables receiving the forward fading information from the mobile station and form a further reliable

- transmission beam to thereby increase capacity and save transmission power of the mobile station.
- [19] The transaction entitled "Exploiting the short-term and long-term channel properties in space and time: Eigenbeam forming concepts for the BS in WCDMA" is disclosed in the European Trans. Telecomm. (pp. 365 to 378, 12th volume, 2001).
- [20] The transaction disclosed a temporal and spatial transmitter and receiver in the CDMA system with adaptive antennas applied to a base station according to eigenbeam forming concepts which reduces processing dimensions and finds a mean of a spatial covariance matrix in the downlink by using the long-term channel property, or obtains decorrelated diversity branches in the spatial and temporal manner by separating the spatial covariance matrix of a similar temporal tap in the uplink.
- [21] The US Application No. 2003-144032 (filed on July 31, 2003) discloses "Beam forming method" which proposes a spatial and temporal transmitter and receiver in the CDMA system with an adaptive antenna applied to a base station according to the eigenbeam forming concepts.
- [22] In detail, the US Application removes the problems of the long-term eigenbeam formation and the short-term optimal combination which are properties of a rake receiver to thereby reduce calculation complexity, increases no feedback for short-term processing since an eigenrake is adaptive to various radio environments when the number of antennas is increased, and obtains diversity gains and an interference alleviating effect by concurrently using the long-term and short-term properties of the channel.
- [23] The eigenbeam forming smart antenna technique proposed for the 3GPP (3rd generation partnership project) standard is realized by feeding back the information required for forming the downlink beams through the uplink, which will now be described.
- [24] First, the spatial channel property includes a long-term channel property and a short-term channel property. In this instance, the long-term channel property represents a spatial channel property which are varied in the long-term manner according to correlation of between antenna elements, buildings and mountains, and locations of mobile stations, and the short-term channel property represents a spatial channel property which are quickly varied in the short manner depending on the Rayleigh fading.
- [25] In general, the short-term spatial covariance matrix  $R_{ST}$  of the mobile station obtained by using an orthogonal pilot tone transmitted by the base station is given in

Math Figure 1.

[26] MathFigure 1

$$\mathbf{R}_{ST} = \sum_{n=1}^N \mathbf{h}_n \mathbf{h}_n^H$$

[27] where  $\mathbf{h}_n$  is a channel vector of the  $n^{\text{th}}$  temporal tap and given as  $\mathbf{h}_n = (h_{n1}, h_{n2}, \dots, h_{nL})^T$ , and  $L$  is a number of transmit antennas.

[28] Also, the long-term spatial covariance matrix  $\mathbf{R}_{LT}$  is given in Math Figure 2.

[29] MathFigure 2

$$\mathbf{R}_{LT}(i) = \rho \mathbf{R}_{LT}(i-1) + (1-\rho) \mathbf{R}_{ST}(i)$$

[30] where  $\rho$  is a forgetting factor.

[31] The long-term spatial covariance matrix  $\mathbf{R}_{LT}$  is given in Math Figure 3 according to eigendecomposition.

[32] MathFigure 3

$$\mathbf{R}_{LT} \mathbf{V} = \mathbf{V} \mathbf{\Theta}$$

[33] where

$$\mathbf{\Theta} = \text{diag}(\lambda_1, \lambda_2, \dots, \lambda_L)$$

is a diagonal matrix with eigenvalues of

$$\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_L$$

as elements, and

$$\mathbf{V} = [\mathbf{v}_1 \ \mathbf{v}_2 \ \dots \ \mathbf{v}_L]$$

where  $\mathbf{v}_L$  is an eigenvector corresponding to  $\lambda_L$ .

[34] Also, in order to quickly reduce a less amount of feedback or computational complexity, eigenvectors which correspond to  $N_f$  large eigenvalues from among  $L$  eigen values are defined to be eigenbeams or eigenmodes. The eigenbeam for maximizing a receive power

$$P_m = \sum_{n=1}^N \left| \mathbf{v}_m^H \mathbf{h}_n \right|^2 = \mathbf{v}_m^H \mathbf{R}_{ST}^T \mathbf{v}_m$$

of the mobile station is selected from among the eigenbeams.

[35] In the 3GPP WCDMA system, the eigenbeams are transmitted per bit for each frame to the base station from the mobile station according to the feedback speed of 1,500bps through the DPCCH (dedicated physical control channel), and when two eigenmodes are provided, it is determined to select one of the two eigenmodes for each slot, and a corresponding result is transmitted to the base station from the mobile station.

[36] However, since the OFDM method has different beam forming vectors for the respective subcarriers in the case of using the 3GPP method, feedback information is substantially increased, and it is impossible to realize the effective communication system.

## **Disclosure of Invention**

### **Technical Problem**

[37] It is an advantage of the present invention to provide a smart antenna system and method thereof for forming OFDM/TDD-based downlink eigenbeams for reducing complexity of a communication system by using the fact that the subcarriers of the OFDM system have the same spatial covariance and the TDD system has channel reciprocity.

[38] It is another advantage of the present invention to provide a smart antenna system and method thereof for forming OFDM/TDD-based downlink eigenbeams for obtaining a spatial covariance matrix for forming eigenbeams without feedback by using pilot tones of uplink subcarriers allocated for a user.

[39] It is still another advantage of the present invention to provide a smart antenna system and method thereof for forming OFDM/TDD-based downlink eigenbeams for obtaining temporal spatial covariance of a downlink by using interpolation of temporal spatial covariance of an uplink subcarrier.

### **Technical Solution**

[40] In one aspect of the present invention, a base station transmitter and receiver of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD comprises: multiple antennas for transmitting OFDM symbols to a mobile station receiver, and receiving OFDM symbols from the mobile station receiver; a base station receiver for performing FFT on the OFDM symbols which are received by a pre-determined number through the multiple antennas, outputting FFT-performed symbols as parallel signals, estimating a channel from the parallel signals, detecting symbols

from the parallel signals and converting the detected symbols into serial signals by using channel estimation results, and outputting decoded signals; and a base station transmitter for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, generating respective beam weights from the channels of the respective pilot tones of the subcarriers according to the channel estimation results executed by the base station receiver, generating respective OFDM symbols with formed eigenbeams, and outputting them.

[41] The base station transmitter comprises: a S/P (serial/parallel) converter for converting the channel-coded symbols which are input in series into a predetermined number of parallel signals; a signal repeater for repeating the parallel signals by the number of the multiple antennas; a beam weight generator for generating an eigenbeam weight from per-pilot channel of each subcarrier according to a channel estimation result; a beam weight multiplier for respectively multiplying the beam weight generated by the beam weight generator by the output of the signal repeater, and outputting results; and a plurality of IFFT units for receiving the predetermined number of parallel signals, generating one OFDM symbol, and outputting the OFDM symbol.

[42] The beam weight generator comprises: a per-pilot spatial covariance matrix generator for receiving per-pilot channel matrices according to the channel estimation result, and generating per-pilot spatial covariance matrices of the respective subcarriers; a per-subcarrier spatial covariance matrix generator for using a predetermined number of pilot tones provided in a subcarrier, receiving the per-pilot spatial covariance matrices, and generating respective per-subcarrier spatial covariance matrices; a short-term spatial covariance matrix generator for using a property that uplink subcarriers have the same spatial covariance matrix, receiving the respective per-subcarrier spatial covariance matrices, and generating short-term spatial covariance matrices; a long-term spatial covariance matrix generator for receiving the short-term spatial covariance matrices, and outputting long-term spatial covariance matrices; an inter-subcarrier spatial covariance matrix interpolator for receiving the uplink per-subcarrier spatial covariance matrices obtained through the uplink, and outputting a predetermined number of downlink per-subcarrier spatial covariance matrices; an eigen divider for receiving the long-term spatial covariance matrices, dividing them into respective eigenbeams, and outputting the eigenbeams; and a beam weight selector for receiving the divided eigenbeams and the downlink per-subcarrier spatial covariance matrices, and outputting respective per-subcarrier beam weights.

- [43] The short-term spatial covariance matrices corresponds to the long-term spatial covariance matrices when a received packet is short.
- [44] The eigenbeam of the eigen divider is defined to be an eugenvector which corresponds to the largest eigenvalue from among a predetermined number of eigenvectors, and is divided by the eigenbeam which maximizes the receiving power of the mobile station from among a plurality of eigenbeams.
- [45] The base station receiver comprises: a plurality of FFT units for receiving the respective OFDM symbols through the multiple antennas, performing FFT on the OFDM symbols by the number of multiple antennas, and outputting parallel signals; a channel estimator for estimating channels from the parallel signals; a signal detector for using results of the channel estimator, detecting symbols from the parallel signals, and outputting a predetermined number of detected parallel signals; a P/S (parallel/serial) converter for converting the detected parallel signals into serial signals; and a channel decoder for decoding the serial signals, and outputting decoded signals.
- [46] The channel estimator outputs channel matrices of the respective pilot tones for the respective subcarriers in order to calculate beam weight weights.
- [47] In another aspect of the present invention, a mobile station transmitter and receiver of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD, comprises: multiple antennas for receiving respective OFDM symbols from a base station transmitter, and transmitting OFDM symbols to a base station receiver; a mobile station receiver for receiving the OFDM symbols with formed respective eigenbeams from the base station transmitter, performing FFT on them, outputting FFT-performed OFDM symbols as parallel signals, detecting symbols from the parallel signals, converting the detected symbols into serial signals, and outputting decoded signals; and a mobile station transmitter for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, repeating N parallel signals by the number of the multiple antennas to which the N parallel signals are input, generating respective OFDM symbols, and outputting the OFDM symbols, the N parallel signals being obtained by multiplexing user signals.
- [48] The mobile station receiver comprises: a plurality of FFT units for receiving the OFDM symbols through the multiple antennas, performing FFT on them by the number of multiple antennas, and outputting FFT-performed symbols as parallel signals; a signal detector for detecting symbols from the parallel signals, and outputting a predetermined number of detected parallel signals; a P/S converter for converting the detected parallel signals into serial signals, and outputting the serial

signals; and a channel decoder for decoding the serial signals, and outputting the serial signals.

[49] The channel decoder corrects random errors when the interval of uplink subcarriers exceeds a channel bandwidth to allow inaccurate interpolation or when the moving speed of the mobile station is fast that an inaccurate optimized eigenbeam is selected.

[50] The mobile station transmitter comprises: N S/P converters for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, N corresponding to the number of base station antennas; a signal repeater for repeating N parallel signals by the number of the base station antennas when user signals are multiplexed to be input as the N parallel signals; and a plurality of IFFT units for receiving the N parallel signals, and generating an OFDM symbol.

[51] In still another aspect of the present invention, a base station transmitting and receiving method of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD comprises: (a) receiving respective OFDM symbols from a mobile station transmitter through an uplink; (b) performing FFT on the received OFDM symbols, outputting FFT-performed OFDM symbols as parallel signals, and estimating channels from the parallel signals; (c) converting channel-coded symbols which are input in series into a predetermined number of parallel signals; (d) generating respective beam weights from the channels of the respective pilot tones of the respective subcarriers according to a channel estimation result; and (e) forming eigenbeams according to the respective beam weights, generating respective OFDM symbols, and transmitting the OFDM symbols to the mobile station receiver through the uplink.

[52] The step (b) comprises: (i) receiving per-pilot channel matrices according to the channel estimation result, and generating per-pilot spatial covariance matrices of respective subcarriers; (ii) using a predetermined number of pilot tones provided on a subcarrier, receiving the per-pilot spatial covariance matrices, and generating respective per-subcarrier spatial covariance matrices; (iii) using a property that a predetermined number of uplink subcarriers have the same spatial covariance matrix, receiving the respective per-subcarrier spatial covariance matrices, and generating short-term spatial covariance matrices; (iv) receiving the short-term spatial covariance matrices and outputting long-term spatial covariance matrices; (v) receiving uplink per-subcarrier spatial covariance matrices obtained through the uplink, and outputting a predetermined number of downlink per-subcarrier spatial covariance matrices; (vi) receiving the long-term spatial covariance matrices, dividing them into respective

eigenbeams, and outputting the eigenbeams; and (vii) receiving the divided eigenbeams and the uplink per-subcarrier spatial covariance matrices, and outputting beam weights for the respective subcarriers.

[53] The step (i) comprises: using the equation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c) = \tilde{\mathbf{H}}_c^H(n_c) \tilde{\mathbf{H}}_c(n_c)$$

and finding per-pilot spatial covariance matrices of respective subcarriers where

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

is the temporal spatial covariance matrix obtained from the  $n_c^{\text{th}}$  pilot tone of the  $c^{\text{th}}$  subcarrier.

[54] The step (ii) comprises: using  $N_c$  pilot tones provided on a subcarrier and finding the spatial covariance matrix of the subcarrier  $c$  defined by the equation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_c} = \frac{1}{N_c} \sum_{n_c=1}^{N_c} \mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

[55] The step (iii) comprises: finding the short-term spatial covariance matrix  $\mathbf{R}_{ST}$  by using the equation of

$$\mathbf{R}_{ST} = \frac{1}{C} \sum_{c=1}^C \mathbf{R}_{\tilde{\mathbf{H}}_c}$$

since  $C$  uplink subcarriers have the same spatial covariance matrix.

[56] The step (iv) comprises: finding the long-term spatial covariance matrix  $\mathbf{R}_{LT}$  by using the equation of

$$\mathbf{R}_{LT}(i) = \rho \mathbf{R}_{LT}(i-1) + (1-\rho) \mathbf{R}_{ST}(i)$$

where  $i$  is a number of frames and  $\rho$  is a forgetting factor.

[57] The step (vi) comprises: performing eigen division by using the equation of

$$\mathbf{R}_{LT} \mathbf{V} = \mathbf{V} \mathbf{\Theta}$$

where

$$\mathbf{\Theta} = \text{diag}(\lambda_1, \lambda_2, \dots, \lambda_L)$$

is a diagonal matrix having the eigenvalues of

$$\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_L$$

as elements, and it is given that

$$\mathbf{V} = [\mathbf{v}_1 \ \mathbf{v}_2 \ \dots \ \mathbf{v}_L]$$

where  $\mathbf{v}_L$  is an eigenvector corresponding to  $\lambda_L$ .

- [58] The step (vii) comprises outputting the respective per-subcarrier beam weights by using the equation of

$$\mathbf{w}_k = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \left\| \tilde{\mathbf{H}}_k \mathbf{v}_n \right\|^2 = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \mathbf{v}_n^H \mathbf{R}_{\tilde{\mathbf{H}}_k} \mathbf{v}_n$$

where  $\mathbf{w}_k$  is the  $k^{\text{th}}$  downlink subcarrier.

- [59] In still yet another aspect of the present invention, a mobile station transmitting and receiving method of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD comprises: (a) receiving respective OFDM symbols with eigenbeams transmitted from a base station transmitter; (b) performing FFT on the OFDM symbols, and outputting them as parallel signals; (c) detecting symbols from the parallel signals, converting the symbols into serial signals, and outputting decoded signals; (d) converting channel-coded symbols which are input in series into a pre-determined number of parallel signals; (e) repeating N parallel signals by the number of mobile station antennas to which the N parallel signals are input, and generating respective OFDM symbols, the N parallel signals being obtained by multiplexing user signals; and (f) respectively transmitting the OFDM symbols to a base station receiver.

- [60] The step (c) further comprises: correcting random errors when the interval of uplink subcarriers exceeds a channel bandwidth to allow inaccurate interpolation or when the moving speed of the mobile station is so fast that an inaccurate optimized eigenbeam is selected.

[61] Therefore, according to the preferred embodiment of the present invention, the complexity of the communication system is reduced by using the characteristic that the subcarriers of the OFDM/TDD system have the same spatial covariance and the TDD system has channel reciprocity, the spatial covariance matrix for forming the eigenbeams is obtained without feedback by using pilot tones of subcarriers of the uplink allocated for one user, temporal spatial covariance of the downlink is obtained by using interpolation of the temporal spatial covariance of the uplink subcarrier, and most errors which are randomly generated because of inaccurate selection of the optimized eigenbeam are restored by a channel decoder provided at the latter part of a receiver.

[62]

### **Brief Description of the Drawings**

[63] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate an embodiment of the invention, and, together with the description, serve to explain the principles of the invention;

[64] FIG. 1 shows a block diagram of a mobile station of an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention;

[65] FIG. 2 shows a block diagram of a base station of an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention;

[66] FIG. 3 shows a block diagram of a beam weight generator of a base station in an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention; and

[67] FIG. 4 shows a block diagram of a beam weight multiplier of a base station in an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention.

### **Best Mode for Carrying Out the Invention**

[68] In the following detailed description, only the preferred embodiment of the invention has been shown and described, simply by way of illustration of the best mode contemplated by the inventor(s) of carrying out the invention. As will be realized, the invention is capable of modification in various obvious respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not restrictive. To clarify the present invention, parts which are not described in the specification are omitted, and parts for which similar descriptions are provided have the same reference numerals.

[69] A smart antenna system and method thereof for forming OFDM/TDD-based downlink eigenbeams according to a preferred embodiment of the present invention will be described with reference to drawings.

[70] L base station antennas and M mobile station antennas will be considered in the OFDM/TDD system according to the preferred embodiment of the present invention. In general, a downlink subcarrier group allocated to one user and an uplink subcarrier group allocated thereto are different in the OFDM (or OFDMA) system.

[71] When it is assumed that K downlink subcarriers are allocated to the user, the K subcarriers are provided with constant intervals therebetween in order to use frequency diversity, and are not consecutive. The subcarrier with a subcarrier index of k represents the k<sup>th</sup> subcarrier from among the K subcarriers allocated to the user. Also, C uplink subcarriers are allocated to the user, and are not consecutive in a like manner of the downlink case. The subcarrier with a subcarrier index of c represents the c<sup>th</sup> subcarrier from among the C subcarriers allocated to the user.

[72] A downlink transmit signal is given in Math Figure 4.

[73] MathFigure 4

$$\mathbf{S}(t) = [\mathbf{w}_1(t) \ \mathbf{w}_2(t) \ \cdots \ \mathbf{w}_K(t)]\mathbf{D}(t)$$

[74] where  $\mathbf{w}_k(t)$  is an (Lx1) beam forming vector with respect to the k<sup>th</sup> subcarrier, it is defined such that

$$\mathbf{D}(t) = \text{diag}\{s_1(t), s_2(t), \cdots, s_K(t)\}$$

, and  $s_k(t)$  is an OFDM symbol transmitted to the k<sup>th</sup> subcarrier.

[75] Since the OFDM system according to the preferred embodiment uses a broadband, transmit signals are transmitted through a frequency selective fading channel. A CIR (channel impulse response) between a transmit antenna l and a receive antenna m is given as

$$\{h_{p,m,l}\}_{p=0,1,\cdots,P-1, m=1,\cdots,M, l=1,\cdots,L}$$

where P is a number of multi-paths.

[76] Therefore, the channel response in the frequency domain is given in Math Figure 5.

[77] MathFigure 5

$$\tilde{h}_{k,m,l} = \sum_{p=0}^{P-1} h_{p,m,l} d^{-j2\pi pk / K}$$

[78] A MIMO (multi input multi output) channel matrix with respect to the subcarrier k is given in Math Figure 6.

[79] MathFigure 6

$$\left[ \tilde{\mathbf{H}}_k(t) \right]_{m,l} = \tilde{h}_{k,m,l}(t), \quad m = 1, 2, \dots, M, \quad l = 1, 2, \dots, L.$$

[80] Signals passed through a DFT unit at the receiver are given in Math Figure 7.

[81] MathFigure 7

$$\mathbf{R}(t) = \left[ \tilde{\mathbf{H}}_1(t) \mathbf{w}_1(t) \quad \tilde{\mathbf{H}}_1(t) \mathbf{w}_1(t) \cdots \tilde{\mathbf{H}}_1(t) \mathbf{w}_1(t) \right] \mathbf{D}(t) + \mathbf{N}(t)$$

[82] where  $\mathbf{N}(t)$  is an (MxL) noise matrix.

[83] Math Figure 8 is defined assuming that no correlation is provided between other paths from the channel of Math Figure 5.

[84] MathFigure 8

$$E \left[ \mathbf{H}_p^H \mathbf{H}_{p'} \right] = \sigma_{h,p}^2 \mathbf{R}_{\mathbf{H}_p} \delta_{p,p'}$$

[85] where  $\sigma_{h,p}^2$  is a power delay profile of the CIR.

[86] It is satisfied as Math Figure 9.

[87] MathFigure 9

$$\left[ \mathbf{R}_{\mathbf{H}_p} \right]_{s,t} = \frac{1}{\sigma_{h,p}^2} E \left[ h_{p,m,s}^* h_{p,m,t} \right], \quad s, t = 1, 2, \dots, L$$

[88] The spatial covariance matrix of the channel

$$\tilde{\mathbf{H}}_k$$

is defined in Math Figure 10.

[89] MathFigure 10

$$\mathbf{R}_{\tilde{\mathbf{H}}_k} = E\left[\tilde{\mathbf{H}}_k^H \tilde{\mathbf{H}}_k\right]$$

[90] Accordingly, the spatial covariance matrix

$$\mathbf{R}_{\tilde{\mathbf{H}}_k}$$

of the channel matrix

$$\tilde{\mathbf{H}}_k$$

of each subcarrier is given in Math Figure 11.

[91] MathFigure 11

$$\begin{aligned} \left[\mathbf{R}_{\tilde{\mathbf{H}}_k}\right]_{s,t} &= \sum_{m=1}^M E\left[\tilde{h}_{k,m,s}^* \tilde{h}_{k,m,t}\right] \quad s, t = 1, 2, \dots, L \\ &= \sum_{m=1}^M E\left[\left(\sum_{p=0}^{P-1} h_{p,m,s} e^{-j2\pi p k / N}\right)^* \left(\sum_{p'=0}^{P-1} h_{p',m,t} e^{-j2\pi p' k / N}\right)\right] \\ &= \sum_{m=1}^M \sum_{p=0}^{P-1} E\left[h_{p,m,s}^* h_{p,m,t}\right] \\ &= \sum_{p=0}^{P-1} \sigma_{h,p}^2 \left[\mathbf{R}_{\mathbf{H}_p}\right]_{s,t} \\ &= \mathbf{R}_{\tilde{\mathbf{H}}} \\ &\triangleq \left[\sum_{p=0}^{P-1} \sigma_{h,p}^2 \mathbf{R}_{\mathbf{H}_p}\right]_{s,t} \end{aligned}$$

[92] It is shown from Math Figure 11 that the spatial covariance matrix

$$\mathbf{R}_{\tilde{\mathbf{H}}_k}$$

is not a function of the random subcarrier  $k$ . In detail, since each subcarrier of the OFDM system undergoes different frequency selective fading, each subcarrier has a different channel property, but the spatial covariance matrix is the same for the subcarriers.

[93] As a result, since the spatial covariance matrix is the same for the subcarriers, an accurate estimate is found by averaging the subcarriers.

[94] A frequency-domain channel response of between the  $m^{\text{th}}$  mobile station antenna of the  $c^{\text{th}}$  subcarrier and the  $l^{\text{th}}$  base station antenna is defined to be

$$\tilde{h}_{c,m,l}$$

which corresponds to the frequency-domain channel response of between the  $l^{\text{th}}$  downlink base station antenna and the  $m^{\text{th}}$  mobile station antenna because of the channel reciprocity of the TDD system as described above. The downlink MIMO channel matrix defined in Math Figure 12 is found by using the  $n_c^{\text{th}}$  pilot tone of the  $c^{\text{th}}$  subcarrier in the uplink.

[95] MathFigure 12

$$\tilde{\mathbf{H}}_c(n_c) = \begin{bmatrix} \tilde{h}_{c,1,1}(n_c) & \tilde{h}_{c,1,2}(n_c) & \cdots & \tilde{h}_{c,1,L}(n_c) \\ \tilde{h}_{c,2,1}(n_c) & \tilde{h}_{c,2,2}(n_c) & \cdots & \tilde{h}_{c,2,L}(n_c) \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{h}_{c,M,1}(n_c) & \tilde{h}_{c,M,2}(n_c) & \cdots & \tilde{h}_{c,M,L}(n_c) \end{bmatrix}$$

[96] where

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

is the temporal spatial covariance matrix obtained from the  $n_c^{\text{th}}$  pilot tone of the  $c^{\text{th}}$  subcarrier, and defined in Math Figure 13.

[97] MathFigure 13

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c) = \tilde{\mathbf{H}}_c^H(n_c) \tilde{\mathbf{H}}_c(n_c)$$

[98] In this instance, the spatial covariance matrix of the  $c^{\text{th}}$  subcarrier is found below by using  $N_c$  pilot tones provided at one subcarrier.

[99] MathFigure 14

$$\mathbf{R}_{\tilde{\mathbf{H}}_c} = \frac{1}{N_c} \sum_{n_c=1}^{N_c} \mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

[100] As described above, the short-term spatial covariance matrix as given in Math Figure 15 is found since the C uplink subcarriers allocated to one user have the same spatial covariance matrix.

[101] MathFigure 15

$$\mathbf{R}_{ST} = \frac{1}{C} \sum_{c=1}^C \mathbf{R}_{\tilde{\mathbf{H}}_c}$$

[102] Also, the long-term spatial covariance matrix  $\mathbf{R}_{LT}$  is given in Math Figure 16 in a like manner of Math Figure 2 of the above-described 3GPP WCDMA system.

[103] MathFigure 16

$$\mathbf{R}_{LT}(i) = \rho \mathbf{R}_{LT}(i-1) + (1-\rho) \mathbf{R}_{ST}(i)$$

[104] where  $i$  is a number of frames, and  $\mathbf{R}_{ST}(i)$  is a short-term spatial covariance matrix found at the  $i^{\text{th}}$  frame. When the length of the packet is very short,  $\rho$  can be established to be 0 and as a result, it is given that  $\mathbf{R}_{LT}(i) = \mathbf{R}_{ST}(i)$ .

[105] Further, the eigenmode is obtained by performing eigendivision as given in Math Figure 17.

[106] MathFigure 17

$$\mathbf{R}_{LT} \mathbf{V} = \mathbf{V} \mathbf{\Theta}$$

[107] where

$$\mathbf{\Theta} = \text{diag}(\lambda_1, \lambda_2, \dots, \lambda_L)$$

is a diagonal matrix having the eigenvalues of

$$\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_L$$

as elements, and it is given that

$$\mathbf{V} = [\mathbf{v}_1 \ \mathbf{v}_2 \ \cdots \ \mathbf{v}_L]$$

where  $\mathbf{v}_L$  is an eigenvector corresponding to  $\lambda_L$ . Here, the L eigenvectors can be defined with the eigenmodes since no feedback is provided differing from the above-described 3GPP.

[108] When the subcarriers used for the downlink are different from the subcarriers used for the uplink,  $\mathbf{W}_k$  for the  $k^{\text{th}}$  subcarrier of the downlink is found as Math Figure 18.

[109] MathFigure 18

$$\mathbf{w}_k = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \left\| \tilde{\mathbf{H}}_k \mathbf{v}_n \right\|^2 = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \mathbf{v}_n^H \mathbf{R}_{\tilde{\mathbf{H}}_k} \mathbf{v}_n$$

[110] In this instance,

$$\mathbf{R}_{\tilde{\mathbf{H}}_k}$$

is found by interpolation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}$$

obtained by using the uplink in consideration of the coherent property between the subcarriers. For example, when it is assumed that the downlink subcarrier  $k$  is the  $j^{\text{th}}$  subcarrier, the nearest uplink subcarrier  $c$  before the downlink subcarrier  $k$  is the  $(j-d_1)^{\text{th}}$  subcarrier, and the nearest uplink subcarrier  $c$  after the downlink subcarrier  $k$  is the  $(j+d_2)^{\text{th}}$  subcarrier,

$$\mathbf{R}_{\tilde{\mathbf{H}}_j}$$

is found by interpolation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_{j-d_1}}$$

and

$$\mathbf{R}_{\tilde{\mathbf{H}}_{j+d_2}}$$

[111] When first linear interpolation is used and

$$\mathbf{R}_{\tilde{\mathbf{H}}_j}, \mathbf{R}_{\tilde{\mathbf{H}}_{j-d_1}}$$

, and

$$\mathbf{R}_{\tilde{\mathbf{H}}_{j+d_2}}$$

are assumed as follows:

[112] MathFigure 19

$$\mathbf{R}_{\tilde{\mathbf{H}}_j} = \begin{bmatrix} e_{j,1,1} & e_{j,1,2} \\ e_{j,2,1} & e_{j,2,2} \end{bmatrix}$$

[113] MathFigure 20

$$\mathbf{R}_{\tilde{\mathbf{H}}_{j-d_1}} = \begin{bmatrix} e_{j-d_1,1,1} & e_{j-d_1,1,2} \\ e_{j-d_1,2,1} & e_{j-d_1,2,2} \end{bmatrix}$$

[114] MathFigure 21

$$\mathbf{R}_{\tilde{\mathbf{H}}_{j+d_2}} = \begin{bmatrix} e_{j-d_2,1,1} & e_{j-d_2,1,2} \\ e_{j-d_2,2,1} & e_{j-d_2,2,2} \end{bmatrix}$$

[115] Therefore, respective elements of

$$\mathbf{R}_{\tilde{\mathbf{H}}_j}$$

are given below.

[116] MathFigure 22

$$e_{j,1,1} = e_{j-d_1,1,1} + \frac{d_1}{d_1+d_2} (e_{j+d_2,1,1} - e_{j-d_1,1,1}) = \frac{d_1}{d_1+d_2} e_{j+d_2,1,1} - \frac{d_2}{d_1+d_2} e_{j-d_1,1,1}$$

[117] MathFigure 23

$$e_{j,1,2} = e_{j-d_1,1,2} + \frac{d_1}{d_1+d_2} (e_{j+d_2,1,2} - e_{j-d_1,1,2}) = \frac{d_1}{d_1+d_2} e_{j+d_2,1,2} - \frac{d_2}{d_1+d_2} e_{j-d_1,1,2}$$

[118] MathFigure 24

$$e_{j,2,1} = e_{j-d_1,2,1} + \frac{d_1}{d_1+d_2} (e_{j+d_2,2,1} - e_{j-d_1,2,1}) = \frac{d_1}{d_1+d_2} e_{j+d_2,2,1} - \frac{d_2}{d_1+d_2} e_{j-d_1,2,1}$$

[119] MathFigure 25

$$e_{j,2,2} = e_{j-d_1,2,2} + \frac{d_1}{d_1+d_2} (e_{j+d_2,2,2} - e_{j-d_1,2,2}) = \frac{d_1}{d_1+d_2} e_{j+d_2,2,2} - \frac{d_2}{d_1+d_2} e_{j-d_1,2,2}$$

[120] Therefore, the optimized downlink beams found from the uplink frame are applicable to the downlink of the subsequent frame of (i+1).

[121] Wrong eigenbeams may be selected when the gap of uplink subcarriers is greater than a coherent bandwidth, or when the moving speed of the mobile station is fast. Errors caused by selecting the wrong eigenbeam have randomness, and they are corrected by a channel decoder.

[122] The smart antenna system according to the preferred embodiment of the present invention will be described in detail with reference to the above-described principles.

[123] FIG. 1 shows a block diagram of a mobile station of an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention, and FIG. 2 shows a block diagram of a base station of an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention.

[124] The mobile station of the OFDM/TDD-based smart antenna system includes M antennas 140-1 to 140-M, the base station includes L antennas 250-1 to 250-L, and the mobile station and the base station include a transmitter and a receiver respectively.

[125] Referring to FIG. 1, the transmitter of the mobile station comprises an S/P (serial to parallel) converter 110 a signal repeater 120 and M IFFT (inverse fast Fourier transform) units 130-1 to 130-M (where M corresponds to the number of transmit antennas). The receiver of the mobile station comprises M FFT (fast Fourier transform) units 160-1 to 160-M (where M corresponds to the number of receive antennas), a signal detector 170 a P/S (parallel to serial) converter 180 and a channel decoder 190. The antennas 140-1 to 140-M of the mobile station are accessed through respective switches 150-1 to 150-M to the transmitter of the mobile station in the case

of downlink communication, and to the receiver of the mobile station in the case of uplink communication.

[126] Referring to FIG. 2, the transmitter of the base station comprises an S/P converter 210 a signal repeater 220 a beam weight multiplier 230 and L IFFT units 240-1 to 240-L (L corresponds to the number of antennas), and the receiver thereof comprises L FFT units 270-1 to 270-L (L corresponds to the number of base station antennas), a channel estimator 290 a signal detector 280 a P/S converter 320 and a channel decoder 330. Further, the antennas 250-1 to 250-L of the base station are accessed through respective antenna switches 260-1 to 260-L to the receiver of the base station in the case of downlink communication, and to the transmitter of the base station in the case of uplink communication.

[127] Referring to FIG. 1 again, the S/P converter 110 of the transmitter of the mobile station converts channel-coded symbols into C parallel signals.

[128] The signal repeater 120 repeats C parallel signals by the number M of antennas of the mobile station. The respective IFFT units 130-1 to 130-M receive the C parallel signals to generate an OFDM symbol.

[129] OFDM symbols 121-1 to 121-M output by the signal repeater 120 are passed through the respective IFFT units 130-1 to 130-M and transmitted through the antennas 140-1 to 140-M of the mobile station.

[130] The OFDM symbols 121-1 to 121-M are received through the L mobile station antennas 250-1 to 250-L shown in FIG. 2, and the L FFT units 270-1 to 270-L output parallel signals 271-1 to 271-M.

[131] The FFT-performed signals are input to the channel estimator 290 and the signal detector 280 and the signal detector 280 uses results of the channel estimator 290 to output C detected signals.

[132] The P/S converter 320 processes the detected signals to output serial signals, and the channel decoder 330 processes the serial signals and outputs decoded data.

[133] The channel estimator 290 outputs a channel matrix for each pilot tone of the subcarrier in order to calculate a beam forming weight. For example, the channel estimator 290 finds a spatial covariance matrix for each pilot tone of the  $n_c$  subcarrier of the  $c$  subcarrier.

[134] FIG. 3 shows a block diagram of a beam weight generator 310 of a base station in an OFDM/TDD-based smart antenna system according to a preferred embodiment of the present invention.

[135] Referring to FIG. 3, the beam weight generator 310 comprises a per-pilot spatial

covariance matrix generator 311, a per-subcarrier spatial covariance matrix generator 312, a short-term spatial covariance matrix generator 313, a long-term spatial covariance matrix generator 314, an eigen divider 315, an inter-subcarrier spatial covariance interpolator 316, and a beam weight selector 317.

[136] The beam weight generator 310 finds the per-pilot spatial covariance matrix of each subcarrier given in Math Figure 13 from the per-pilot channel matrix of each subcarrier through the per-pilot spatial covariance matrix generator 311.

[137] The per-pilot spatial covariance matrix of each subcarrier is input to the inter-subcarrier spatial covariance matrix interpolator 316, and a per-subcarrier temporal spatial covariance matrix is output by using Math Figure 14.

[138] In this instance, per-subcarrier spatial covariance matrix generates a short-term spatial covariance matrix according to Math Figure 15 through the short-term spatial covariance matrix generator 313, and outputs a long-term spatial covariance matrix according to Math Figure 16 through the long-term spatial covariance matrix generator 314.

[139] When  $\rho$  is defined to be 0 in Math Figure 16, a result of  $\mathbf{R}_{LT}(i) = \mathbf{R}_{ST}(i)$  is given, and in this case, there is no need of separating long-term spatial covariance matrix and the short-term spatial covariance matrix.

[140] The eigen divider 315 receives the long-term spatial covariance matrix, and outputs L eigenbeams according to Math Figure 17.

[141] As described, the subcarriers used for the downlink are different from the subcarriers used for the uplink in the general OFDM system. Therefore, the uplink per-subcarrier spatial covariance matrix

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}$$

obtained by using the uplink according to the frequency coherent property between the subcarriers is input to the inter-subcarrier spatial covariance matrix interpolator 316, and K downlink per-subcarrier spatial covariance matrices

$$\mathbf{R}_{\tilde{\mathbf{H}}_k}$$

are output.

[142] Also, the eigenbeams and the per-subcarrier spatial covariance matrices

$$\mathbf{R}_{\tilde{\mathbf{H}}_k}$$

are input to the beam weight selector 317, and beam weights

$$\mathbf{W}_1 = [w_{11}, w_{12}, \dots, w_{1K}]$$

, 311-1

$$\mathbf{W}_2 = [w_{21}, w_{22}, \dots, w_{2K}]$$

, 311-2 ...,

$$\mathbf{W}_L = [w_{L1}, w_{L2}, \dots, w_{LK}]$$

311-K are output according to Math Figure 18.

- [143] Referring to FIG. 2 again, the S/P converter 210 of the base station transmitter converts the channel-coded symbols which are input in series into K parallel signals, the signal repeater 220 repeats the K parallel signals by the number L of mobile station antennas, and the beam weight multiplier 230 multiplies beam weights by the outputs of the signal repeater.
- [144] FIG. 4 shows a block diagram of the beam weight multiplier of a base station in the OFDM/TDD-based smart antenna system according to the preferred embodiment of the present invention.
- [145] Referring to FIG. 4, in the beam weight multiplier, the respective IFFT converters 240-1 to 240-L receive K signals and generates one OFDM symbol, and OFDM symbols are transmitted through the base station antennas 250-1 to 250-L.
- [146] As shown in FIG. 1, the transmitted OFDM symbols are received through the M base station antennas 140-1 to 140-M, and the respective M FFT units 160-1 to 160-M output the parallel signals 161-1 to 161-M.
- [147] The FFT-performed signals are input to the signal detector 170 the detected signals are converted into serial signals by the P/S converter 180 and the serial signals are output to be final result signals by the channel decoder 190.
- [148] According to the preferred embodiment, the optimized downlink beam found in the  $i^{\text{th}}$  uplink frame is applicable to the downlink of the subsequent  $(i+1)^{\text{th}}$  frame. Errors may occur because of wrong selection of the eigenbeams when the interval of the uplink subcarriers is greater than the coherent bandwidth or the moving speed of the mobile station is fast. The errors may have randomness, and most of the errors are

corrected by the channel decoder 190.

[149] As a result, the feedback of information for forming the beams is eliminated through the uplink by using the property that the subcarriers of the OFDM/TDD system have spatial covariance and the TDD system has channel reciprocity, and the spatial covariance matrix for forming the eigenbeams is found by using pilot tones of uplink subcarriers.

[150] While this invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

[151] According to the present invention, complexity of the communication systems are reduced by using the property that the subcarriers of the OFDM/TDD system have the same spatial covariance and the TDD system has channel reciprocity.

[152] Also, the spatial covariance matrix for forming eigenbeams is directly obtained without feedback by using the pilot tones of the uplink subcarriers allocated to one user.

[153] Further, the downlink temporal spatial covariance is obtained by using interpolation of the temporal spatial covariance of the uplink subcarriers.

[154] In addition, most errors which are randomly generated because of inaccurate selection of the optimized eigenbeam are corrected by the channel decoder provided at the latter part of the receiver.

[155]

## Claims

- [1] A base station transmitter and receiver of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD (orthogonal frequency division multiplex/time division duplex), comprising:  
multiple antennas for transmitting OFDM symbols to a mobile station receiver, and receiving OFDM symbols from the mobile station receiver;  
a base station receiver for performing FFT (fast Fourier transform) on the OFDM symbols which are received by a predetermined number through the multiple antennas, outputting FFT-performed symbols as parallel signals, estimating a channel from the parallel signals, detecting symbols from the parallel signals and converting the detected symbols into serial signals by using channel estimation results, and outputting decoded signals; and  
a base station transmitter for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, generating respective beam weights from the channels of the respective pilot tones of the subcarriers according to the channel estimation results executed by the base station receiver, generating respective OFDM symbols with formed eigenbeams, and outputting them.
- [2] The base station transmitter and receiver of claim 1, wherein the base station transmitter comprises:  
a S/P (serial/parallel) converter for converting the channel-coded symbols which are input in series into a predetermined number of parallel signals;  
a signal repeater for repeating the parallel signals by the number of the multiple antennas;  
a beam weight generator for generating an eigenbeam weight from per-pilot channel of each subcarrier according to a channel estimation result;  
a beam weight multiplier for respectively multiplying the beam weight generated by the beam weight generator by the output of the signal repeater, and outputting results; and  
a plurality of IFFT (inverse fast Fourier transform) units for receiving the predetermined number of parallel signals, generating one OFDM symbol, and outputting the OFDM symbol.
- [3] The base station transmitter and receiver of claim 2, wherein the beam weight generator comprises:

a per-pilot spatial covariance matrix generator for receiving per-pilot channel matrices according to the channel estimation result, and generating per-pilot spatial covariance matrices of the respective subcarriers;

a per-subcarrier spatial covariance matrix generator for using a predetermined number of pilot tones provided in a subcarrier, receiving the per-pilot spatial covariance matrices, and generating respective per-subcarrier spatial covariance matrices;

a short-term spatial covariance matrix generator for using a property that uplink subcarriers have the same spatial covariance matrix, receiving the respective per-subcarrier spatial covariance matrices, and generating short-term spatial covariance matrices;

a long-term spatial covariance matrix generator for receiving the short-term spatial covariance matrices, and outputting long-term spatial covariance matrices;

an inter-subcarrier spatial covariance matrix interpolator for receiving the uplink per-subcarrier spatial covariance matrices obtained through the uplink, and outputting a predetermined number of downlink per-subcarrier spatial covariance matrices;

an eigen divider for receiving the long-term spatial covariance matrices, dividing them into respective eigenbeams, and outputting the eigenbeams; and

a beam weight selector for receiving the divided eigenbeams and the downlink per-subcarrier spatial covariance matrices, and outputting respective per-subcarrier beam weights.

- [4] The base station transmitter and receiver of claim 3, wherein the short-term spatial covariance matrices correspond to the long-term spatial covariance matrices when a received packet is short.
- [5] The base station transmitter and receiver of claim 3, wherein the eigenbeam of the eigen divider is defined to be an eigenvector which corresponds to the largest eigenvalue from among a predetermined number of eigenvectors, and is divided by the eigenbeam which maximizes the receiving power of the mobile station from among a plurality of eigenbeams.
- [6] The base station transmitter and receiver of claim 1, wherein the base station receiver comprises:
- a plurality of FFT (fast Fourier transform) units for receiving the respective OFDM symbols through the multiple antennas, performing FFT on the OFDM

symbols by the number of the multiple antennas, and outputting parallel signals;  
a channel estimator for estimating channels from the parallel signals;  
a signal detector for using results of the channel estimator, detecting symbols from the parallel signals, and outputting a predetermined number of detected parallel signals;  
a P/S (parallel/serial) converter for converting the detected parallel signals into serial signals; and  
a channel decoder for decoding the serial signals, and outputting decoded signals.

[7] The base station transmitter and receiver of claim 6, wherein the channel estimator outputs channel matrices of the respective pilot tones for the respective subcarriers in order to calculate beam weight weights.

[8] A mobile station transmitter and receiver of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD (orthogonal frequency division multiplex/time division duplex), comprising:  
multiple antennas for receiving respective OFDM symbols from a base station transmitter, and transmitting OFDM symbols to a base station receiver;  
a mobile station receiver for receiving the OFDM symbols with formed respective eigenbeams from the base station transmitter, performing FFT (fast Fourier transform) on them, outputting FFT-performed OFDM symbols as parallel signals, detecting symbols from the parallel signals, converting the detected symbols into serial signals, and outputting decoded signals; and  
a mobile station transmitter for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, repeating N parallel signals by the number of multiple antennas to which the N parallel signals are input, generating respective OFDM symbols, and outputting the OFDM symbols, the N parallel signals being obtained by multiplexing user signals.

[9] The mobile station transmitter and receiver of claim 8, wherein the mobile station receiver comprises:  
a plurality of FFT units for receiving the OFDM symbols through the multiple antennas, performing FFT on them by the number of the multiple antennas, and outputting FFT-performed symbols as parallel signals;  
a signal detector for detecting symbols from the parallel signals, and outputting a predetermined number of detected parallel signals;

- a P/S (parallel/serial) converter for converting the detected parallel signals into serial signals, and outputting the serial signals; and  
a channel decoder for decoding the serial signals, and outputting the serial signals.
- [10] The mobile station transmitter and receiver of claim 9, wherein the channel decoder corrects random errors when the interval of uplink subcarriers exceeds a channel bandwidth to allow inaccurate interpolation or when the moving speed of the mobile station is fast that an inaccurate optimized eigenbeam is selected.
- [11] The mobile station transmitter and receiver of claim 8, wherein the mobile station transmitter comprises:  
N S/P (serial/parallel) converters for converting channel-coded symbols which are input in series into a predetermined number of parallel signals, N corresponding to the number of base station antennas;  
a signal repeater for repeating N parallel signals by the number of the base station antennas when user signals are multiplexed to be input as the N parallel signals; and  
a plurality of IFFT units for receiving the N parallel signals, and generating an OFDM symbol.
- [12] A base station transmitting and receiving method of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD (orthogonal frequency division multiplex/time division duplex), comprising:  
(a) receiving respective OFDM symbols from a mobile station transmitter through an uplink;  
(b) performing FFT (fast Fourier transform) on the received OFDM symbols, outputting FFT-performed OFDM symbols as parallel signals, and estimating channels from the parallel signals;  
(c) converting channel-coded symbols which are input in series into a predetermined number of parallel signals;  
(d) generating respective beam weights from the channels of the respective pilot tones of the respective subcarriers according to a channel estimation result; and  
(e) forming eigenbeams according to the respective beam weights, generating respective OFDM symbols, and transmitting the OFDM symbols to the mobile station receiver through the uplink.
- [13] The base station transmitting and receiving method of claim 12, wherein (b) comprises:

- (i) receiving per-pilot channel matrices according to the channel estimation result, and generating per-pilot spatial covariance matrices of respective subcarriers;
- (ii) using a predetermined number of pilot tones provided on a subcarrier, receiving the per-pilot spatial covariance matrices, and generating respective per-subcarrier spatial covariance matrices;
- (iii) using a property that a predetermined number of uplink subcarriers have the same spatial covariance matrix, receiving the respective per-subcarrier spatial covariance matrices, and generating short-term spatial covariance matrices;
- (iv) receiving the short-term spatial covariance matrices and outputting long-term spatial covariance matrices;
- (v) receiving uplink per-subcarrier spatial covariance matrices obtained through the uplink, and outputting a predetermined number of downlink per-subcarrier spatial covariance matrices;
- (vi) receiving the long-term spatial covariance matrices, dividing them into respective eigenbeams, and outputting the eigenbeams; and
- (vii) receiving the divided eigenbeams and the uplink per-subcarrier spatial covariance matrices, and outputting beam weights for the respective subcarriers.

[14] The base station transmitting and receiving method of claim 13, wherein (i) comprises: using the equation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c) = \tilde{\mathbf{H}}_c^H(n_c) \tilde{\mathbf{H}}_c(n_c)$$

and finding per-pilot spatial covariance matrices of respective subcarriers where

$$\mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

is the temporal spatial covariance matrix obtained from the  $n_c^{\text{th}}$  pilot tone of the  $c^{\text{th}}$  subcarrier.

[15] The base station transmitting and receiving method of claim 14, wherein (ii) comprises: using  $N_c$  pilot tones provided on a subcarrier and finding the spatial covariance matrix of the subcarrier  $c$  defined by the equation of

$$\mathbf{R}_{\tilde{\mathbf{H}}_c} = \frac{1}{N_c} \sum_{n_c=1}^{N_c} \mathbf{R}_{\tilde{\mathbf{H}}_c}(n_c)$$

[16] The base station transmitting and receiving method of claim 15, wherein (iii) comprises: finding the short-term spatial covariance matrix  $\mathbf{R}_{ST}$  by using the equation of

$$\mathbf{R}_{ST} = \frac{1}{C} \sum_{c=1}^C \mathbf{R}_{\tilde{\mathbf{H}}_c}$$

since C uplink subcarriers have the same spatial covariance matrix.

[17] The base station transmitting and receiving method of claim 16, wherein (iii) comprises: finding the long-term spatial covariance matrix  $\mathbf{R}_{LT}$  by using the equation of

$$\mathbf{R}_{LT}(i) = \rho \mathbf{R}_{LT}(i-1) + (1-\rho) \mathbf{R}_{ST}(i)$$

where i is a number of frames and  $\rho$  is a forgetting factor.

[18] The base station transmitting and receiving method of claim 17, wherein (vi) comprises: performing eigen division by using the equation of

$$\mathbf{R}_{LT} \mathbf{V} = \mathbf{V} \mathbf{\Theta}$$

where

$$\mathbf{\Theta} = \text{diag}(\lambda_1, \lambda_2, \dots, \lambda_L)$$

is a diagonal matrix having the eigenvalues of

$$\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_L$$

as elements, and it is given that

$$\mathbf{V} = [\mathbf{v}_1 \ \mathbf{v}_2 \ \dots \ \mathbf{v}_L]$$

where  $\mathbf{V}_L$  is an eigenvector corresponding to  $\lambda_L$ .

- [19] The base station transmitting and receiving method of claim 17, wherein (vii) comprises outputting the respective per-subcarrier beam weights by using the equation of

$$\mathbf{w}_k = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \left\| \tilde{\mathbf{H}}_k \mathbf{v}_n \right\|^2 = \arg \max_{\mathbf{v}_n, n=1, 2, \dots, L} \mathbf{v}_n^H \mathbf{R}_{\tilde{\mathbf{H}}_k} \mathbf{v}_n$$

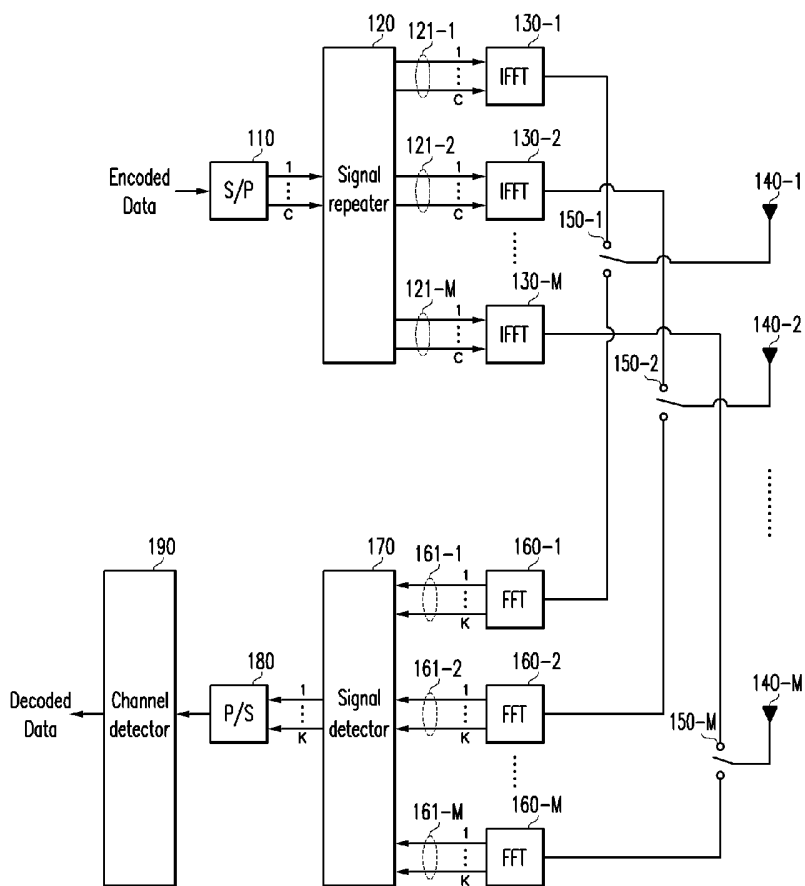
where  $\mathbf{W}_k$  is the  $k^{\text{th}}$  downlink subcarrier.

- [20] A mobile station transmitting and receiving method of a smart antenna system for forming downlink eigenbeams of the OFDM/TDD (orthogonal frequency division multiplex/time division duplex), comprising:

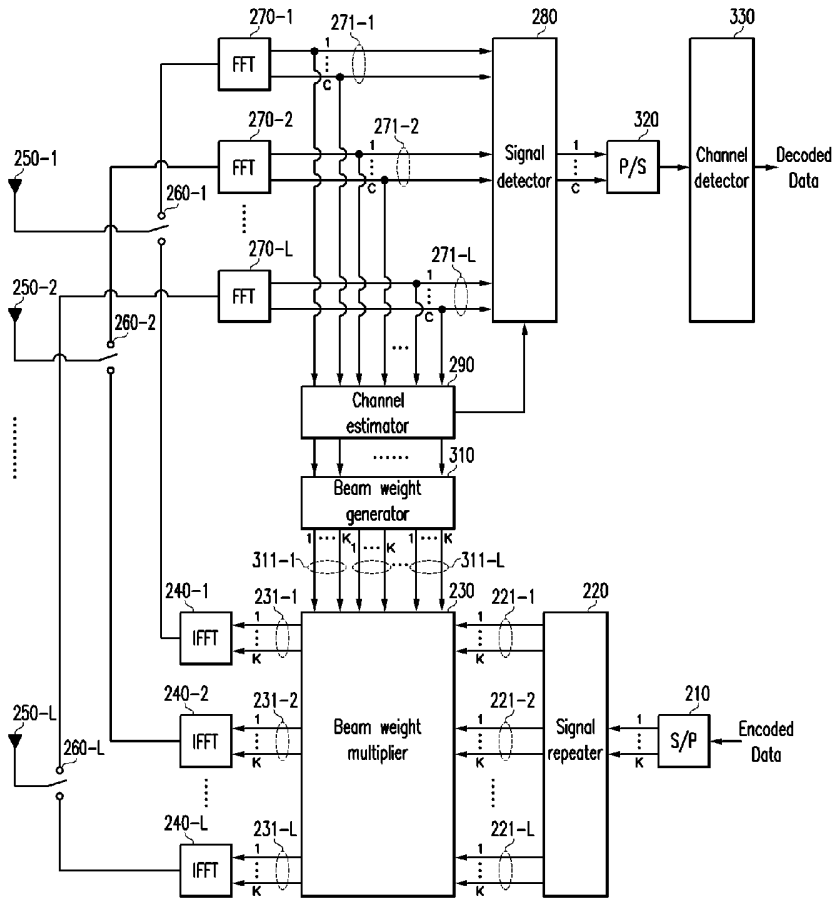
- (a) receiving respective OFDM symbols with eigenbeams transmitted from a base station transmitter;
- (b) performing FFT (fast Fourier transform) on the OFDM symbols, and outputting them as parallel signals;
- (c) detecting symbols from the parallel signals, converting the symbols into serial signals, and outputting decoded signals;
- (d) converting channel-coded symbols which are input in series into a pre-determined number of parallel signals;
- (e) repeating N parallel signals by the number of mobile station antennas to which the N parallel signals are input, and generating respective OFDM symbols, the N parallel signals being obtained by multiplexing user signals; and
- (f) respectively transmitting the OFDM symbols to a base station receiver.

- [21] The mobile station transmitting and receiving method of claim 20 wherein (c) further comprises: correcting random errors when the interval of uplink subcarriers exceeds a channel bandwidth to allow inaccurate interpolation or when the moving speed of the mobile station is fast that an inaccurate optimized eigenbeam is selected.

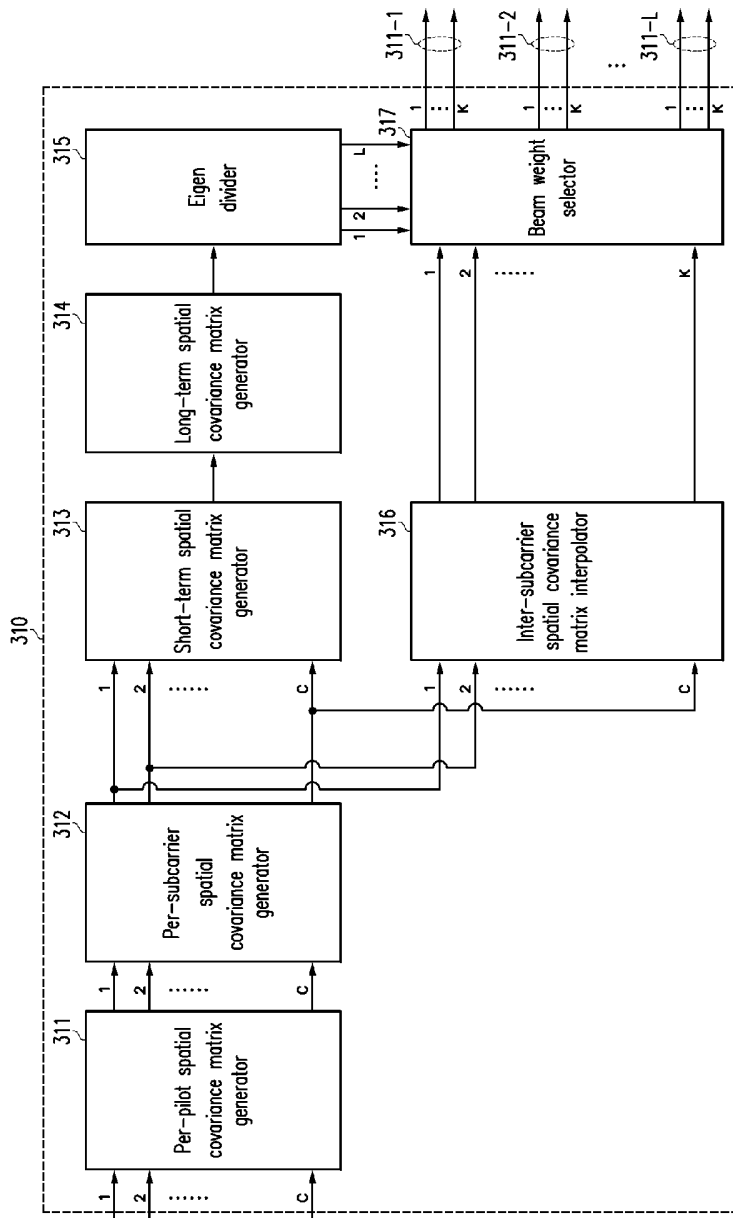
[Fig. 1]



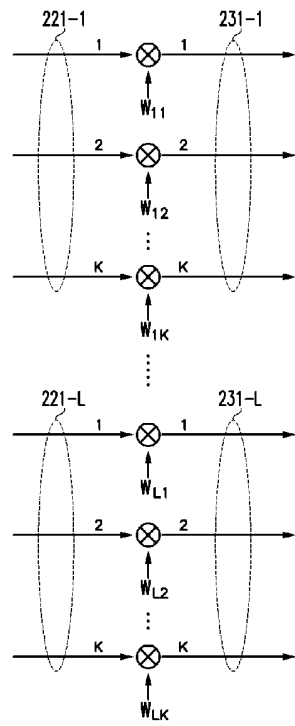
[Fig. 2]



[Fig. 3]



[Fig. 4]



# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/KR 2004/002741

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>IPC <sup>7</sup> : H04B 7/04<br>According to International Patent Classification (IPC) or to both national classification and IPC  |   |   |
|--|---|---|
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br>IPC <sup>7</sup> : H04B, H04Q, H04L<br>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br>----<br>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br>WPI, EPODOC, PAJ   |   |   |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>  |   |   |
| Category*  | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No.   |
| Y  | US 2002/0196734 A1 (TANAKA, M. et al.) 26 December 2002 (26.12.2002)<br><i>abstract, figures 1, 5, 7, 8, paragraphs [0013]-[0019], [0026]-[0029], [0045]-[0079].</i><br>--  | 1, 2, 6, 7, 12  |
| Y  | HUANG et al. 'A Reduced Complexity Coded OFDM System with MIMO Antennas for Broadband Wireless Communications.' In: Global Telecommunications Conference, 2002. GLOBECOM '02. New York: IEEE, 21 November 2002 (21.11.2002), Vol.1, pages 661-665.<br><i>section III, figure 2.</i><br>-- | 1, 2, 6, 7, 12  |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.  |   |   |
| * Special categories of cited documents:<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |   |   |
| Date of the actual completion of the international search<br>11 March 2005 (11.03.2005)  |   | Date of mailing of the international search report<br>5 April 2005 (05.04.2005) |
| Name and mailing address of the ISA/ AT<br><b>Austrian Patent Office</b><br>Dresdner Straße 87, A-1200 Vienna<br>Facsimile No. +43 / 1 / 534 24 / 535  |   | Authorized officer<br>LOIBNER K.<br>Telephone No. +43 / 1 / 534 24 / 323        |

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/KR 2004/002741

| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |  |                       |
|---|--|-----------------------|
| Category*   | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
| A   | WO 2002/033852 A2 (SIEMENS AKTIENGESELLSCHAFT)<br>25 April 2002 (25.04.2002)<br><i>abstract, figures 2, 3, 5, 6; page 5, lines 16-21; page 7, lines 26-32; page 8, line 13 - page 9, line 8; page 10, line 30 - page 16, line 9; page 17, lines 12-35.</i> | 1-21                  |
| A   | --<br>WO 1997/000543 A1 (WATKINS-JOHNSON COMPANY)<br>3 January 1997 (03.01.1997)<br><i>abstract, figures 3, 4; page 8, line 6 - page 9, line 12; page 10, lines 4-6; page 24, line 29 - page 25, line 14; page 28, line 25 - page 29, line 10.</i>         | 1-21                  |
| X   | --<br>JP 2003318853 A (NIPPON TELEGR & TELEPH)<br>7 November 2003 (07.11.2003) (abstract). [online] [retrieved on 10.3.2005]. Retrieved from: EPOQUE PAJ Database.<br><br><i>abstract.</i>   | 8-11, 20, 21          |
|   | ----   |                       |

# INTERNATIONAL SEARCH REPORT

International application No.  
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## Continuation of first sheet

### Continuation No. III:

#### Observations where unity of invention is lacking

#### (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

#### Group 1:

Claims 1-7 and 12-19 directed to a base station transmitting and receiving method and to a corresponding base station transmitter and receiver performing the steps of said method wherein OFDM symbols which are transmitted from a mobile station are received at the base station via multiple antennas and further processed to estimate the characteristic of the uplink channel for each subcarrier based on pilot tones and wherein beam weights are determined to form the downlink eigenbeam based on the estimated characteristic of the uplink channel.

#### Group 2:

Claims 8-11, 20 and 21 directed to a mobile station transmitting and receiving method and a corresponding mobile station performing the steps of said receiving method wherein OFDM symbols which are transmitted from a base station are received at the mobile station via multiple antennas and further processed and decoded by a channel decoder wherein random errors are corrected by said channel decoder.

The special technical feature common to Group 1 invention is the concept of determining the beam weights to form the downlink eigenbeam based on the estimated characteristic of the uplink channel, thereby utilising the reciprocity characteristic of uplink and the downlink channel due to time division duplex transmission.

The special technical feature common to Group 2 invention is the concept of correcting random errors by a channel decoder of a mobile station receiving OFDM symbols.

As the special technical feature common to Group 1 invention is not present in Group 2 invention and the special technical feature common to Group 2 invention is not present in Group 1 invention it is considered that the group of inventions are not so linked as to form a single general inventive concept and therefore the requirement of unity of invention is not met.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.  
PCI/KR 2004/002741

| Patent document cited<br>in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|---|---------------------|----------------------------|---------------------|
| A   |                     | none                       |                     |
| JP A                                      | 20033188<br>53A2    | none                       |                     |
| US A                                      | 20020196<br>734     | none                       |                     |
| WO A                                      | 19970005<br>43      | none                       |                     |
| WO A                                      | 20020338<br>52      | none                       |                     |