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(54) **Title**: A BASE STATION AND A METHOD OF OPERATING A BASE STATION

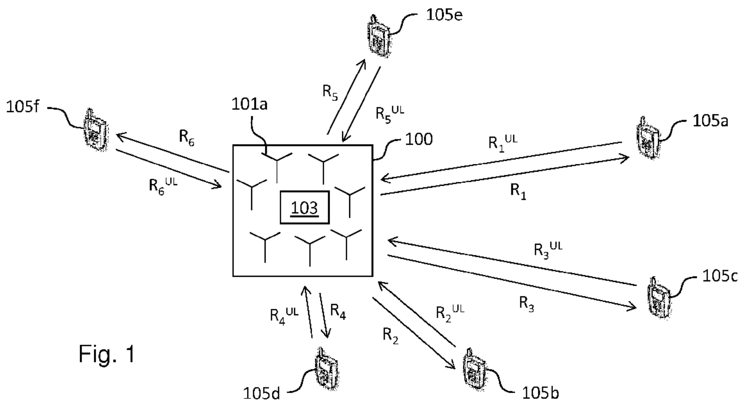

Fig. 1

(57) **Abstract**: The invention relates to a base station (100) configured to communicate with at least one user equipment (105a-g). The base station (100) comprises: an antenna array (101a) with a plurality of antennas configured to establish a duplex communication channel with the at least one user equipment (105a-g), wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction; and a processor (103) configured to in a training phase, generate for a plurality of positions of the at least one user equipment (105a-g) or a plurality of times a plurality of correlation matrix pairs (R_i, R_i^{UL}), wherein the processor (103) is configured to determine each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) on the basis of a respective uplink training signal received from the at least one user equipment (105a-g) and to associate each uplink correlation matrix R_i^{UL} with a corresponding downlink correlation matrix R_i; and in an exploitation phase, determine a further uplink correlation matrix Rj UL on the basis of a further uplink training signal received from the at least one user equipment (105a-g) and estimate a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

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DESCRIPTION

A base station and a method of operating a base station

TECHNICAL FIELD

The present invention relates to mobile communications. In particular, the present invention relates to a multi-antenna base station and a method of operating a multi-antenna base station.

BACKGROUND

In comparison to single-antenna transceivers multiple-antenna transceivers in a base station and a user equipment can improve the performance of a wireless communication link. In order to exploit the potential of such Multiple-In-Multiple-Out (MIMO) systems it is usually necessary to have information about the communication link, which is also known as channel state information (CSI), available at the transmitter side, in particular in multi-user equipment scenarios.

For the case of a MIMO channel with N transmitting antennas at the base station, usually a training sequence having at least a length or duration N is required to estimate a channel matrix representing the channel state information, if no prior information about the statistics (including correlation) of the channel is available. Consequently, for a coherence time T, the fraction of channels N that can be dedicated to data cannot be larger than (T-N)/T, which is problematic for large N (massive MIMO case).

In the article "Joint Spatial Division and Multiplexing - The Large-Scale Array Regime", A. Adhikary, J. Nam, J-Y. Ahn and G. Caire, IEEE Trans. on Inform. Th., 59, no.10, 2013 it has been proposed to decompose the matrix H_i of a MIMO channel representing the channel state information according to the following equation:

$$H_i = W_i R_i^{1/2}, \qquad (1)$$

wherein R_i is the covariance matrix at the antenna array (user location dependent) and W_i is a matrix representing the fast fading. If R_i is known and rank limited (equal to d), the length of the training sequence can be reduced from N to d, thereby reducing the amount of pilot symbols required to estimate the channel matrix H_i.

For instance, in a FDD (frequency division duplex) mode, the full reciprocity is not available. In this case it is generally not possible to derive the downlink CSI from the uplink CSI. The problem is then to estimate the downlink covariance CSI with reduced time costs. As already mentioned above, the prior knowledge of the covariance matrix R_i can potentially reduce drastically the pilot overhead due to the CSI acquisition.

Several approaches are known for the estimation of the covariance CSI in a FDD mode. In a first known approach a feedback scheme is used. The user equipment (UE) estimates the downlink channel matrix H_i for the downlink channel and feeds this information back to the base station which computes the covariance matrix R_i. Alternatively, the UE computes the covariance matrix R_i on the basis of the matrix H_i, and feeds the covariance matrix R_i back to the base station. The drawback of these approaches is the substantial data traffic, i.e. the continuous feedback, between the base station and the user equipment.

A further known approach is based on a model of the user equipment and/or the geometry of the array of antennas (Uniform Linear Array, Uniform Circular Array). This approach, however, is very sensitive to a change of the position and/or orientation of the antenna array and, thus, to the difference between uplink and downlink frequencies. Consequently, this approach has a rather limited applicability in practice.

Thus, there is a need for an improved base station and an improved method of operating such a base station, in particular an improved base station and an improved method of operating such a base station allowing for an efficient estimation of the channel state information.

SUMMARY

It is an objective of the invention to provide an improved base station and an improved method of operating such a base station, in particular an improved base station and an improved method of operating such a base station allowing for an efficient estimation of the channel state information.

This objective is achieved by the subject matter of the independent claims. Further implementation forms are provided in the dependent claims, the description and the figures.

According to a first aspect the invention relates to a base station configured to communicate with at least one user equipment. The base station comprises an antenna array with a plurality of antennas configured to establish a duplex communication channel with the at least one user equipment, wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction. Moreover, the base station comprises a processor configured to, in a training phase, generate for a plurality of positions of the at least one user equipment or a plurality of times a plurality of correlation matrix pairs, wherein the processor is configured to determine each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) on the basis of a respective uplink training signal received from the at least one user equipment and to associate each uplink correlation matrix R_i^{UL} with a corresponding downlink correlation matrix R_i, and, in an exploitation phase, determine a further uplink correlation matrix R_j^{UL} on the basis of a further uplink training signal received from the at least one user equipment and estimate a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

In a first possible implementation form of the first aspect of the invention as such the processor is configured to estimate the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}) by using a matrix interpolation scheme. Using a matrix interpolation scheme improves the accuracy of estimating the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL}, while keeping the size of the dictionary, i.e. the number of correlation matrix pairs (R_i, R_i^{UL}) reasonably small.

In a second possible implementation form of the first implementation form of the first aspect of the invention the processor is configured to estimate the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}) by using the matrix interpolation scheme defined by the following equation:

$$R_j = \underset{Y \epsilon S_N(C)}{\operatorname{argmin}} \sum_{i=1}^{K} w_i d(R_i, Y)^2,$$

wherein Y is a matrix in the space of positive definite matrices $S_N(C)$, N is the number of antennas of the antenna array used in the downlink direction, w_i are interpolation weights calculated on the basis of the further uplink correlation matrix R_j^{UL} and the uplink correlation matrices R_i^{UL} of the plurality of correlation matrix pairs, d(,) defines a distance metric in $S_N(C)$, and K is the number of correlation matrix pairs (R_i, R_i^{UL}).

In a third possible implementation form of the second implementation form of the first aspect of the invention the distance metric d(,) is an Euclidean distance metric defined by the following equation:

$$d_E(X_1, X_2) = \|X_1 - X_2\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

In a fourth possible implementation form of the second implementation form of the first aspect of the invention the distance metric d(,) is a Log-Euclidean distance metric defined by the following equation:

$$d_{LE}(X_1, X_2) = \|\log(X_1) - \log(X_2)\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

In a fifth possible implementation form of the second implementation form of the first aspect of the invention the distance metric d(,) is an affine invariant Riemannian distance metric defined by the following equation:

$$d_{AI}(X_1, X_2) = \left\|\log(X_1^{-1/2} X_2 X_1^{-1/2})\right\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

In a sixth possible implementation form of any one of the second to fifth implementation form of the first aspect of the invention the processor is configured to determine the interpolation weights w_i by a nearest neighbor method according to the following equation:

$$w_i = \begin{cases} 1 & if\ d(R_i^{UL}, R_j^{UL}) = \min_i d(R_i^{UL}, R_j^{UL}) \\ 0 & otherwise \end{cases}.$$

Using a nearest neighbor method provides a computationally efficient solution.

In a seventh possible implementation form of any one of the second to fifth implementation form of the first aspect of the invention the processor is configured to determine the interpolation weights w_i by a self-interpolation method according to the following equation:

$$(w_1, \ldots, w_L) = \underset{\substack{w_1,\ldots,w_L \\ \sum_{i=1}^{L} w_i = 1}}{\operatorname{argmin}} \left\| \sum_{i=1}^{L} w_i exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\| \text{ and } w_i = 0 \text{ for } i > L,$$

wherein $exp_{R_j^{UL}}^{-1}$ denotes the Riemannian exponential map, $(R_1^{UL}, \ldots, R_L^{UL})$ are the L closest matrices to R_j^{UL} with respect to the distance metric d(,). In an embodiment, L is chosen equal to $\min(K, M^2)$, wherein M is the number of antennas of the antenna array used in the uplink direction. In an embodiment, the norm for determining the interpolation weights w_i is the Frobenius norm.

In an eighth possible implementation form of any one of the second to fifth implementation form of the first aspect of the invention the processor is configured to determine the interpolation weights w_i by a kernel interpolation method according to the following equation:

$$w_i = \frac{\varphi(d(R_i^{UL}, R_j^{UL}))}{\sum_{m=1}^{K} \varphi(d(R_m^{UL}, R_j^{UL}))},$$

wherein φ is a decreasing kernel function.

In a ninth possible implementation form of the eight implementation form of the first aspect of the invention the decreasing kernel function φ is defined by the following equation:

$$\varphi_\sigma(r) = e^{-\frac{r^2}{\sigma^2}},$$

wherein σ is chosen such that:

$$\sigma = \underset{\sigma > 0}{\operatorname{argmin}} \left\| \sum_{i=1}^{K} \frac{\varphi_\sigma(d(R_i^{UL}, R_j^{UL}))}{\sum_{m=1}^{K} \varphi_\sigma(d(R_m^{UL}, R_j^{UL}))} exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\|.$$

In a tenth possible implementation form of any one of the second to ninth implementation form of the first aspect of the invention the processor is configured to return from the exploitation phase to the training phase, in case the distance $d(R_j^{UL}, R_i^{UL})$ between the further uplink correlation matrix R_j^{UL} and each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is larger than a distance threshold.

In an eleventh possible implementation form of the first aspect of the invention as such or any one of the first to tenth implementation form thereof the corresponding downlink correlation matrix R_i is received by the base station from the user equipment or is determined by the base station on the basis of information, in particular an estimate of a channel matrix H_i, fed back from the user equipment on the basis of a downlink training signal sent by the base station.

In a twelfth possible implementation form of the eleventh implementation form of the first aspect of the invention the corresponding downlink correlation matrix R_i received from the user equipment by the base station is determined by the user equipment on the basis of a downlink training signal sent by the base station.

In a thirteenth possible implementation form of the first aspect of the invention as such or any one of the first to twelfth implementation form thereof the processor is configured to perform the training phase and the exploitation phase in chronologically successive intervals, in chronologically interleaved intervals or simultaneously.

In a fourteenth possible implementation form of the first aspect of the invention as such or any one of the first to thirteenth implementation form thereof the antenna array is configured to use a first subset of the plurality of antennas in the downlink direction and a second subset of the plurality of antennas in the uplink direction. In an implementation form the first subset of antennas and the second subset of antennas can be identical, overlapping, or disjoint. For N antennas used in the downlink direction the downlink correlation matrix R_i is of dimension NxN, while for M antennas used in the uplink direction the uplink correlation matrix R_i^{UL} is of size MxM.

According to a second aspect the invention relates to a method of operating a base station configured to communicate with at least one user equipment. The method comprises the steps of: establishing a duplex communication channel with the at least one user equipment using an antenna array with a plurality of antennas, wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction; in a training phase, generating for a plurality of positions of the at least one user equipment or a plurality of times a plurality of correlation matrix pairs (R_i, R_i^{UL}), wherein each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is determined on the basis of a respective uplink training signal received from the at least one user equipment and wherein each uplink correlation matrix R_i^{UL} is associated with a corresponding downlink correlation matrix R_i; and in an exploitation phase, determining a further uplink correlation matrix R_j^{UL} on the basis of a further uplink training signal received from the at least one user equipment and estimating a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

The method according to the second aspect of the invention can be performed by the base station according to the first aspect of the invention. Further features of the method according to the second aspect of the invention result directly from the functionality of the base station according to the first aspect of the invention and its different implementation forms described above.

According to a third aspect the invention relates to a computer program comprising program code for performing the method according to the second aspect of the invention when executed on a computer.

The invention can be implemented in hardware and/or software.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments of the invention will be described with respect to the following figures, in which:

Fig. 1 shows a schematic diagram of a communication scenario including a base station according to an embodiment;

Fig. 2 shows a schematic diagram of a communication scenario including a base station according to an embodiment;

Fig. 3 shows a schematic diagram of a method of operating a base station according to an embodiment;

Fig. 4 shows a diagram showing an estimate of the mean square error as a function of the number of correlation matrix pairs for base stations according to different embodiments; and

Fig. 5 shows a diagram showing an estimate of the mean square error as a function of the number of correlation matrix pairs for base stations according to different embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following detailed description, reference is made to the accompanying drawings, which form a part of the disclosure, and in which are shown, by way of illustration, specific aspects in which the disclosure may be practiced. It is understood that other aspects may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims.

It is understood that a disclosure in connection with a described method may also hold true for a corresponding device or system configured to perform the method and vice versa. For example, if a specific method step is described, a corresponding device may include a unit to perform the described method step, even if such unit is not explicitly described or illustrated in the figures. Further, it is understood that the features of the various exemplary aspects described herein may be combined with each other, unless specifically noted otherwise.

Figure 1 shows a schematic diagram of a communication scenario including a base station 100 according to an embodiment. The base station 100 is configured to communicate with at least one user equipment, for instance, at least one mobile phone. Figure 1 shows six exemplary user equipments 105a-f. As will be described in more detail further below, according to an embodiment the six exemplary user equipments 105a-f can be different user equipments or one or more user equipments at different positions and/or times.

The base station 100 comprises an antenna array 101a, wherein the antenna array comprises at least two antennas and is configured to establish a duplex communication channel with the at least one user equipment 105a-f. The duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction. In an embodiment, the antenna array 101a is configured to use a first subset of its antennas in the downlink direction and a second subset of its antennas in the uplink direction. The first subset of antennas and the second subset of antennas can be identical, overlapping, or disjoint. For N antennas used in the downlink direction the downlink correlation matrix R_i is of dimension NxN, while for M antennas used in the uplink direction the uplink correlation matrix R_i^{UL} is of size MxM.

Moreover, the base station 100 comprises a processor 103 configured to, in a training phase, generate for a plurality of positions of the one or more user equipments 105a-f or a plurality of times a plurality of correlation matrix pairs, wherein the processor 103 is configured to determine each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) on the basis of a respective uplink training signal received from the one or more user equipments 105a-f and to associate each uplink correlation matrix R_i^{UL} with a corresponding downlink correlation matrix R_i.

For instance, on the basis of the six exemplary positions and/or times of the one or more user equipments 105a-f shown in figure 1 the processor 103 of the base station 100 is configured generate six correlation matrix pairs (R_i, R_i^{UL}), as indicated in figure 1.

Furthermore, the processor 103 of the base station 100 is configured, in an exploitation phase, to determine a further uplink correlation matrix R_j^{UL} on the basis of a further uplink training signal received from the at least one user equipment and estimate a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

For instance, in the exemplary scenario shown in figure 2 the processor 103 of the base station 100 is configured in the exploitation phase to determine the further uplink correlation matrix R^{UL} for the user equipment 105g on the basis of an uplink training signal received from the user equipment 105g and to estimate a further downlink correlation matrix R corresponding to the further uplink correlation matrix R^{UL} on the basis of the further uplink correlation matrix R^{UL} and the six correlation matrix pairs (R_i, R_i^{UL}) determined in figure 1.

In an embodiment, the processor 103 is configured to estimate the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}) by using a matrix interpolation scheme. In an embodiment, the matrix interpolation scheme is defined by the following equation:

$$R_j = \underset{Y \epsilon S_N(C)}{\operatorname{argmin}} \sum_{i=1}^{K} w_i d(R_i, Y)^2, \qquad (2)$$

wherein Y is a matrix in the space of positive definite matrices $S_N(C)$, N is the number of antennas of the antenna array 101a used in the downlink direction, w_i are interpolation weights calculated on the basis of the further uplink correlation matrix R_j^{UL} and the uplink correlation matrices R_i^{UL} of the plurality of correlation matrix pairs, d(,) defines a distance metric in $S_N(C)$, and K is the number of correlation matrix pairs (R_i, R_i^{UL}).

In an embodiment, the distance metric d(,) is an Euclidean distance metric defined by the following equation:

$$d_E(X_1, X_2) = \|X_1 - X_2\|_F, \qquad (3)$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \ \|_F$ denotes the Frobenius norm.

In an embodiment, the distance metric d(,) is a Log-Euclidean distance metric defined by the following equation:

$$d_{LE}(X_1, X_2) = \|\log(X_1) - \log(X_2)\|_F, \qquad (4)$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \ \|_F$ denotes the Frobenius norm.

In an embodiment, the distance metric d(,) is an affine invariant Riemannian distance metric defined by the following equation:

$$d_{AI}(X_1, X_2) = \left\|\log(X_1^{-1/2} X_2 X_1^{-1/2})\right\|_F, \qquad (5)$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \ \|_F$ denotes the Frobenius norm.

In an embodiment, the processor 103 of the base station 100 is configured to determine the interpolation weights w_i by a nearest neighbor method according to the following equation:

$$w_i = \begin{cases} 1 & if\ d(R_i^{UL}, R_j^{UL}) = \min_i d(R_i^{UL}, R_j^{UL}) \\ 0 & otherwise \end{cases}. \qquad (6)$$

In an embodiment, the processor 103 is configured to determine the interpolation weights w_i by a self-interpolation method according to the following equation:

$$(w_1, \dots, w_L) = \underset{\substack{w_1,\dots,w_L \\ \sum_{i=1}^{L} w_i = 1}}{\operatorname{argmin}} \left\| \sum_{i=1}^{L} w_i exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\| \text{ and } w_i = 0 \text{ for } i > L, \qquad (7)$$

wherein $exp_{R_j^{UL}}^{-1}$ denotes the Riemannian exponential map, $(R_1^{UL}, \dots, R_L^{UL})$ are the L closest matrices to R_j^{UL} with respect to the distance metric d(,) and $L = \min(K, M^2)$, wherein M is the number of antennas of the antenna array 101a used in the uplink direction.

In an embodiment, the processor 103 is configured to determine the interpolation weights w_i by a kernel interpolation method according to the following equation:

$$w_i = \frac{\varphi(d(R_i^{UL}, R_j^{UL}))}{\sum_{m=1}^{K} \varphi(d(R_m^{UL}, R_j^{UL}))}, \qquad (8)$$

wherein φ is a decreasing kernel function. In an embodiment, the decreasing kernel function φ is defined by the following equation:

$$\varphi_\sigma(r) = e^{-\frac{r^2}{\sigma^2}}. \qquad (9)$$

In an embodiment σ is chosen such that:

$$\sigma = \underset{\sigma > 0}{\operatorname{argmin}} \left\| \sum_{i=1}^{K} \frac{\varphi_\sigma(d(R_i^{UL}, R_j^{UL}))}{\sum_{m=1}^{K} \varphi_\sigma(d(R_m^{UL}, R_j^{UL}))} exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\| \qquad (10)$$

As the person skilled in the art will appreciate, σ should be positive. Other options than equation (10) do exist for choosing σ.

In an embodiment, the processor 103 is configured to return from the exploitation phase to the training phase, in case the distance $d(R_j^{UL}, R_i^{UL})$ between the further uplink correlation matrix R_j^{UL} and each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is larger than a distance threshold. This is advantageous in case the dictionary of correlation matrix pairs (R_i, R_i^{UL}) determined during the training phase is not sufficient to determine the further uplink correlation matrix R^{UL}, for instance, by means of one of the above described matrix interpolation methods.

In an embodiment, the corresponding downlink correlation matrix R_i can be received by the base station 100 from the user equipment 105a-g or is determined by the base station 100 on the basis of information, in particular an estimate of a channel matrix H_i (as defined in above equation (1)), fed back from the user equipment 105a-g on the basis of a downlink training signal sent by the base station 100. In an embodiment, the corresponding downlink correlation matrix R_i received from the user equipment 105a-g by the base station 100 is determined by the user equipment 105a-g on the basis of a downlink training signal sent by the base station 100.

In an embodiment, the processor 103 is configured to perform the training phase and the exploitation phase in chronologically successive intervals, in chronologically interleaved intervals or simultaneously.

As the person skilled in the art will appreciate, for an embodiment with $N \neq M$, I a different numbers of antennas used in the downlink direction than in the uplink direction, some of the above equations have to be adapted to the dimension of the considered matrices, in the sense that d(A ,B) defines a distance metric in the space $S_N(C)$ when A and B are downlink covariance matrices, while the distance metric operates in the space $S_M(C)$ when A and B are uplink covariance matrices.

Figure 3 shows a schematic diagram of a method 300 of operating a base station, for instance the base station 100 shown in figures 1 and 2, according to an embodiment.

In a first step 301 a duplex communication channel with the at least one user equipment 105a-g is established using the antenna array 101 having a plurality of antennas, wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction.

In a training phase 303, a plurality of correlation matrix pairs (R_i, R_i^{UL}) are generated for a plurality of positions of the at least one user equipment 105a-g or a plurality of times, wherein each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is determined on the basis of a respective uplink training signal received from the at least one user equipment 105a-g and wherein each uplink correlation matrix R_i^{UL} is associated with a corresponding downlink correlation matrix R_i.

In an exploitation phase 305, a further uplink correlation matrix R_j^{UL} is determined on the basis of a further uplink training signal received from the at least one user equipment 105a-g and a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} is estimated on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

In the following, further implementation forms, embodiments and aspects of the base station 100 and the method 300 will be described.

For estimating the performance of a base station according to an embodiment simulations have been performed using K (with K equal to 50, 100, 150, 300 or 1500) pairs of UL/DL correlation matrices in the base station 100. For the simulations, each correlation matrix pair has been generated by randomly placing a single antenna user equipment surrounded by a ring of scatterers and by computing the corresponding correlation matrices as a function of the UL/DL wavelength. Ten antennas (N=10) are placed randomly in a square. The uplink (UL) and downlink (DL) channels are assumed to operate at different frequencies (uplink at 1.9 GHz and downlink at 1.8 GHz). The covariance matrices are estimated by the sample covariance computed from 1000 realizations of the fast-fading process W_i, as defined in above equation (1).

The three different embodiments described above for estimating the further uplink correlation matrix R_j^{UL} have been compared with the estimation methods known from the prior art, namely (1) by estimating the downlink covariance matrix by assuming that it is identical to the uplink covariance matrix: $R = R^{UL}$ (herein referred to as "no conversion") or (2) by using an interpolation scheme based on the fact that the downlink covariance function is a dilation of the uplink covariance function in the case of a Uniform Linear Array (herein referred to as "spline interpolation"; in this case the uplink can be interpolated by a cubic spline as a function of the distance between antennas, as suggested in the article "Conversion from Uplink to Downlink Spatio-Temporal Correlation with Cubic Splines", M. Jordan, A. Dimofte, X. Gong and G. Ascheid, VTC Spring 09, 69th, 2009). As a benchmark, the three different embodiments described above for estimating the further uplink correlation matrix R_j^{UL} have also been compared with the perfect feedback case as a limit benchmark.

Figure 4 shows a diagram showing an estimate of the mean square error as a function of the number of correlation matrix pairs for the above described cases. The mean square error has been obtained by Monte-Carlo simulations over N_{MC} realizations, defined by the following equation

$$MSE = \frac{1}{N_{MC}} \sum_{n=1}^{N_{MC}} d_{AI}\left(R_n, \hat{R}_n\right)^2. \tag{11}$$

The interpolation method chosen for figure 4 is the nearest neighbour method described above. The results are presented in figure 4 and figure 5 for two possible choices of the frequency gap between the uplink and downlink bands, namely 1.8 and 1.9 GHz for figure 5 and 1.8 and 2.8 GHz for figure 5.

In the case of perfect feedback it has been assumed that there is no accuracy loss due to the quantization of $\hat{R}$ when it is transmitted from the user equipment to the base station. However, $\hat{R}$ remains affected by the estimation noise due to the sample covariance estimator, which explains the floor that can be observed on the MSE in figures 4 and 5.

It can be observed that the interpolation-based solutions generally perform better than the spline method, and the naïve method consisting in assuming that $R = R^{UL}$.

Alternatively, the performance of the above described embodiments can be estimated using a different benchmark. To this end it is assumed that the objective of estimating R is to identify its dominant eigenvectors, or more accurately its dominant P-dimensional eigenspace, for some P<N. This metric is relevant since certain schemes considered for multi-user Massive MIMO transmission (such as zero-forcing based approaches) require the knowledge of the dominant eigenspace of the users only. The results for the case P=3 are presented below.

For the metric the chordal distance $d_c(V, \hat{V}) = \|VV^+ - \hat{V}\hat{V}^+\|$ is chosen, which is the appropriate distance between two subspaces spanned by the NxP orthonormal matrices $(V, \hat{V})$. Since during the exploitation phase the embodiments according to the invention require no feedback from the user equipment, these embodiments have been benchmarked by evaluating the number of bits that would be required to achieve a similar accuracy if a classical feedback scheme based on quantization was used.

For this case a Grassmannian feedback scheme is used, where the number of bits is linked to the achieved quantization error by the following equation

$$N_{bits} = -\log_2\left(c_{P,N}\right) + 2P(N-P)\log_2\left(\frac{2}{E[d_c(V,\hat{V})]}\right), \qquad (12)$$

where $c_{P,N}$ is a constant that depends on the dimension of the considered Grassmannian space. The following tables 1 to 4 show the number of spared bits for the different embodiments described above.

Dictionary size	Euclidean metric	Log-Euclidean metric	Affine Invariant metric	No Conversion	Spline Interpolation
K = 50	51	55	55	61	62
K = 150	52	59	59	61	62
K = 500	52	60	60	61	62

Table 1: Number of spared bits for the nearest-neighbor interpolation for three Riemannian metrics with uplink and downlink frequencies respectively equal to 1.8 GHz and 1.9 GHz (Uniform Linear Array)

Dictionary Size	Euclidean metric	Log-Euclidean metric	Affine Invariant metric	No Conversion	Spline Interpolation
K = 50	49	55	56	62	25
K = 150	53	55	56	62	25
K = 500	55	60	60	62	25

Table 2: Number of spared bits for the nearest-neighbor interpolation for three Riemannian metrics with uplink and downlink frequencies respectively equal to 1.8 GHz and 1.9 GHz (Random Geometry of antennas)

Dictionary Size	Euclidean metric	Log-Euclidean metric	Affine Invariant metric	No Conversion	Spline Interpolation
K = 50	51	56	52	62	25
K = 150	45	60	60	62	25

K = 500	46	63	71	62	25

Table 3: Number of spared bits for the self-interpolation for three Riemannian metrics with uplink and downlink frequencies respectively equal to 1.8 GHz and 1.9 GHz (Random Geometry of antennas)

Dictionary Size	Euclidean metric	Log-Euclidean metric	Affine Invariant metric	No Conversion	Spline Interpolation
K = 50	29	68	66	62	25
K = 150	31	72	70	62	25
K = 500	31	72	70	62	25

Table 4: Number of spared bits for the kernel interpolation for three Riemannian metrics with uplink and downlink frequencies respectively equal to 1.8GHz and 1.9GHz (Random Geometry of antennas)

The chordal error conditioning the amount of spared feedback bits partially depends on the estimation noise due to a sample covariance estimator, which explains the small difference between the spline interpolation and the approach without conversion.

Table 5 provides an overview of the computational complexity of different embodiments of the invention described above in the case where the number of transmitting and receiving antennas at base station are equal (N=M). C(K,N) represents the complexity of the Riemannian gradient descent used for the computation of the barycenter for the affine invariant metric. Since this is an iterative algorithm, this complexity is difficult to evaluate as it depends on the required accuracy. However, it can be reduced by choosing a good initialization, such as the covariance estimated shortly before for the same user (equipment).

	Euclidean	Log-Euclidean	Affine Invariant
Nearest Neighbor	KN^2	KN^3	KN^3
Self-interpolation	KN^4	KN^4	$KN^4 + KN^3C(K,N)$
Kernel method	KN^3	KN^3	$KN^3\ C(K,N)$

Table 5: Computational complexity of different embodiments according to the invention

The complexity is often related to the complexity of the computation of K logarithms of matrices of size NxN (equal to $O(KN^3)$). In practice, the gradient descent is the limiting factor for the Affine Invariant, but its complexity analysis is non-trivial. The Log-Euclidean metric acts like the Euclidean metric once the logarithm of every covariance matrix is considered. The complexity then differs only from the computation of these logarithm matrices.

Embodiments of the invention provide, amongst others, for the following advantages. Embodiments of the invention allow obtaining information about the covariance matrices or CSI without continuous feedback, as no feedback is required during the exploitation phase. Embodiments of the invention are valid for any antenna array configuration and do not depend on a physical or statistical modelling of user equipments. Embodiments of the invention are independent of the considered uplink and downlink frequencies. Embodiments of the invention exploit reciprocity in the FDD mode.

The devices described herein may be implemented as a circuit within a chip or an integrated circuit or an application specific integrated circuit (ASIC). The invention can be implemented in digital and/or analogue electronic and circuitry.

While a particular feature or aspect of the disclosure may have been disclosed with respect to only one of several implementations or embodiments, such feature or aspect may be combined with one or more other features or aspects of the other implementations or embodiments as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "include", "have", "with", or other variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprise". Also, the terms "exemplary", "for example" and "e.g." are merely meant as an example, rather than the best or optimal. The terms “coupled” and “connected”, along with derivatives may have been used. It should be understood that these terms may have been used to indicate that two elements cooperate or interact with each other regardless whether they are in direct physical or electrical contact, or they are not in direct contact with each other.

Although specific aspects have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific aspects shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific aspects discussed herein.

Although the elements in the following claims are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.

Many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the above teachings. Of course, those skilled in the art readily recognize that there are numerous applications of the invention beyond those described herein. While the present invention has been described with reference to one or more particular embodiments, those skilled in the art recognize that many changes may be made thereto without departing from the scope of the present invention. It is therefore to be understood that within the scope of the appended claims and their equivalents, the invention may be practiced otherwise than as specifically described herein.

CLAIMS

1. A base station (100) configured to communicate with at least one user equipment (105a-g), wherein the base station (100) comprises:

an antenna array (101a) with a plurality of antennas configured to establish a duplex communication channel with the at least one user equipment (105a-g), wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction; and

a processor (103) configured to

in a training phase, generate for a plurality of positions of the at least one user equipment (105a-g) or a plurality of times a plurality of correlation matrix pairs (R_i, R_i^{UL}), wherein the processor (103) is configured to determine each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) on the basis of a respective uplink training signal received from the at least one user equipment (105a-g) and to associate each uplink correlation matrix R_i^{UL} with a corresponding downlink correlation matrix R_i; and

in an exploitation phase, determine a further uplink correlation matrix R_j^{UL} on the basis of a further uplink training signal received from the at least one user equipment (105a-g) and estimate a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

2. The base station (100) of claim 1, wherein the processor (103) is configured to estimate the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}) by using a matrix interpolation scheme.

3. The base station (100) of claim 2, wherein the processor (103) is configured to estimate the further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the

plurality of correlation matrix pairs (R_i, R_i^{UL}) by using the matrix interpolation scheme defined by the following equation:

$$R_j = \underset{Y \epsilon S_N(C)}{\operatorname{argmin}} \sum_{i=1}^{K} w_i d(R_i, Y)^2,$$

wherein Y is a matrix in the space of positive definite matrices $S_N(C)$, N is the number of antennas of the antenna array (101a) used in the downlink direction, w_i are interpolation weights calculated on the basis of the further uplink correlation matrix R_j^{UL} and the uplink correlation matrices R_i^{UL} of the plurality of correlation matrix pairs, d(,) defines a distance metric in $S_N(C)$, and K is the number of correlation matrix pairs (R_i, R_i^{UL}).

4. The base station (100) of claim 3, wherein the distance metric d(,) is an Euclidean distance metric defined by the following equation:

$$d_E(X_1, X_2) = \|X_1 - X_2\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

5. The base station (100) of claim 3, wherein the distance metric d(,) is a Log-Euclidean distance metric defined by the following equation:

$$d_{LE}(X_1, X_2) = \|\log(X_1) - \log(X_2)\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

6. The base station (100) of claim 3, wherein the distance metric d(,) is an affine invariant Riemannian distance metric defined by the following equation:

$$d_{AI}(X_1, X_2) = \left\|\log(X_1^{-1/2} X_2 X_1^{-1/2})\right\|_F,$$

wherein X_1 and X_2 are matrices in $S_N(C)$ and $\| \quad \|_F$ denotes the Frobenius norm.

7. The base station (100) of any one of claims 3 to 6, wherein the processor (103) is configured to determine the interpolation weights w_i by a nearest neighbor method according to the following equation:

$$w_i = \begin{cases} 1 & if\ d(R_i^{UL}, R_j^{UL}) = \min_i d(R_i^{UL}, R_j^{UL}) \\ 0 & otherwise \end{cases}.$$

8. The base station (100) of any one of claims 3 to 6, wherein the processor (103) is configured to determine the interpolation weights w_i by a self-interpolation method according to the following equation:

$$(w_1, \dots, w_L) = \underset{\substack{w_1,\dots,w_L \\ \sum_{i=1}^{L} w_i = 1}}{\operatorname{argmin}} \left\| \sum_{i=1}^{L} w_i exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\| \text{ and } w_i = 0 \text{ for } i > L,$$

wherein $exp_{R_j^{UL}}^{-1}$ denotes the Riemannian exponential map and $(R_1^{UL}, \dots, R_L^{UL})$ are the L closest matrices to R_j^{UL} with respect to the distance metric d(,).

9. The base station (100) of any one of claims 3 to 6, wherein the processor (103) is configured to determine the interpolation weights w_i by a kernel interpolation method according to the following equation:

$$w_i = \frac{\varphi(d(R_i^{UL}, R_j^{UL}))}{\sum_{m=1}^{K} \varphi(d(R_m^{UL}, R_j^{UL}))},$$

wherein φ is a decreasing kernel function.

10. The base station (100) of claim 9, wherein the decreasing kernel function φ is defined by the following equation:

$$\varphi_\sigma(r) = e^{-\frac{r^2}{\sigma^2}},$$

wherein σ is chosen such that:

$$\sigma = \underset{\sigma > 0}{\operatorname{argmin}} \left\| \sum_{i=1}^{K} \frac{\varphi_\sigma\left(d(R_i^{UL}, R_j^{UL})\right)}{\sum_{m=1}^{K} \varphi_\sigma\left(d(R_m^{UL}, R_j^{UL})\right)} exp_{R_j^{UL}}^{-1}(R_i^{UL}) \right\|.$$

11. The base station (100) of any one of claims 3 to 10, wherein the processor (103) is configured to return from the exploitation phase to the training phase, in case the distance $d(R_j^{UL}, R_i^{UL})$ between the further uplink correlation matrix R_j^{UL} and each uplink correlation

matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is larger than a distance threshold.

12. The base station (100) of any one of the preceding claims, wherein the antenna array (101a) is configured to use a first subset of the plurality of antennas in the downlink direction and a second subset of the plurality of antennas in the uplink direction.

13. The base station (100) of any one of the preceding claims, wherein the corresponding downlink correlation matrix R_i is received by the base station (100) from the user equipment (105a-g) or is determined by the base station (100) on the basis of information, in particular an estimate of a channel matrix H_i, fed back from the user equipment (105a-g) on the basis of a downlink training signal sent by the base station (100).

14. The base station (100) of claim 13, wherein the corresponding downlink correlation matrix R_i received from the user equipment (105a-g) by the base station (100) is determined by the user equipment (105a-g) on the basis of a downlink training signal sent by the base station (100).

15. A method (300) of operating a base station (100) configured to communicate with at least one user equipment (105a-g), wherein the method (300) comprises:

establishing (301) a duplex communication channel with the at least one user equipment (105a-g) using an antenna array (101a) with a plurality of antennas, wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix R_i describing the channel state in the downlink direction and an uplink correlation matrix R_i^{UL} describing the channel state in the uplink direction;

in a training phase, generating (303) for a plurality of positions of the at least one user equipment (105a-g) or a plurality of times a plurality of correlation matrix pairs (R_i, R_i^{UL}), wherein each uplink correlation matrix R_i^{UL} of the plurality of correlation matrix pairs (R_i, R_i^{UL}) is determined on the basis of a respective uplink training signal received from the at least one user equipment (105a-g) and wherein each uplink correlation matrix R_i^{UL} is associated with a corresponding downlink correlation matrix R_i; and

in an exploitation phase, determining (305) a further uplink correlation matrix R_j^{UL} on the basis of a further uplink training signal received from the at least one user equipment (105a-g) and estimating a further downlink correlation matrix R_j corresponding to the further uplink correlation matrix R_j^{UL} on the basis of the further uplink correlation matrix R_j^{UL} and the plurality of correlation matrix pairs (R_i, R_i^{UL}).

16. A computer program comprising a program code for performing the method (300) of claim 15 when executed on a computer.

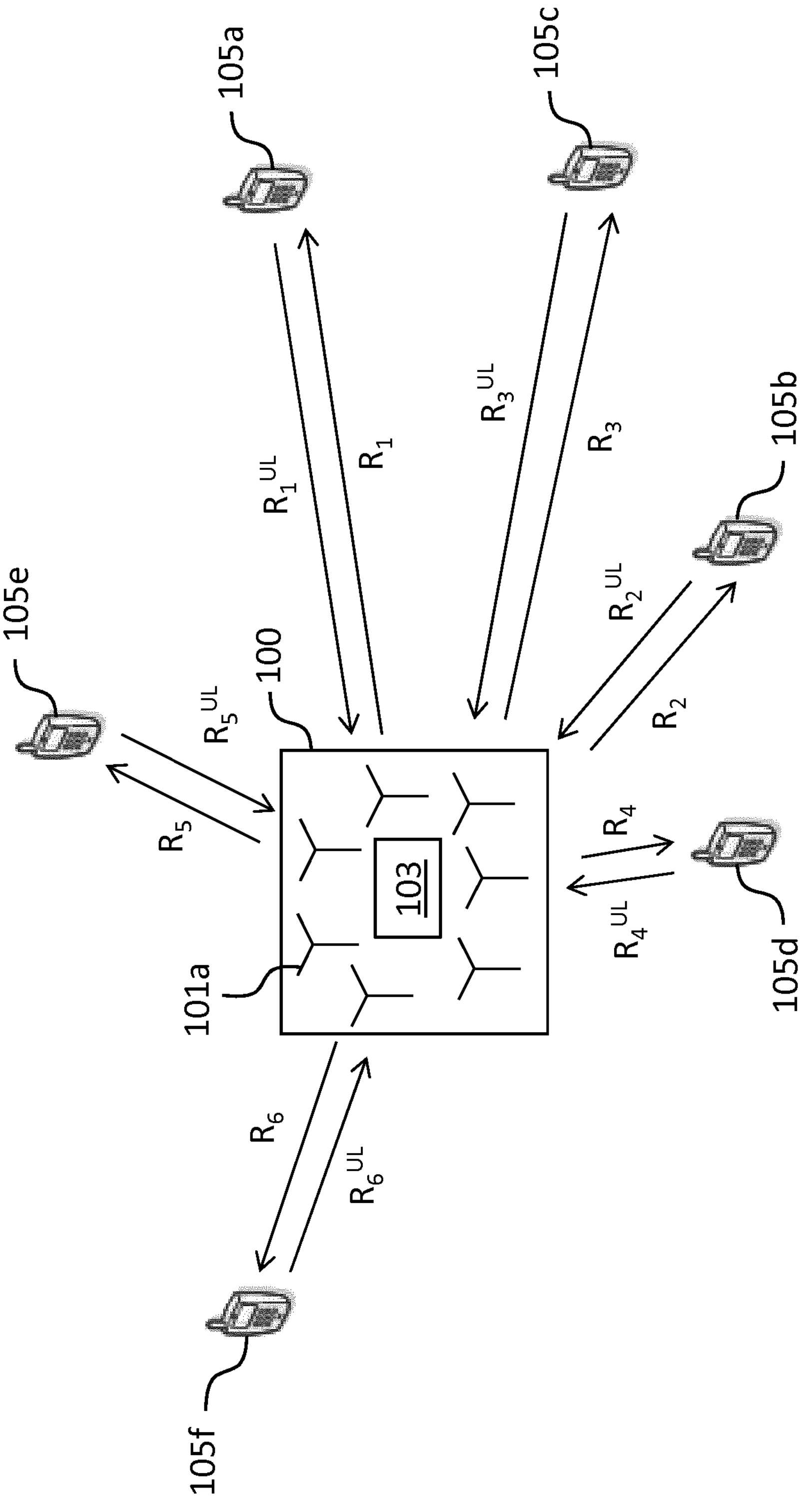
105a
105c
105b
105e
105d
105f
100
101a
103
R_1
R_1^{UL}
R_2
R_2^{UL}
R_3
R_3^{UL}
R_4
R_4^{UL}
R_5
R_5^{UL}
R_6
R_6^{UL}

Fig. 1

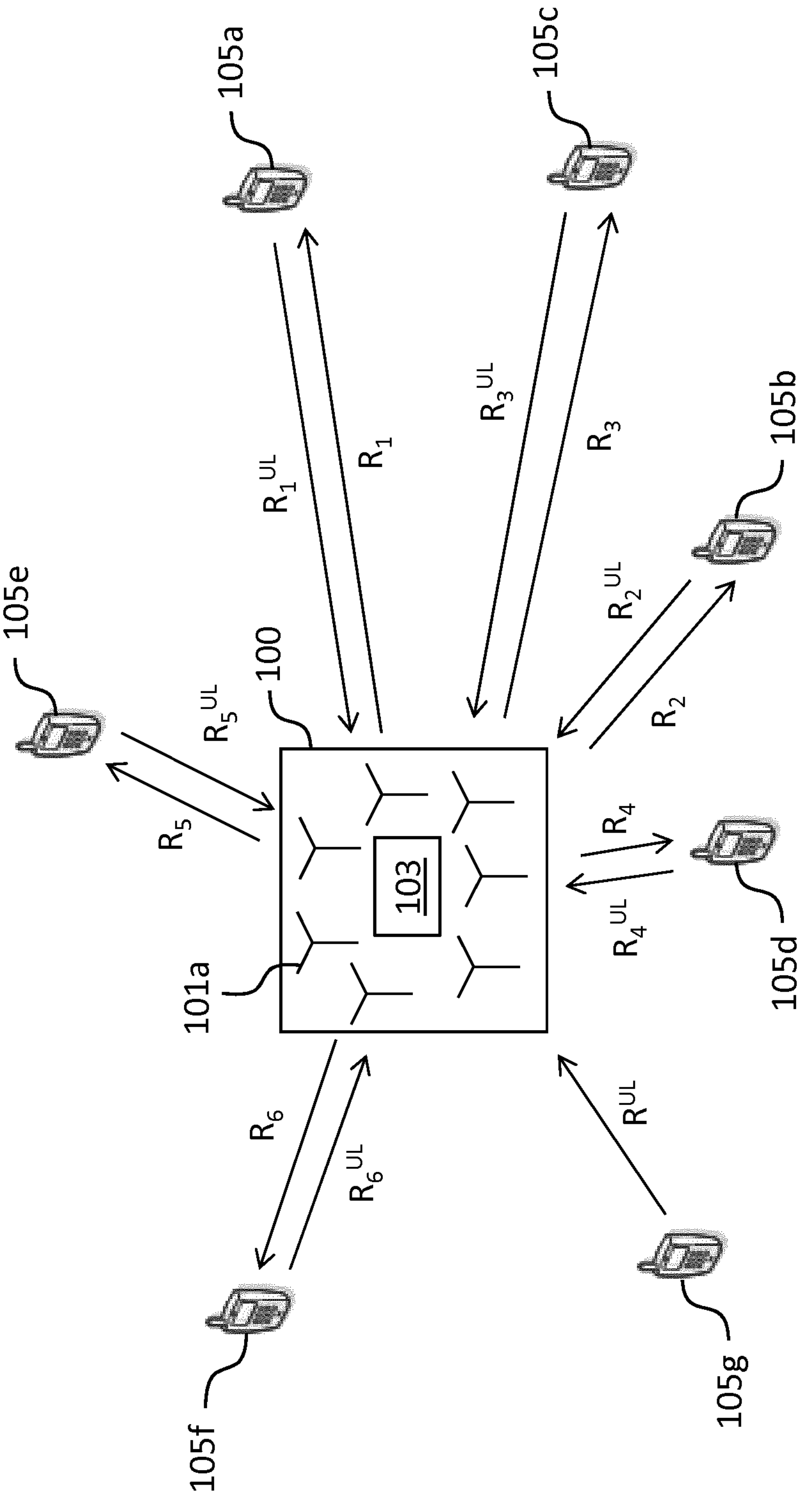
105a
105c
105b
105e
105d
105f
105g
100
101a
103
R_1^{UL}
R_1
R_3^{UL}
R_3
R_2^{UL}
R_2
R_5^{UL}
R_5
R_4
R_4^{UL}
R_6
R_6^{UL}
R^{UL}

Fig. 2

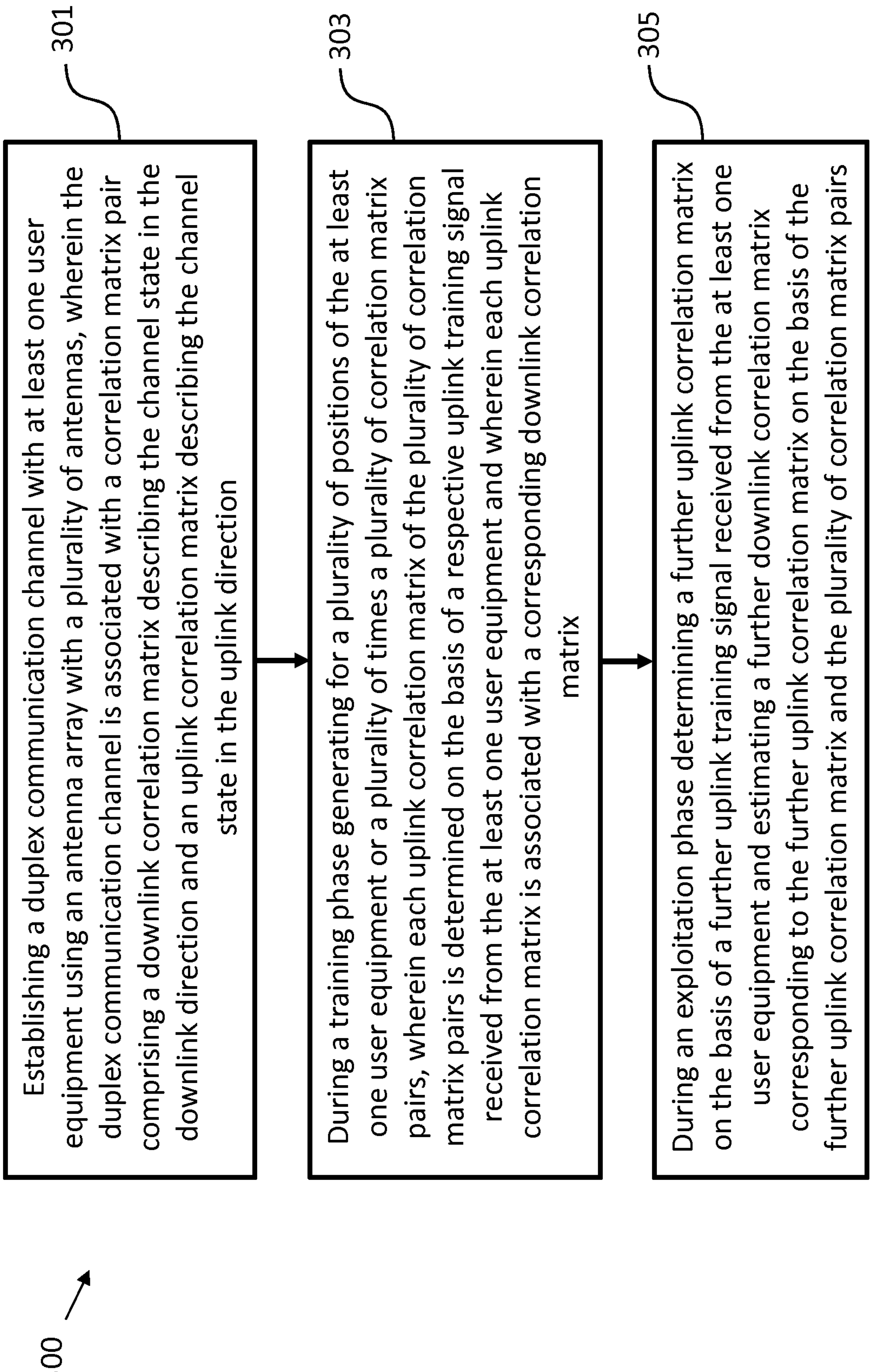
301
Establishing a duplex communication channel with at least one user equipment using an antenna array with a plurality of antennas, wherein the duplex communication channel is associated with a correlation matrix pair comprising a downlink correlation matrix describing the channel state in the downlink direction and an uplink correlation matrix describing the channel state in the uplink direction
303
During a training phase generating for a plurality of positions of the at least one user equipment or a plurality of times a plurality of correlation matrix pairs, wherein each uplink correlation matrix of the plurality of correlation matrix pairs is determined on the basis of a respective uplink training signal received from the at least one user equipment and wherein each uplink correlation matrix is associated with a corresponding downlink correlation matrix
305
During an exploitation phase determining a further uplink correlation matrix on the basis of a further uplink training signal received from the at least one user equipment and estimating a further downlink correlation matrix corresponding to the further uplink correlation matrix on the basis of the further uplink correlation matrix and the plurality of correlation matrix pairs
300

Fig. 3

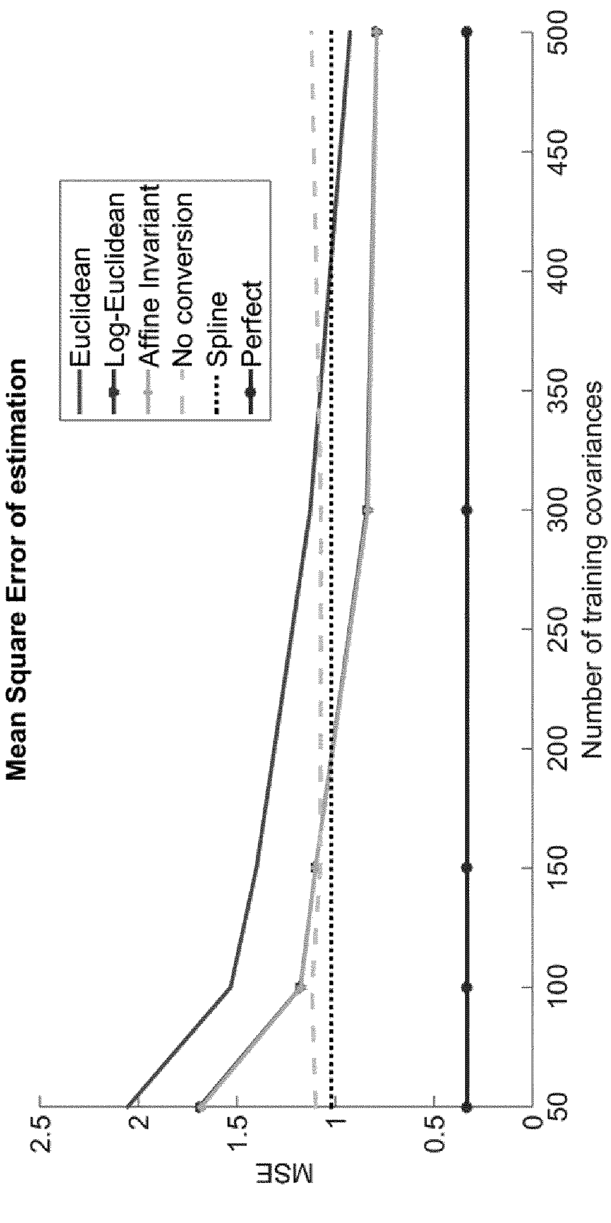
Mean Square Error of estimation
Euclidean
Log-Euclidean
Affine Invariant
No conversion
Spline
Perfect
MSE
0
0.5
1
1.5
2
2.5
Number of training covariances
50
100
150
200
250
300
350
400
450
500

Fig. 4

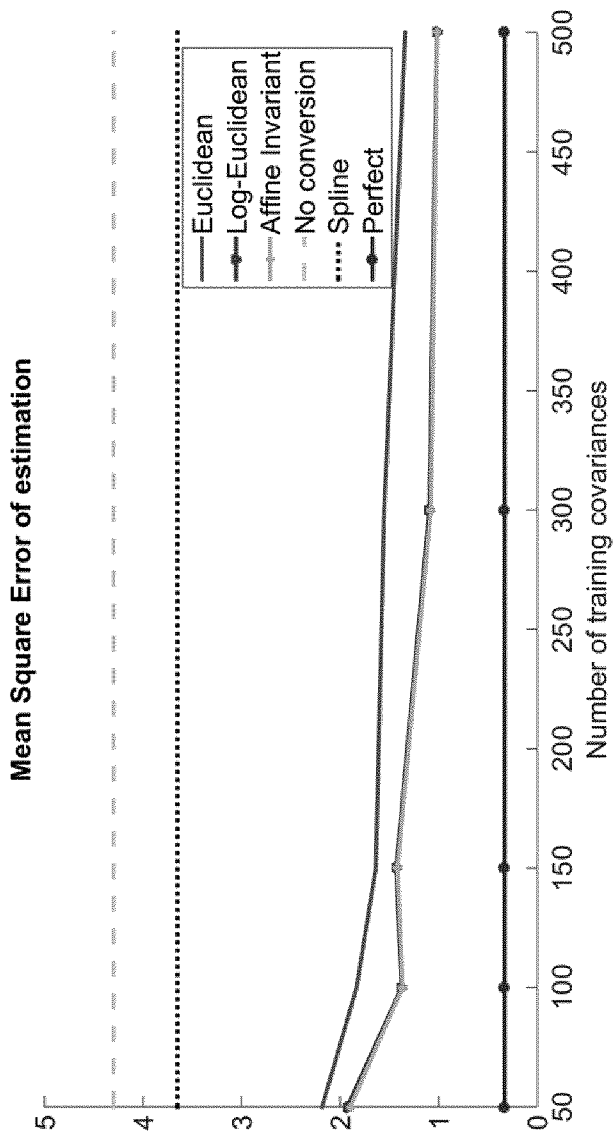
Mean Square Error of estimation
MSE
0
1
2
3
4
5
50
100
150
200
250
300
350
400
450
500
Number of training covariances
Euclidean
Log-Euclidean
Affine Invariant
No conversion
Spline
Perfect

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/064883

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/04 H04B7/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ADHIKARY ANSUMAN ET AL: "Joint Spatial Division and Multiplexing-The Large-Scale Array Re", IEEE TRANSACTIONS ON INFORMATION THEORY, IEEE PRESS, USA, vol. 59, no. 10, 1 October 2013 (2013-10-01), pages 6441-6463, XP011526827, ISSN: 0018-9448, DOI: 10.1109/TIT.2013.2269476 [retrieved on 2013-09-11] cited in the application abstract page 6442, left-hand column, paragraph 3 page 6443, left-hand column, paragraph 2 - page 6443, right-hand column, paragraph 1 page 6444, paragraph IV -----	1-16

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 February 2016	02/03/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Fernández Cuenca, B

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 207 292 A1 (SUMITOMO ELECTRIC INDUSTRIES [JP]) 14 July 2010 (2010-07-14) abstract paragraphs [0016] - [0047] paragraphs [0073] - [0079], [0088] - [0104] figures 9,10 -----	1-16
A	US 2012/027140 A1 (WENG JIANFENG [CA] ET AL) 2 February 2012 (2012-02-02) abstract paragraphs [0014] - [0019], [0040] - [0046], [0076] - [0090] -----	1-16
A	WO 2008/154653 A2 (ERICSSON TELEFON AB L M; WANG YI-PING ERIC [US]; ERIKSSON HAKAN BENGT) 18 December 2008 (2008-12-18) abstract page 3, line 11 - page 5, line 12 paragraphs [0059] - [0065] paragraphs [0069] - [0073] figures 1,5,5A,5B,6,7 -----	1-16
A	EP 2 819 313 A1 (KOREA ELECTRONICS TELECOMM [KR]) 31 December 2014 (2014-12-31) abstract paragraphs [0006], [0008] - [0013], [0037] - [0040] paragraphs [0089] - [0092], [0211] - [0247] -----	1-16
A	ALEXIOU A ET AL: "RECONFIGURABLE MIMO TRANSCEIVERS FOR NEXT-GENERATION WIRELESS SYSTEMS", BELL LABS TECHNICAL JOURNAL, WILEY, CA, US, vol. 10, no. 2, 21 June 2005 (2005-06-21), pages 139-156, XP001540896, ISSN: 1089-7089, DOI: 10.1002/BLTJ.20098 abstract page 142, left-hand column, lines 6-36 -----	1-16

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/064883

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			EP	2819313	A1	31-12-2014
			JP	2015513257	A	30-04-2015
			KR	20130097117	A	02-09-2013
			US	2015016379	A1	15-01-2015