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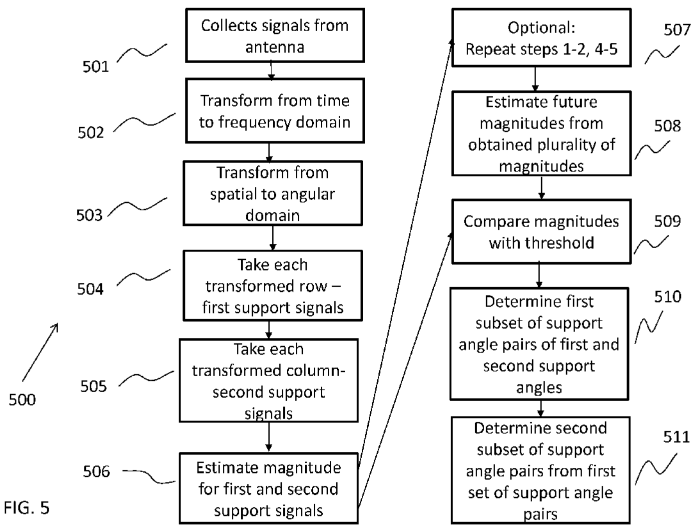

FIG. 5

(57) Abstract: A multiple-input multiple output (MIMO) downlink (DL) data stream control apparatus configured to determine a subset of first and second support angles or support angle pairs for use in downlink transmission from antenna elements of MIMO antenna arrays. The subsets of support angles are determined from one or more uplink signals (UL) received at antenna elements of the MIMO antenna arrays. The elements of the MIMO arrays are arranged in rows and columns being angled to each other. The control apparatus transforms signals received by row and column elements from spatial domain to first and second support signals, respectively, in angular domain. Each support signal is a function of a corresponding support angle, and the magnitude of the support signals is a function of the angle of arrival of the UL signals. Based on magnitudes of the support signals, the control apparatus determines subsets of pairs of support angles.

TITLE

APPARATUS AND METHOD FOR DETERMINING ANGLE OF DEPARTURE FOR MULTI-INPUT-MULTI-OUTPUT DOWNLINK TRANSMISSION

TECHNICAL FIELD

The present disclosure relates to wireless communication and, in particular, to a method and apparatus for transmitting and receiving data using an angle-of-departure selection technique, and mapping the data to be transmitted to these angles and subsequently, transforming the data to signals to be transmitted on transmit antennas in a Multiple Input Multiple Output (MIMO) system having a plurality of antennas.

BACKGROUND

Massive MIMO or very large scale MIMO antenna systems is a technique that can offer large network capacities in multi-user scenarios, where the base stations are equipped with a large number of antenna elements simultaneously serving multiple single-antenna users. Additional antenna elements are usually inexpensive, and the additional digital signal processing becomes ever cheaper. However, when there are many antennas, the link between the baseband unit and the remote antenna unit becomes a bottleneck in terms of rate when I-Q (or in-phase and quadrature) antenna data (one stream for each transmit antenna element) needs to be transmitted over this link to a very large number of antennas. A low cost, low complexity solution to this problem is to choose a subset of antenna elements out of the total number of antenna elements. With a certain number of RF chains and more antenna elements than that, antenna element selection can improve the system performance by exploiting the spatial selectivity, and a subset of antenna elements may be selected and switched to the RF chains. However, selecting a subset of antennas does not permit the system to benefit from the known benefits of simultaneously using a very large number of antennas elements to transmit (or receive as in Massive MIMO systems. When transmitting or receiving on a large number of antenna elements at the base station, such as in a massive MIMO antenna system, the propagation channel potentially provides much more spatial selectivity, from which the system performance can be improved due to increased energy efficiency since the energy radiated is more focused towards a desired receiver and thereby, reducing interference to other non-intended users. There is also an improvement in spectral efficiency since higher data rates can be supported with Massive MIMO since the intra-cell interference and thermal noise become negligible as the number of antennas become very large.

Thus, there is a need for providing an apparatus and a method for reducing the backhaul requirements for the link between a remote antenna unit and a baseband unit in a MIMO or massive MIMO antenna system to be used for downlink transmission. Additionally, there is also a need to reduce the computational complexity when the number of antenna elements far exceeds the number of user data streams to be transmitted to intended users.

SUMMARY

It is an objective of the present invention to provide an apparatus or system and a method, which reduces the computational complexity and backhaul requirements of a Massive MIMO system when the number of user data streams is very much less than the number of antennas. The method in this invention determines subsets of support angles based on uplink signals received at antenna elements of one or more MIMO antenna arrays. The determined support angles can be used for mapping downlink data streams to a subset of the antenna elements of the MIMO antenna array.

The foregoing and other objectives are achieved by the features of the independent claims. Further implementation forms are apparent from the dependent claims, the description and figures.

According to a first aspect, there is provided a multiple-input multiple output (MIMO) downlink (DL) data stream control apparatus comprising at least one processor configured to: obtain uplink signals (UL) received at antenna elements of one or more MIMO antenna arrays, the elements of the MIMO arrays being arranged in one or more rows and columns; transform, for each of a selected number of rows, the number of row signals from spatial domain to a number of first support signals in an angular domain, with each first support signal of a given row being a function of a corresponding first support angle; transform, for each of a selected number of columns, the number of column signals from spatial domain to a number of second support signals in an angular domain, with each second support signal of a given column being a function of a corresponding second support angle; determine first and second sets of support signal magnitudes by determining a magnitude for each or at least part of the first and second support signals; calculate a first average magnitude for each or at least part of the first support angles based on determined magnitudes for first support signals being a function of the same first support angle, and calculate a second average magnitude for each or at least part of the second support angles based on determined magnitudes for second support signals being a function of the same second support angle; compare the first averaged magnitudes with a predetermined first threshold magnitude, and compare the second averaged magnitudes with a predetermined second threshold magnitude; and determine a subset of first support angles and a subset of second support angles, each of the subset of first angles having a corresponding first averaged magnitude exceeding the first threshold magnitude, and each of the subset of second angles having a corresponding second averaged magnitude exceeding the second threshold magnitude.

In a first possible implementation form of the control apparatus according to the first aspect, the at least one processor is configured to use Discrete Fourier Transform (DFT) or Discrete Space Fourier Transform (DSFT) in transforming the number of row signals from spatial domain to the number of first support signals in the angular domain, and in transforming the number of column signals from spatial domain to the number of second support signals in the angular domain.

In a second possible implementation form of the control apparatus according to the first aspect as such or according to the first implementation form of the first aspect, the at least one processor is further configured to determine a first subset of support angle pairs or support angle co-ordinate pairs by combining each angle of the subset of first support angles with each angle of the subset of second support angles.

In a third possible implementation form of the control apparatus according to the second implementation form of the first aspect, the at least one processor is further configured to: perform a two-dimensional transform from spatial domain to angular domain of the signals of the selected rows and columns using as discrete variables the first support angles and the second support angles represented by the first subset of support angle pairs; determine for each or at least part of the first subset of support angle pairs the magnitude of the corresponding two-dimensional transform; compare the determined two-dimensional transform magnitudes with a third predetermined threshold value; and determine a second subset of support angle pairs or support angle co-ordinate pairs, each of the second subset of support angle pairs having a corresponding two-dimensional transform magnitude exceeding the third threshold magnitude.

In a fourth possible implementation form of the control apparatus according to the second or the third implementation form of the first aspect, the at least one processor is further configured to assign a number of downlink (DL) data streams to a corresponding number of support angle pairs for downlink transmission, wherein each support angle pair is selected from the first or the second subset of support angle pairs.

In a fifth possible implementation form of the control apparatus according to the fourth implementation form of the first aspect, the at least one processor is further configured to transform the downlink data streams assigned to the support angles from the angular domain to the spatial domain by use of Inverse Discrete Fourier Transformation (IDFT).

In a sixth possible implementation form of the control apparatus according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, the at least one processor is further configured to: estimate a new set of first support signal magnitudes based on a plurality of determined sets of first support signal magnitudes corresponding to a plurality of subsequent received uplink signals, the new set of first support signal magnitudes corresponding to a future point in time for receiving an uplink signal; estimate a new set of second support signal magnitudes based on a plurality of determined sets of second support signal magnitudes corresponding to the plurality of subsequent received uplink signals, the new set of second support signal magnitudes corresponding to the future point in time for receiving an uplink signal; and calculate the first and second average magnitudes based on the estimated new first and second support signal magnitudes.

In a seventh possible implementation form of the control apparatus according to the fifth implementation form of the first aspect, the at least one processor is configured to estimate a new set of support signal magnitudes by use of a linear estimation in time based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

In an eighth possible implementation form of the control apparatus according to the sixth or the seventh implementation form of the first aspect, the at least one processor is configured to estimate a new set of support signal magnitudes by use of a moving time average or weighted moving time average based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

In a ninth possible implementation form of the control apparatus according to the first aspect as such or according to any of the preceding implementation forms of the first aspect, then for the transformation of row signals from spatial domain to angular domain and for the transformation of column signals from spatial domain to angular domain, the at least one processor is configured to: form a time signal matrix representing signal values received by the antenna elements in the selected rows and columns, with rows and columns of the signal matrix corresponding to the selected rows and columns of receiving elements; form a frequency signal matrix by transforming the time signal matrix from spatial time domain to spatial frequency domain; transform the signals of each row of the frequency signal matrix, each of which rows corresponds to a selected row of receiving elements, from the spatial frequency domain to an angular frequency domain; and transform the signals of each column of the frequency signal matrix, each of which columns corresponds to a selected column of receiving elements, from the spatial frequency domain to an angular frequency domain. The transformation of the time signal matrix from spatial time domain to spatial frequency domain may be performed by use of Fourier Transform (FT) or Fast Fourier Transform (FFT) or any other fast implementation of the Fourier Transform, and the transformation from the spatial frequency domain to the angular frequency domain may be performed by use of Discrete Fourier Transform (DFT) or Discrete Space Fourier Transform (DSFT).

According to a second aspect, there is provided a method for determining a subset of support angles for use in transmission of downlink (DL) data streams from a plurality of antenna elements of one or more multiple-input multiple output (MIMO) antenna arrays, the method comprising: receiving at the antenna elements of one or more MIMO antenna arrays one or more uplink signals (UL), the elements of the MIMO array(s) being arranged in one or more rows and columns; transforming, for each of a selected number of rows, the number of row signals from spatial domain to a number of first support signals in an angular domain, with each first support signal of a given row being a function of a corresponding first support angle; transforming, for each of a selected number of columns, the number of column signals from spatial domain to a number of second support signals in an angular domain, with each second support signal of a given column being a function of a corresponding second support angle; determining first and second sets of support signal magnitudes by determining a magnitude for each or at least part of the first and second support signals; calculate a first average magnitude for each or at least part of the first support angles based on determined magnitudes for first support signals being a function of the same first support angle; calculate a second average magnitude for each or at least part of the second support angles based on determined magnitudes for second support signals being a function of the same second support angle; comparing the first averaged magnitudes with a predetermined first threshold magnitude; comparing the second averaged magnitudes with a predetermined second threshold magnitude; and determining a subset of first support angles and a subset of second support angles, each of the subset of first angles having a corresponding first averaged magnitude exceeding the first threshold magnitude, and each of the subset of second angles having a corresponding second averaged magnitude exceeding the second threshold magnitude.

In a first possible implementation form of the method according to the second aspect, the transformation of the number of row signals from spatial domain to the number of first support signals in the angular domain, and the transformation of the number of column signals from spatial domain to the number of second support signals in the angular domain, is performed by use of Discrete Fourier Transform (DFT) or Discrete Space Fourier Transform (DSFT).

In a second possible implementation form of the method according to the second aspect as such or according to the first implementation form of the second aspect, the method further comprises determining a first subset of support angle pairs or support angle co-ordinate pairs by combining each angle of the subset of first support angles with each angle of the subset of second support angles.

In a third possible implementation form of the method according to the second implementation form of the second aspect, the method further comprises: performing a two-dimensional transform from spatial domain to angular domain of the signals of the selected rows and columns using as discrete variables the first support angles and the second support angles represented by the first subset of support angle pairs;

determining for each or at least part of the first subset of support angle pairs the magnitude of the corresponding two-dimensional transform; comparing the determined two-dimensional transform magnitudes with a third predetermined threshold value; and determining a second subset of support angle pairs or support angle co-ordinate pairs, each of the second subset of support angle pairs having a corresponding two-dimensional transform magnitude exceeding the third threshold magnitude.

In a fourth possible implementation form of the method according to the second or the third implementation form of the second aspect, the method further comprises assigning a number of downlink (DL) data streams to a corresponding number of support angle pairs for downlink transmission, wherein each support angle pair is selected from the first or the second subset of support angle pairs.

In a fifth possible implementation form of the method according to the fourth implementation form of the second aspect, the method further comprises transforming the downlink data streams mapped to the support angles from the angular domain to the spatial domain by use of Inverse Discrete Fourier Transformation (IDFT).

In a sixth possible implementation form of the method according to the second aspect as such or according to any of the preceding implementation forms of the second aspect, the step of determining first and second sets of support signal magnitudes further comprises: estimating a new set of first support signal magnitudes based on a plurality of determined sets of first support signal magnitudes corresponding to a plurality of subsequent received uplink signals, the new set of first support signal magnitudes corresponding to a future point in time for receiving an uplink signal; and estimating a new set of second support signal magnitudes based on a plurality of determined sets of second support signal magnitudes corresponding to the plurality of subsequent received uplink signals, the new set of second support signal magnitudes corresponding to the future point in time for receiving an uplink signal; and the step of calculating first and second average magnitudes is based on the estimated new first and second support signal magnitudes.

In a seventh possible implementation form of the method according to the sixth implementation form of the second aspect, the estimation of a new set of support signal magnitudes is performed by use of a linear estimation in time based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

In an eighth possible implementation form of the method according to the sixth or the seventh implementation form of the second aspect, the estimation of a new set of support signal magnitudes is performed by use of a moving time average or weighted moving time average based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates delay in arrival time for a single plane wave impinging on a one-dimensional uniform linear array antenna, or uniform linear array of antenna elements;

Fig. 2 illustrates delay in arrival time for a single plane wave impinging on a two-dimensional uniform rectangular array antenna or uniform linear array of antenna elements;

Fig. 3 is a block diagram illustrating transmission of an uplink signal from a user equipment, receipt of the uplink signal at a base station, determination of support angles at the base station, and use of the support angles for transmission of downlink signals in accordance with an embodiment of the invention;

Fig. 4 is a block diagram showing processor configurations blocks of a control apparatus according to an embodiment of the invention;

Fig. 5 is a block diagram of processor configurations of a control apparatus according to an embodiment of the invention, showing different processing configurations corresponding to part of the configuration blocks of Fig. 4;

Fig. 6 is a block diagram of processor configurations of a control apparatus according to an embodiment of the invention, showing different processing configurations corresponding to the last block of Fig. 3; and

Fig. 7 is a system diagram illustrating data flow using a control apparatus according to an embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

It is an object of the present invention to reduce latency and improve accuracy in the selection of spectral angles to be used for transmission of downlink (DL) data streams using a large number of antenna elements of one or more Massive MIMO antenna arrays (of two or more dimensions). The DL data streams, which are to be transmitted, can be mapped to selected support spectral angles, and then an inverse Fourier transform of the mapped DL signals can be performed from the spectral angular domain to the spatial domain. The resultant output of the inverse Fourier transform can be mapped directly to the antenna ports of a multi-dimensional antenna array. It is within objects of the present invention: (i) to be able to use a single transmission of an uplink (UL) sounding reference signal (SRS) by a given user equipment (UE) via spatial averaging to obtain a subset of support spectral angles on the uplink and use these support angles for transmission of downlink signals. (ii) use time average or weighted time average of obtained spectral magnitudes in the angular domain of subsequent SRS transmissions to determine subsequent updates of a selected subset of support spectral angles. The principles of the present invention may facilitate easier design and implementation of pre-coders by reducing latency and improving accuracy in selection of the spectral angles based on UL signals, which selected spectral angles may have the largest spectral magnitudes, and which selected spectral angles may be used as spectral angles for transmission of data streams on the downlink.

It is within embodiments of the invention that for a massive MIMO antenna array, rather than performing time averaging of the magnitudes of the angular domain signal strength over time, over multiple SRSs, one can perform averaging along one spatial dimension (e.g. vertical) when trying to determine a subset of support spectral angles with largest spectral magnitude in another orthogonal spatial dimension (e.g horizontal). After averaging the spectral magnitude in the angular domain across a spatial dimension (vertical), then one can select a subset of support spectral angles for the given spatial dimension (horizontal) which have the largest spatially (vertical) averaged spectral magnitude.

To determine a subset of support spectral angles with largest spectral magnitude in another spatial dimension (vertical), the procedure similar to that just described can be applied, where the spectral magnitudes in the angular domain (vertical spatial dimension) is averaged along the other (horizontal) spatial dimension.

Note that a time average or weighted time average of the two dimensional array of spectral magnitudes in the angular domain can be performed to obtain better selection of subsets of support angles corresponding to the largest spectral magnitudes.

Fig. 1 illustrates delay in arrival time for a single plane wave impinging on a one-dimensional uniform linear array, ULA, antenna 100. The antenna 100 has five antenna elements, 1-5, arranged along a line, and a signal wave transmitted from a Source, is impinging on the antenna 100 at an angle of arrival β relative to a direction perpendicular to the antenna 100. The distance between two antenna elements 1 and 2 is *d*, and there is a delay in arrival time of the signal wave from element 1 to element 2 due to the travelling distance *d* sin(β).

Fig. 2 illustrates delay in arrival time for a single plane wave impinging on a two-dimensional uniform rectangular array antenna 200. The antenna 200 has five rows of equally spaced antenna elements 201, where the spacing between the elements of rows 201 is given by *d*H, and five columns of equally spaced antenna elements 202, where the spacing between the elements of columns 202 is given by d*V*. A signal wave is transmitted from a Source 203, and the signal wave is impinging on the antenna 200 at an angle of arrival θH relative to a direction perpendicular to the rows 201, and the delay in arrival time of the signal wave from one element to another element in a row is due to the travelling distance *dH* sin(θH). The signal wave is impinging on the antenna 200 at an angle of arrival θV relative to a direction perpendicular to the columns 202, and the delay in arrival time of the signal wave from one element to another element in a column is due to the travelling distance *dV* sin(θV).

In the following is given a detailed analysis of the principles of embodiments of the present invention based on a single plane wave impinging upon an antenna array as shown in Fig. 2. However, the principles of the invention are general and are applicable to cases where there are multiple impinging waves on an antenna array from different directions.

The present invention covers embodiments, for which the rows and columns of antenna elements may be arranged at an angle to each other, and they may be arranged perpendicular to each other, but the angle need not be perpendicular, and other angles can be used, such as 60 degrees, 45 degrees, or 30 degrees. Also for the arrangement of elements within different rows, the elements of a given row may be staggered to the left or right with respect to the elements of one or more neighboring rows. The elements in the different columns can also be staggered with respect to the elements of one or more neighboring columns. When signals are received from several MIMO antenna arrays, the arrays may preferably be arranged in the same plane, i.e. co-planar.

Thus, the present invention also covers embodiments, for which the rows and columns of antenna elements are not perpendicular. If they are not perpendicular, then a first angle of arrival, azimuth angle, can be estimated or determined from signals received at row elements; then a second angle of arrival can be estimated or determined from signals received at column elements, where the columns may be at angle different to 90 degrees (diagonal columns) relative to the rows. An elevation angle can now be determined based on the second angle of arrival obtained from the column elements and based on the first angle of arrival, azimuth, obtained from the row elements. If there are only rows of elements, then an angle of arrival can be determined only from the row elements.

For a massive MIMO antenna array, the following describes and embodiment of the invention for a procedure for determining a subset $\mathcal{A} = \mathcal{C} \times \mathcal{B}$ of support "spectral angles" from which a smaller subset of spectral angles, $\mathcal{A}^*$, where $\mathcal{A}^* \subset \mathcal{A}$, is determined and where spectral angles in the set, $\mathcal{A}^*$, are to be used in downlink transmission. The downlink data signal streams, which can be mapped to these support spectral angles $\mathcal{A}^*$, can be transformed from the angular to the spatial domain via an inverse discrete Fourier transform. The streams output of the inverse Fourier transform can then be mapped to antenna ports to be sent on the downlink. To simplify notation, assume that the size of a rectangular antenna array has (M + 1) rows and (M_2 + 1) columns. To illustrate the concept, the following describes the procedure due to the impingement of a single plane wave on the antenna array as shown in Fig. 1 and/or Fig. 2 above. Note that the method is general and applies to cases with impingement of multiple waves on the antenna array arriving from different directions. The following procedure assumes channel reciprocity and employs signals received on the uplink to determine the subset of support angles to be used on the downlink.

In Fig. 2 the incoming signal wave has an angle of arrival, AoA, of θ_H relative to a direction perpendicular to the rows 201, and there is a delay in arrival time τ_H of the signal wave from one element to another element in a row due to the difference in travelling distance $dH \sin(\theta_H)$. The incoming signal has an angle of arrival θ_V relative to a direction perpendicular to the columns 202, and there is a delay in arrival time τ_V of the signal wave from one element to another element in a column is given by the travelling distance $dV \sin(\theta_V)$.

Using the row delay time τ_H and the column delay time τ_V, the uplink received signal from each antenna element, in the $(M + 1) \times (M_2 + 1)$ antenna array, is given by the respective entry in the matrix $\mathbf{R}(t)$ which is given by

$$\mathbf{R}(t) = \begin{bmatrix} s(t) & \cdots & s(t + M_2\tau_H) \\ \vdots & \ddots & \vdots \\ s(t + M\tau_V) & \cdots & s(t + M\tau_V + M_2\tau_H) \end{bmatrix} \quad (1)$$

By use of Fourier transformation, such as Fourier Transform, FT, or Fast Fourier Transform, FFT, the spatial signal presentation of equation (1), where the signals are a function of both space and time, is transformed to the frequency domain. In the frequency domain, where the signals are a function of both space and frequency, $\mathbf{R}(\omega) = \mathcal{F}\{\mathbf{R}(t)\}$ is given by

$$\mathbf{R}(\omega) = \begin{bmatrix} S(\omega) & \cdots & S(\omega)e^{-j\omega(M_2\tau_H)} \\ \vdots & \ddots & \vdots \\ S(\omega)e^{-j\omega M\tau_V} & \cdots & S(\omega)e^{-j\omega(M\tau_V + M_2\tau_H)} \end{bmatrix} \quad (2)$$

Step 1 of the procedure: For each row, r, of antennas elements, transform the received and detected signals, $\{s_{rn}(t), n = 1, \ldots, M_2 + 1\}$, where n is the column index in the matrix in equation (1), from the spatial time domain to an angular frequency domain or spectral angular domain, where the signals are a function of both frequency and an angle. This can be done in two steps, by first transforming the signals from the spatial time domain, equation (1) to the frequency domain or spatial frequency domain, equation (2). The next step is then to transform the signals from the spatial frequency domain, equation (2), to an angular frequency domain or spectral angular domain.

For an incoming wave with a given angle of arrival, AoA, having a given frequency ω set to ω_c, and given delays τ_H and τ_V, equation (2) can be transformed to the angular frequency domain by use of Discrete Fourier Transform, DFT, or Discrete Space Fourier Transform, DSFT, and a number of discrete variables or discrete angles θ_k.

When transforming the row signals of equation (2), then the number of discrete variables θ_k can be set equal to the number of elements in a row, which equals the number of columns $M_2 + 1$, and θ_k is set to $k\ 2\pi/M_2$, where k goes from 0 to M_2.

In the following, r is the row index of a two-dimensional antenna array and k is the index of the discrete variable or angle θ as in θ_k, and by use of DFT, or DSFT on equation (2), then for each row r, a number of first support signals in the angular domain is obtained, where each first support signal is a function of a discrete first support angle θ_k:

$$X_r(\theta_k) = S(\omega_c)\exp(-j\omega_c(r-1)\tau_V)\sum_{n=0}^{M_2}\exp\big(-jn(\omega_c\tau_H - \theta_k)\big), \quad (3)$$
$$r = 1, \dots, (M+1), k = 0, \dots, M_2$$

Equation (3) gives $M_2 + 1$ values for $X_r(\theta_k)$, one for each antenna element in a row. When comparing equation (3) with Fig. 2, it is noted that the discrete variable or angle θ_k is not the actual angle of arrival, AoA, but may be considered as an effective angle, which is related to the angle of arrival. The magnitude of the each value $X_r(\theta_k)$ is a function of the delay time τ_H, which again is a function of angle of arrival of the incoming signal. Thus, the magnitude of $X_r(\theta_k)$ will vary for different values of θ_k and for different angles of arrivals, AoA.

In equation (3), the selected rows, for which the row signals are transformed holds the same number of equally spaced apart elements, and the number of row signals are transformed from spatial domain to an equal number of first support signals in an angular domain, where each first support signal of a given row may be a function of a corresponding first support angle θ_k, with the number of first support angles being equal to the number of elements in the row. However, when being transformed by use of DSTF the rows do not need to hold the same number of elements, nor do the row elements need to be equally spaced apart, since the granularity of the DSFT can be adjusted. The resultant number of transformed first support signals and corresponding first support angles can then be determined by the selected granularity of the DSFT. The same goes for the selected columns.

Step 2: For each row index of antenna elements, form a vector of magnitude values indexed by the discrete first support spectral angle θ_k, by computing the magnitude of the transformed first support signal in equation (3) for each discrete first angle θ_k, (k = 0, … , M_2). Take the vectors of each resultant row and form a matrix:

$$\mathbf{X}^{(\mathrm{r})} = \begin{bmatrix} |X_{r=1}(\theta_{k=0})| & \cdots & |X_{r=1}(\theta_{k=M_2})| \\ \vdots & \ddots & \vdots \\ |X_{r=M+1}(\theta_{k=0})| & \cdots & |X_{r=M+1}(\theta_{k=M_2})| \end{bmatrix} \qquad (4)$$

Step 3: Each entry in the matrix of equation (4) represents the magnitude of a first support signal at a given first spectral angle. Perform a column average of the entries of the matrix of equation (4):

$$\frac{1}{M+1}\sum_{r=1}^{M+1}|X_r(\theta_k)|, k = 0, 1, \ldots, M_2. \qquad (5)$$

Select a subset of first support spectral angles θ_j where the magnitude of the averaged signal strength of equation (5) exceeds a threshold. This subset of first support spectral angles can be used where, for example, each DL data stream is mapped to a unique spectral angle for DL transmission. Such a subset of first support spectral angles is given by:

$$\text{Subset } \mathcal{B} = \left\{ j: \frac{1}{M+1}\sum_{r=1}^{M+1}|X_r(\theta_j)| > threshold, j = 0, 1, \ldots, M_2 \right\} \qquad (6)$$

The above Steps 1 to 3 identify the support or indices of first support spectral angles along any given row of matrix $\mathbf{X}^{(\mathrm{r})}$ above. Below in Step 4, a similar procedure is employed for identifying the support or indices of second support spectral angles along any given column of matrix $\mathbf{X}^{(\mathrm{c})}$ defined below.

Steps 4, 5 and 6: Employ procedures similar to Steps 1, 2 and 3, by Fourier transforming signals along a column of antenna elements and subsequently performing averaging along the horizontal (row) dimension.

Step 4: Let c be the column index of the two-dimensional antenna array and k is the index of a discrete angle θ as in θ_k above, then for each column c of antenna elements, a number of second support signals in the angular domain is obtained, where each second support signal is a function of a discrete second support angle θ_k, where θ_k is set to $k\,2\pi/M$, where k goes from 0 to M.

$$X_c(\theta_k) = S(\omega_c)\exp(-j\omega_c(c-1)\tau_H)\sum_{n=0}^{M}\exp\big(-jn(\omega_c\tau_V-\theta_k)\big), \quad (7)$$
$$c = 1, \ldots, (M_2+1)\,, k = 0, \ldots, M$$

Step 5: For each column index of antenna elements, form a vector of magnitude values indexed by the discrete second support spectral angle, by computing the magnitude of the transformed second support signal for each discrete second angle θ_k, (k = 0, … , M). Take the vectors of each resultant column and form a matrix:

$$\mathbf{X}^{(\mathbf{c})} = \begin{bmatrix} |X_{c=1}(\theta_{k=0})| & \cdots & |X_{c=M_2+1}(\theta_{k=0})| \\ \vdots & \ddots & \vdots \\ |X_{c=1}(\theta_{k=M})| & \cdots & |X_{c=M_2+1}(\theta_{k=M})| \end{bmatrix} \quad (8)$$

Step 6: Each entry in the matrix of equation (8) represents the magnitude of a second support signal at a given second support angle. Perform a row average for the entries of the matrix of equation (8):

$$\frac{1}{M_2+1}\sum_{c=1}^{M_2+1}|X_c(\theta_k)|, k = 0, 1, \ldots, M. \quad (9)$$

Select a subset of second support spectral angles θ_i where the magnitude of the signal strength exceeds a threshold:

$$\text{Subset } \mathcal{C} = \left\{ i : \frac{1}{M_2+1}\sum_{c=1}^{M_2+1}|X_c(\theta_i)| > threshold\_2, i = 0, 1, \ldots, M \right\} (10)$$

Step 7 (optional): For a number of subsequent in time received uplink sounding reference signals, perform the steps 1-2 and 4-5 both for rows and columns, thereby obtaining a corresponding number of first and second support signal magnitudes, $\mathbf{X}^{(\mathbf{r})}$ equation (4) and $\mathbf{X}^{(\mathbf{c})}$ equation (8), and estimate a new set of first support signal magnitudes based on the determined number of first support signal magnitudes, and estimate a new set of second support signal magnitudes based on the determined number of second support signal magnitudes. The estimation of the new sets of first and second support signal magnitudes can be performed by use of linear estimation in time and/or by use of moving time average or weighted moving time average. Calculation of the first and second average magnitudes, steps 3 and 6 and equations (5) and (9), can then be performed based on the estimated new sets of first and second support signal magnitudes, and then subsets $\mathcal{B}$ and $\mathcal{C}$ can be selected in equations (6) and (10) respectively.

Step 8: Once subsets $\mathcal{B}$ and $\mathcal{C}$ are selected, then the set of spectral angles to be used for DL transmission are indexed by the set $\mathcal{A} = \mathcal{C} \times \mathcal{B}$.

The resulting set $\mathcal{A}$ is a first subset of support angle pairs or support angle co-ordinate pairs, where each pair comprises a first support angle from subset $\mathcal{B}$ and a second support angle from subset $\mathcal{C}$. The number of angle pairs of subset $\mathcal{A}$ is a combination of each angle of the subset $\mathcal{B}$ of first support angles with each angle of the subset $\mathcal{C}$ of second support angles.

The angle pairs of the first subset of support angle pairs $\mathcal{A}$ can be used for mapping to downlink, DL, data streams, where each of a number of DL data streams are mapped to a corresponding support angle pair selected from the first subset $\mathcal{A}$.

It is preferred to further reduce the size of the obtained first subset of support angle pairs $\mathcal{A}$, in order to obtain a more optimized set of support angle pairs.

Step 9: From the first subset of support angle pairs $\mathcal{A} = \mathcal{C} \times \mathcal{B}$, select a second and final subset of angle pairs, $\mathcal{A}^*$, to be used for DL data transfer based on whether a given angle pair or co-ordinate pair's magnitude value in the angular domain exceeds a defined threshold, that is:

$$|X(\theta_u, \theta_v)|^2 > threshold\_3 \qquad (11)$$

where $X(\theta_u, \theta_v)$ is the entry in the u-row and v-column of the matrix $\mathbf{X}$, whose entries are the two-dimensional transform of the matrix $\mathbf{R}(\omega)$ given by equation (2) from space to angular domain, where the entries $X(\theta_u, \theta_v)$ are given by:

$$X(\theta_u, \theta_v) = \sum_{n=0}^{M} \sum_{m=0}^{M_2} \mathbf{R}(\omega)[n, m] \ \exp(jn\theta_u)\exp(jm\theta_v) \qquad (12)$$

The expression $\mathbf{R}(\omega)[n, m]$ denotes the entry in the n-row and m-column of matrix $\mathbf{R}(\omega)$ of equation (2). The second subset of support angle pairs or support co-ordinate pairs $\mathcal{A}^*$ are then given by:

$$Subset\ \mathcal{A}^* = \{\,(u,v) \in \mathcal{A} = \mathcal{C} \times \mathcal{B} :\ |X(\theta_u\,,\theta_v)| > threshold\_2\,\}. \quad (13)$$

The angle pairs of the second subset of support angle pairs $\mathcal{A}^*$ can now be used for mapping to DL data streams, where each of a number of DL data streams are mapped to a corresponding support angle pair selected from the second subset $\mathcal{A}^*$.

Step 10: Map downlink, DL, data streams to selected co-ordinate pairs of the second subset of support angle pairs $\mathcal{A}^*$.

The pairs of support angles, $\mathcal{A}^*$, have been determined in the angular frequency domain obtained by use of Discrete Fourier Transform DFT, or Discrete Space Fourier Transform, DSFT. In order to return to the spatial frequency domain before transmission of the mapped DL data streams, an Inverse Discrete Fourier Transform IDFT, or Inverse Discrete Space Fourier Transform, IDSFT, is needed.

Step 11: Perform Inverse Discrete Fourier Transform IDFT, or Inverse Discrete Space Fourier Transform, IDSFT, on the mapped DL data streams.

The mapped DL data streams, which have now been transformed to the spatial frequency domain, need to be transformed to the spatial time domain, which can be done by use of Inverse Fourier Transform, IFT.

Step 12: Perform Inverse Fourier Transform IFT from frequency to time domain, on the mapped DL data streams, which have been transformed to the spatial frequency domain.

From here the transformed and support angle mapped DL data streams can be mapped to physical antenna ports of one or more MIMO antenna arrays for downlink transmission.

Step 13: Map transformed and support angle mapped DL data streams to physical antenna ports of one or more MIMO antenna arrays for downlink transmission.

Fig. 3 is a block diagram illustrating transmission of an uplink signal from a user equipment 301, where the user equipment can be a mobile phone or unit and the uplink signal a sounding reference signal, SRS. The uplink signal SRS is received at a base station, and the base station holds a control apparatus according to embodiments of the present invention, whereby the base station is configured for determination of support angles to be mapped to downlink signals 302. The control apparatus of the base station is further configured to map the support angles to the DL signals, transforming the mapped DL signals, and forwarding the transformed DL signals to antenna ports of one or more MIMO antenna arrays 303.

Fig. 4 is a block diagram showing processor configurations blocks of a control apparatus 400 according to an embodiment of the invention. In block 401, the control apparatus 400 is configured to obtain one or more uplink, UL, signals, which are received at antenna elements of one or more MIMO antenna arrays. In block 402, the apparatus 400 is configured to perform processing for transforming the obtained UL signals from time domain to frequency domain, which may include use of FT. In block 403, the apparatus is configured to perform spatial processing for transforming the frequency signals of block 402 from frequency to an angular domain, which may include use of DFT. In block 404, the apparatus is configured to select pairs of subset support angles based on the transformed signals of block 403. In block 405, the apparatus is configured to map pairs of selected support angles to downlink, DL, signals or DL data streams. In block 406, the apparatus is configured to transform the mapped DL signals from angular frequency domain to spatial time domain, which may include us of IDFT an IFT, and in block 407 the apparatus is configured to map the transformed DL signals from block 406 to physical antenna ports.

Fig. 5 is a block diagram of processor configurations of a control apparatus 500 according to an embodiment of the invention, showing different processing configurations corresponding to configuration blocks 401-404 of Fig. 4.

In block 501, which corresponds to 401 of Fig. 4, the apparatus 500 is configured to obtain one or more uplink, UL, signals, which are received at antenna elements of one or more MIMO antenna arrays. In block 502, the apparatus 500 is configured to perform a Fourier transformation, FT, on the obtained UL signals, to obtain the result of equation (2) and thereby transform the received UL signals from spatial time to spatial frequency domain. In block 503, the apparatus 500 is configured to perform Discrete Fourier Transform, DFT, or Discrete Space Fourier Transform, DSFT, on the rows and columns of the Fourier Transform of equation (2) and thereby transform the signals of equation (2) from spatial frequency domain to angular frequency domain. In block 504, the apparatus 500 is configured to select the rows of the transformed signals of block 503 to obtain a number of first support signals, each being a function of a corresponding first support angle, corresponding to the results of equation (3) in the above Step 1. In block 505, the apparatus 500 is configured to select the columns of the transformed signals of block 503 to obtain a number of second support signals, each being a function of a corresponding second support angle, corresponding to the results of equation (7) in the above Step 4. In block 506, the apparatus 500 is configured to determine or estimate magnitudes of the first and second support signals corresponding to the results of equation (4) in Step 2 and equation (8) of Step 5.

In blocks 507 and 508, which are both optional, the apparatus 500 is configured to repeat steps 1-2 and 4-5 for a number of subsequent in time received uplink sounding reference signals, SRS, thereby obtaining a corresponding number of first and second support signal magnitudes, corresponding to $\mathbf{X}^{(\mathbf{r})}$ of equation (4) and $\mathbf{X}^{(\mathbf{c})}$ of equation (8), block 507, and to estimate new sets of first and second support signal magnitudes based on the determined plurality of first and second support signal magnitudes, block 508. In block 509, the apparatus 500 is configured to calculate average magnitudes for the first and second support signals based on the obtained magnitudes from block 506 or 508, corresponding to equation (5) of Step 3 and equation (9) of Step 6, and the apparatus 500 is further configured to compare the obtained average magnitudes with predetermined threshold magnitudes, corresponding to part of equation (6) of Step 3 and part of equation (10) of Step 6. In block 510, the apparatus 500 is configured to select a first subset of pairs of first and second support angles, being determined by the first and second support angles, for which the average magnitudes of the corresponding first and second support signals are larger than the predetermined threshold magnitudes, corresponding to the selected first and second subsets of support angles of equation (6) of Step 3 and equation (10) of Step 6, and further configured to index the selected first and second support angles in sets of support angles, corresponding to Step 8. In block 511, the apparatus 500 is configured to reduce the first subset of pairs of first and second support angles, to thereby determine a reduced, second subset of pairs of first and second support angles, which is described in Step 9 and equations (11), (12), and (13).

Fig. 6 is a block diagram of processor configurations of a control apparatus 600 according to an embodiment of the invention, showing different processing configurations corresponding to block 303 of Fig. 3. The downlink signals or data streams to be transmitted are received at block 601. In block 602, the apparatus 600 is configured to map pairs of selected support angles to downlink to the DL signals or data streams. In block 603, the apparatus 600 is configured to transform the mapped DL signals back from angular frequency domain to spatial frequency domain, which may include IDFT. In block 604, the apparatus 600 is configured to forward and map the transformed DL signals, which are mapped to support angles, to antenna ports of one or more MIMO antenna arrays for downlink transmission. In block 605, the apparatus is configured to transform the mapped DL signals back from the spatial frequency domain to spatial time domain, which may include IFT, before the mapped DL signals are finally transmitted, and in block 606 the apparatus is configured to map the transformed DL signals from block 605 to physical antenna ports for downlink transmission, TX in DL.

Fig. 7 is a system diagram illustrating data flow using a control apparatus according to an embodiment of the invention. In Fig. 7 uplink sounding reference signals, UL SRS 701, are received by antenna elements of one or more MIMO antenna arrays, and forwarded to a base station comprising a control apparatus according to embodiment of the invention. The received UL SRS signals are processed by the control apparatus at 702 in order to determine first and second support signals with corresponding first and second support angles. The obtained first and second support signals are further processed by the control apparatus at 703 in order to determine or select a subset of pairs of first and second support angles, and pairs of the selected subset of support angles 704, 705 are mapped to downlink, DL, data streams 706. The DL signals or data streams 706, which are mapped to the support angles 704, 705 in angular domain, is transformed back from angular frequency domain to spatial frequency domain 707 by use of Inverse Discrete Fourier Transform, IDFT, then transformed from spatial frequency domain to spatial time domain 708 by use of Inverse Fourier Transform, IFT, and further forwarded and mapped by the control apparatus of the base station to antenna ports 709, 710 of one or more MIMO antenna arrays for downlink transmission.

One effect of the present invention is that the latency can be reduced in obtaining subsets of support spectral angles for data transmission in massive MIMO systems. The latency is reduced from the duration of the need to receive multiple sparse SRSs to the duration of receiving a single SRS. Further benefits are that the large size of a massive MIMO antenna array can be used to improve accuracy of selecting the subset of support spectral angles with the largest spectral magnitudes. This method facilitates the use of massive MIMO for data transmission in 3GPP LTE-Advanced systems and beyond.

The principles of the present invention can be applied to systems where massive MIMO antennas are used in a wireless network, where there is channel state information of the uplink channel when channel reciprocity holds, or where there is channel state information of the downlink channel when channel reciprocity does not hold. The principles of the present invention can be applied to two or more antenna arrays or be applied to sub-arrays within an antenna array.

Although the present invention has been described with reference to specific features and embodiments thereof, it is evident that various modifications and embodiments can be made thereto without departing from the spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded as an illustration of the invention as defined by the appended claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present invention.

The term "comprising" as used in the appended claims does not exclude other elements or steps. The term "a" or "an" as used in the appended claims does not exclude a plurality.

CLAIMS

1. A multiple-input multiple output (MIMO) downlink (DL) data stream control apparatus (400, 500, 600) comprising at least on processor configured to:

obtain uplink signals (UL) (401, 501, 701) received at antenna elements of one or more MIMO antenna arrays (200), the elements of the MIMO arrays being arranged in one or more rows (201) and columns (202);

transform, for each of a selected number of rows (201), the number of row signals from spatial domain to a number of first support signals (504) in an angular domain, with each first support signal of a given row being a function of a corresponding first support angle;

transform, for each of a selected number of columns (202), the number of column signals from spatial domain to a number of second support signals (505) in an angular domain, with each second support signal of a given column being a function of a corresponding second support angle;

determine first and second sets of support signal magnitudes (506) by determining a magnitude for each or at least part of the first and second support signals (504, 505);

calculate a first average magnitude for each or at least part of the first support angles (509) based on determined magnitudes for first support signals being a function of the same first support angle, and calculate a second average magnitude for each or at least part of the second support angles (509) based on determined magnitudes for second support signals being a function of the same second support angle;

compare the first averaged magnitudes with a predetermined first threshold magnitude (509), and compare the second averaged magnitudes with a predetermined second threshold magnitude (509); and

determine a subset of first support angles and a subset of second support angles (404, 510), each of the subset of first angles having a corresponding first averaged magnitude exceeding the first threshold magnitude, and each of the subset of second angles having a corresponding second averaged magnitude exceeding the second threshold magnitude.

2. The apparatus of claim 1, wherein the at least one processor is configured to determine a first subset of support angle pairs (510) or support angle co-ordinate pairs by combining each angle of the subset of first support angles with each angle of the subset of second support angles.

3. The apparatus of claim 2, wherein the at least one processor is configured to:

perform a two-dimensional transform from spatial domain to angular domain of the signals of the selected rows and columns using as discrete variables the first support angles and the second support angles represented by the first subset of support angle pairs;

determine for each or at least part of the first subset of support angle pairs the magnitude of the corresponding two-dimensional transform;

compare the determined two-dimensional transform magnitudes with a third predetermined threshold value; and

determine a second subset of support angle pairs (511) or support angle co-ordinate pairs, each of the second subset of support angle pairs having a corresponding two-dimensional transform magnitude exceeding the third threshold magnitude.

4. The apparatus of claim 2 or 3, wherein the at least one processor is further configured to assign a number of downlink (DL) data streams (601, 706) to a corresponding number of support angle pairs (602, 704, 705) for downlink transmission, wherein each support angle pair is selected (703) from the first or the second subset of support angle pairs.

5. The apparatus of one of claims 1-4, wherein the at least one processor is further configured to:

estimate a new set of first support signal magnitudes based on a plurality of determined sets of first support signal magnitudes corresponding to a plurality of subsequent received uplink signals (507, 508), the new set of first support signal magnitudes corresponding to a future point in time for receiving an uplink signal;

estimate a new set of second support signal magnitudes based on a plurality of determined sets of second support signal magnitudes corresponding to the plurality of subsequent received uplink signals (507, 508), the new set of second support signal magnitudes corresponding to the future point in time for receiving an uplink signal; and

calculate the first and second average magnitudes based on the estimated new first and second support signal magnitudes (509).

6. The apparatus of claim 5, wherein the at least one processor is configured to estimate a new set of support signal magnitudes by use of a linear estimation in time

based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

7. The apparatus of claim 5 or 6, wherein the at least one processor is configured to estimate a new set of support signal magnitudes by use of a moving time average or weighted moving time average based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

8. The apparatus of one of the preceding claims, wherein for the transformation of row signals from spatial domain to angular domain and for the transformation of column signals from spatial domain to angular domain, the at least one processor is configured to:

form a time signal matrix representing signal values received by the antenna elements in the selected rows and columns, with rows and columns of the signal matrix corresponding to the selected rows and columns of receiving elements;

form a frequency signal matrix by transforming the time signal matrix from spatial time domain to spatial frequency domain (502);

transform the signals of each row of the frequency signal matrix, each of which rows corresponds to a selected row of receiving elements, from the spatial frequency domain to an angular frequency domain (503); and

transform the signals of each column of the frequency signal matrix, each of which columns corresponds to a selected column of receiving elements, from the spatial frequency domain to an angular frequency domain (504).

9. A method for determining a subset of support angles for use in transmission of downlink (DL) data streams from a plurality of antenna elements (709, 710) of one or more multiple-input multiple output (MIMO) antenna arrays, the method comprising:

receiving at the antenna elements of one or more MIMO antenna arrays (200) one or more uplink signals (UL) (401, 501, 701), the elements of the MIMO array(s) being arranged in one or more rows (201) and columns (202);

transforming, for each of a selected number of rows (201), the number of row signals from spatial domain to a number of first support signals (504) in an angular domain, with each first support signal of a given row being a function of a corresponding first support angle;

transforming, for each of a selected number of columns (202), the number of column signals from spatial domain to a number of second support signals (505) in an angular domain, with each second support signal of a given column being a function of a corresponding second support angle;

determining first and second sets of support signal magnitudes (506) by determining a magnitude for each or at least part of the first and second support signals (504, 505);

calculate a first average magnitude for each or at least part of the first support angles (509) based on determined magnitudes for first support signals being a function of the same first support angle;

calculate a second average magnitude for each or at least part of the second support angles (509) based on determined magnitudes for second support signals being a function of the same second support angle;

comparing the first averaged magnitudes with a predetermined first threshold magnitude (509);

comparing the second averaged magnitudes with a predetermined second threshold magnitude (509); and

determining a subset of first support angles and a subset of second support angles (404, 510), each of the subset of first angles having a corresponding first averaged magnitude exceeding the first threshold magnitude, and each of the subset of second angles having a corresponding second averaged magnitude exceeding the second threshold magnitude.

10. The method of claim 9, further comprising determining a first subset of support angle pairs (510) or support angle co-ordinate pairs by combining each angle of the subset of first support angles with each angle of the subset of second support angles.

11. The method of claim 10, further comprising:

performing a two-dimensional transform from spatial domain to angular domain of the signals of the selected rows and columns using as discrete variables the first support angles and the second support angles represented by the first subset of support angle pairs;

determining for each or at least part of the first subset of support angle pairs the magnitude of the corresponding two-dimensional transform;

comparing the determined two-dimensional transform magnitudes with a third predetermined threshold value; and

determining a second subset of support angle pairs (511) or support angle co-ordinate pairs, each of the second subset of support angle pairs having a corresponding two-dimensional transform magnitude exceeding the third threshold magnitude.

12. The method of claim 10 or 11, further comprising assigning a number of downlink (DL) data streams (601, 706) to a corresponding number of support angle pairs (602, 704, 705) for downlink transmission, wherein each support angle pair is selected (703) from the first or the second subset of support angle pairs.

13. The method of one of claims 9-12, wherein the step of determining first and second sets of support signal magnitudes further comprises:

estimating a new set of first support signal magnitudes based on a plurality of determined sets of first support signal magnitudes corresponding to a plurality of subsequent received uplink signals (507, 508), the new set of first support signal magnitudes corresponding to a future point in time for receiving an uplink signal; and

estimating a new set of second support signal magnitudes based on a plurality of determined sets of second support signal magnitudes corresponding to the plurality of subsequent received uplink signals (507, 508), the new set of second support signal magnitudes corresponding to the future point in time for receiving an uplink signal; and wherein

calculation of first and second average magnitudes is based on the estimated new first and second support signal magnitudes (509).

14. The method of claim 13, wherein the estimation of a new set of support signal magnitudes is performed by use of a linear estimation in time based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

15. The method of claim 13 or 14, wherein the estimation of a new set of support signal magnitudes is performed by use of a moving time average or weighted moving time average based on the determined magnitudes in the plurality of determined sets of support signal magnitudes.

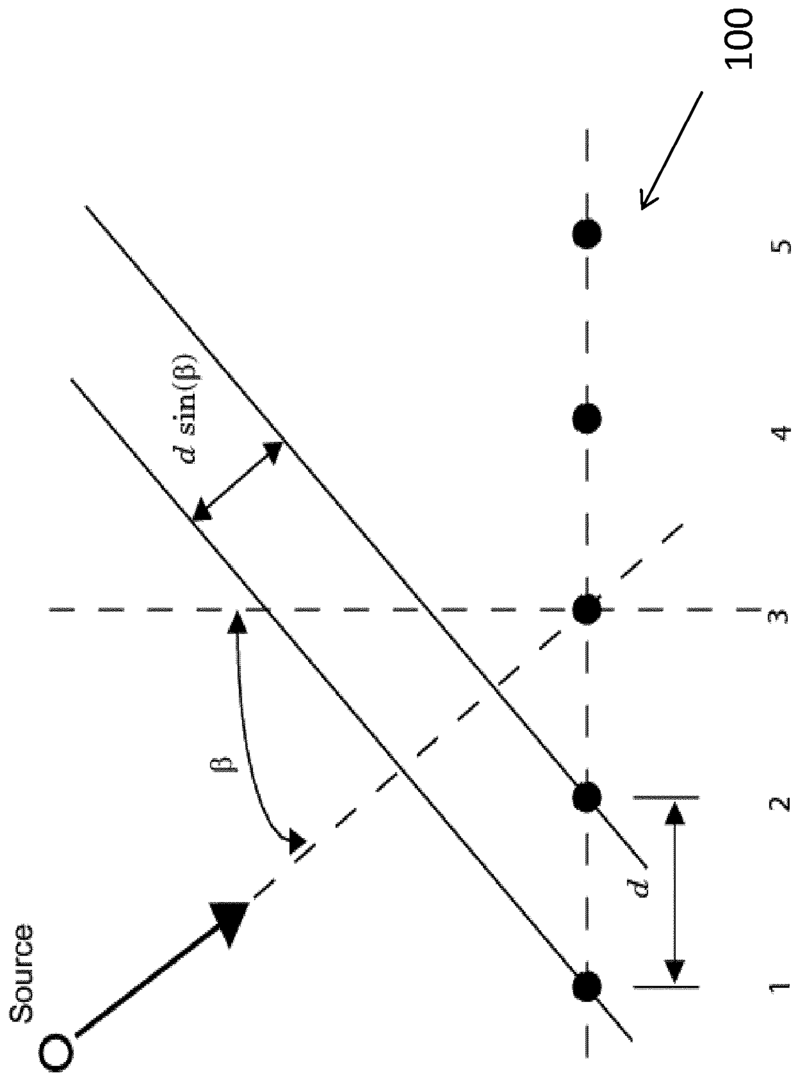

FIG. 1

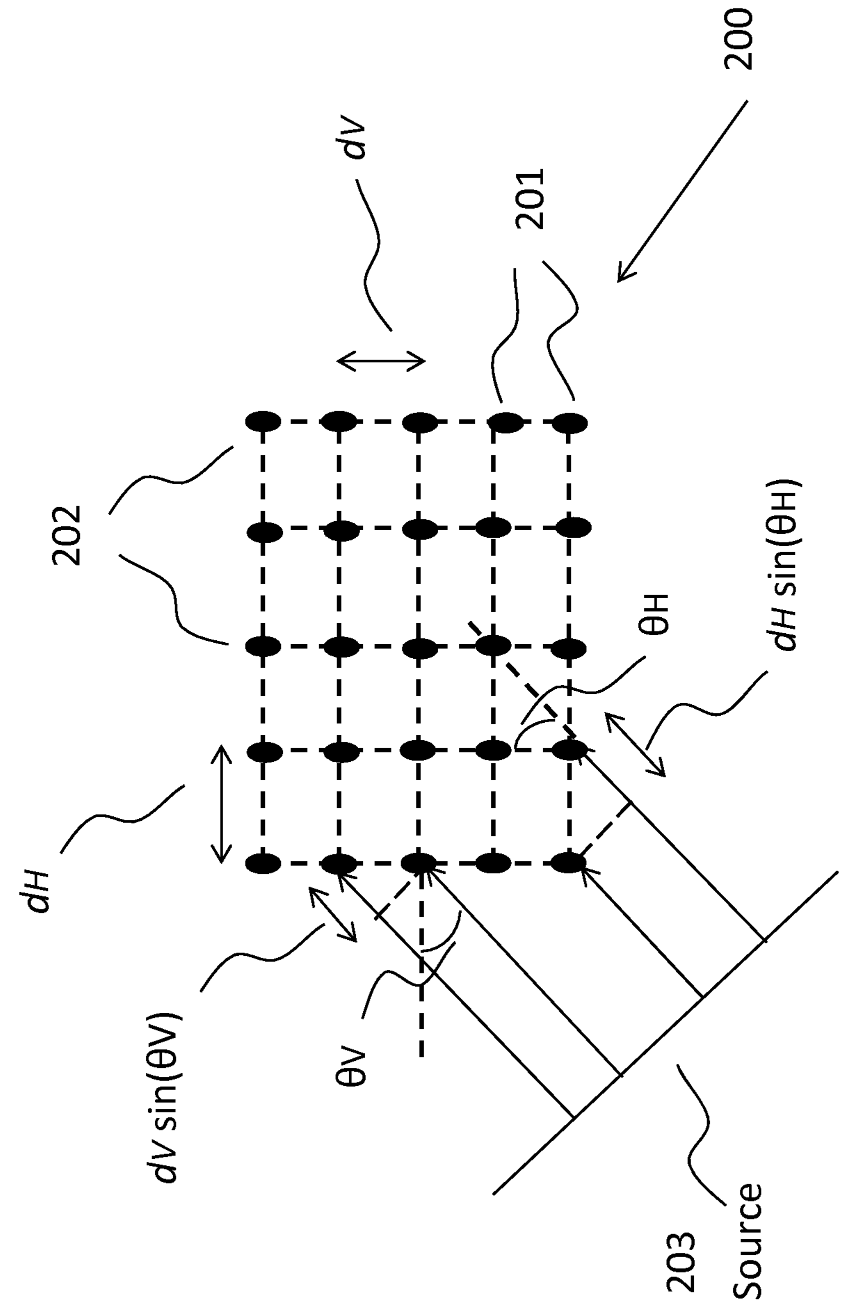

FIG. 2

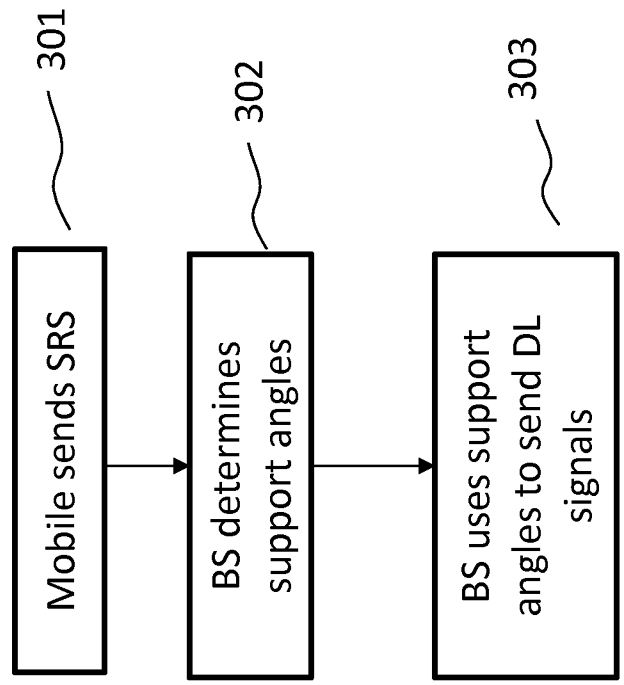
301
302
303
Mobile sends SRS
BS determines support angles
BS uses support angles to send DL signals

FIG. 3

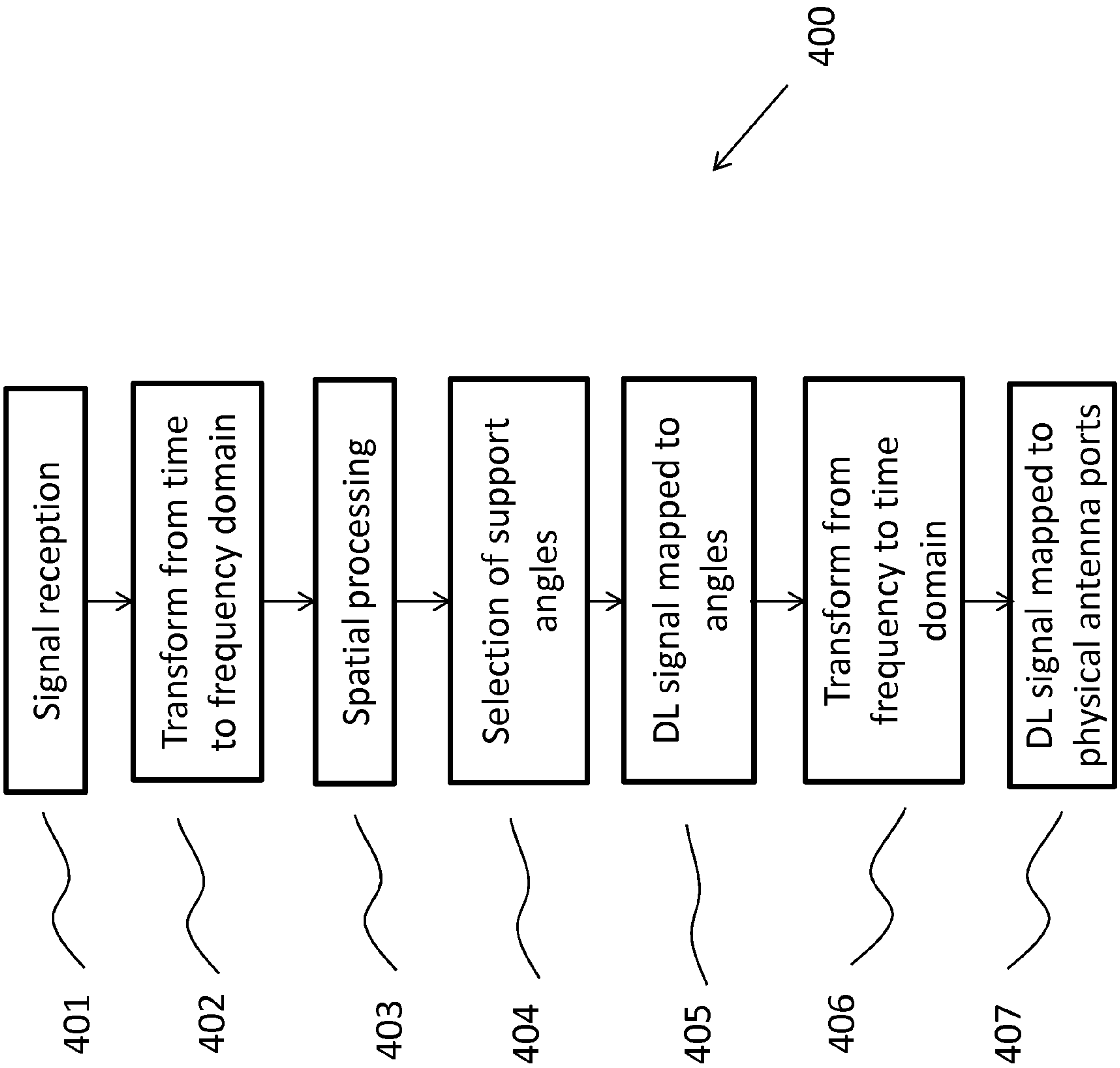
400
Signal reception
Transform from time to frequency domain
Spatial processing
Selection of support angles
DL signal mapped to angles
Transform from frequency to time domain
DL signal mapped to physical antenna ports
401
402
403
404
405
406
407

FIG. 4

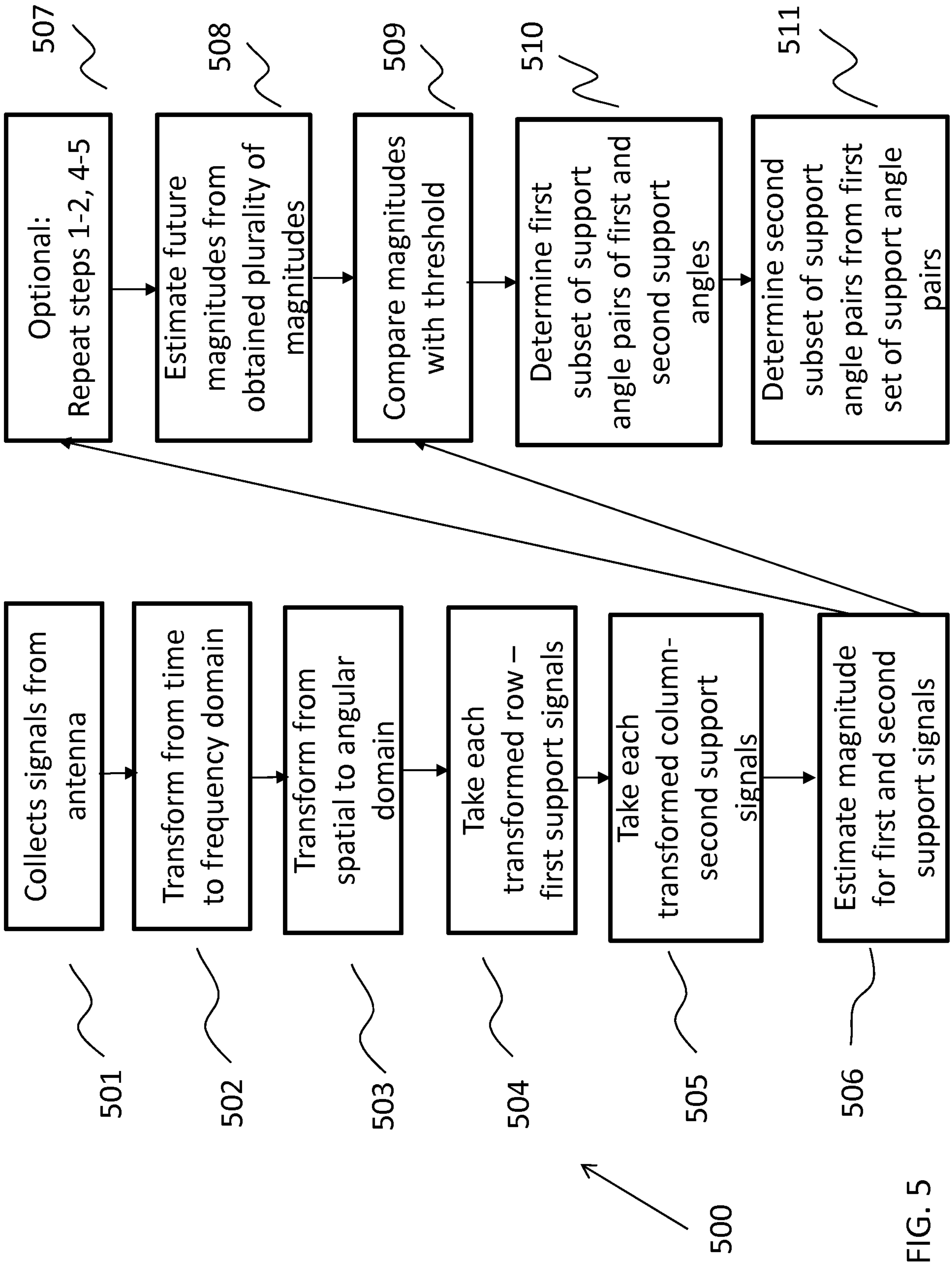
Collects signals from antenna
Transform from time to frequency domain
Transform from spatial to angular domain
Take each transformed row – first support signals
Take each transformed column- second support signals
Estimate magnitude for first and second support signals
Optional: Repeat steps 1-2, 4-5
Estimate future magnitudes from obtained plurality of magnitudes
Compare magnitudes with threshold
Determine first subset of support angle pairs of first and second support angles
Determine second subset of support angle pairs from first set of support angle pairs
501
502
503
504
505
506
507
508
509
510
511
500

FIG. 5

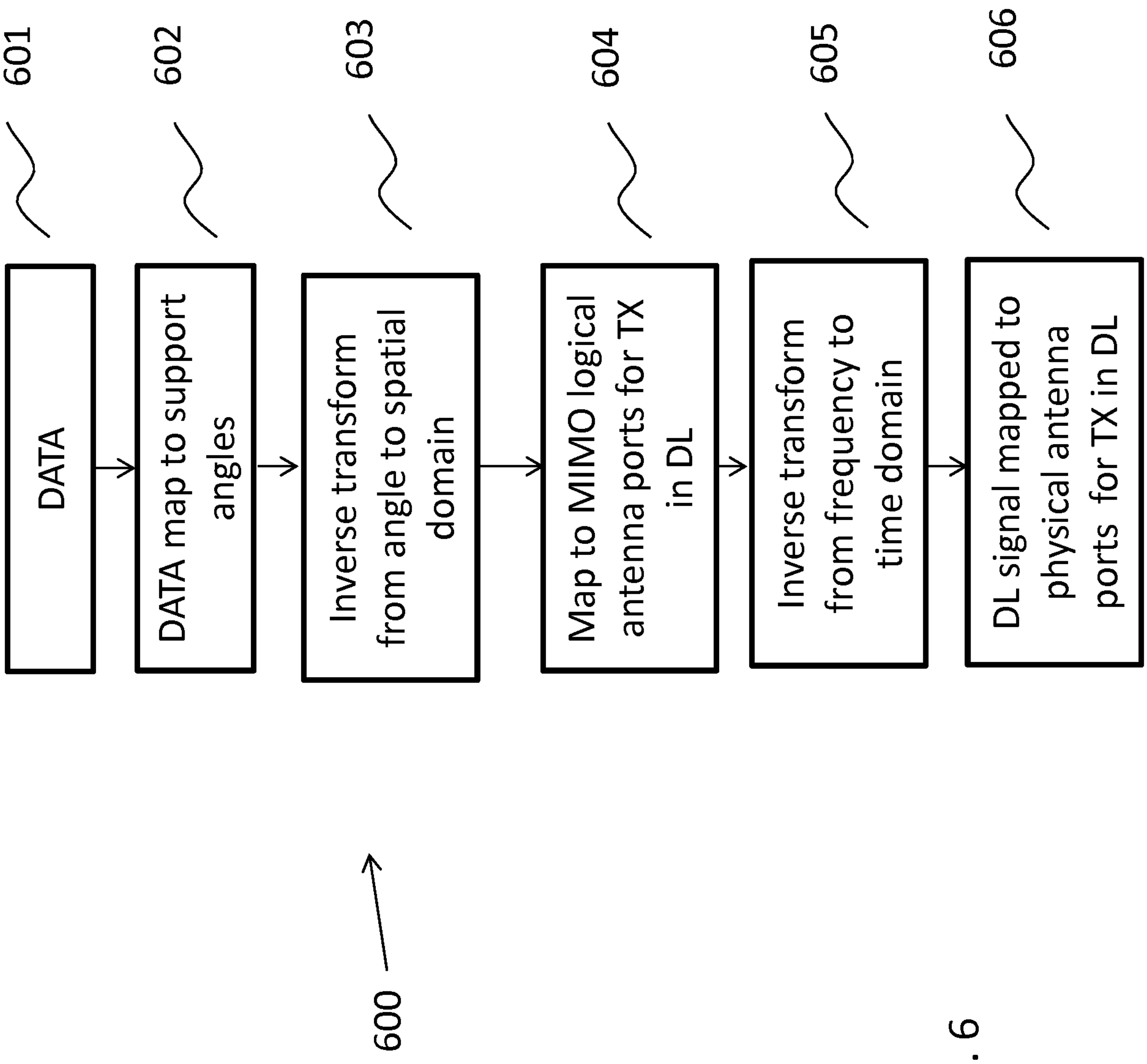
601
602
603
604
605
606
DATA
DATA map to support angles
Inverse transform from angle to spatial domain
Map to MIMO logical antenna ports for TX in DL
Inverse transform from frequency to time domain
DL signal mapped to physical antenna ports for TX in DL
600

FIG. 6

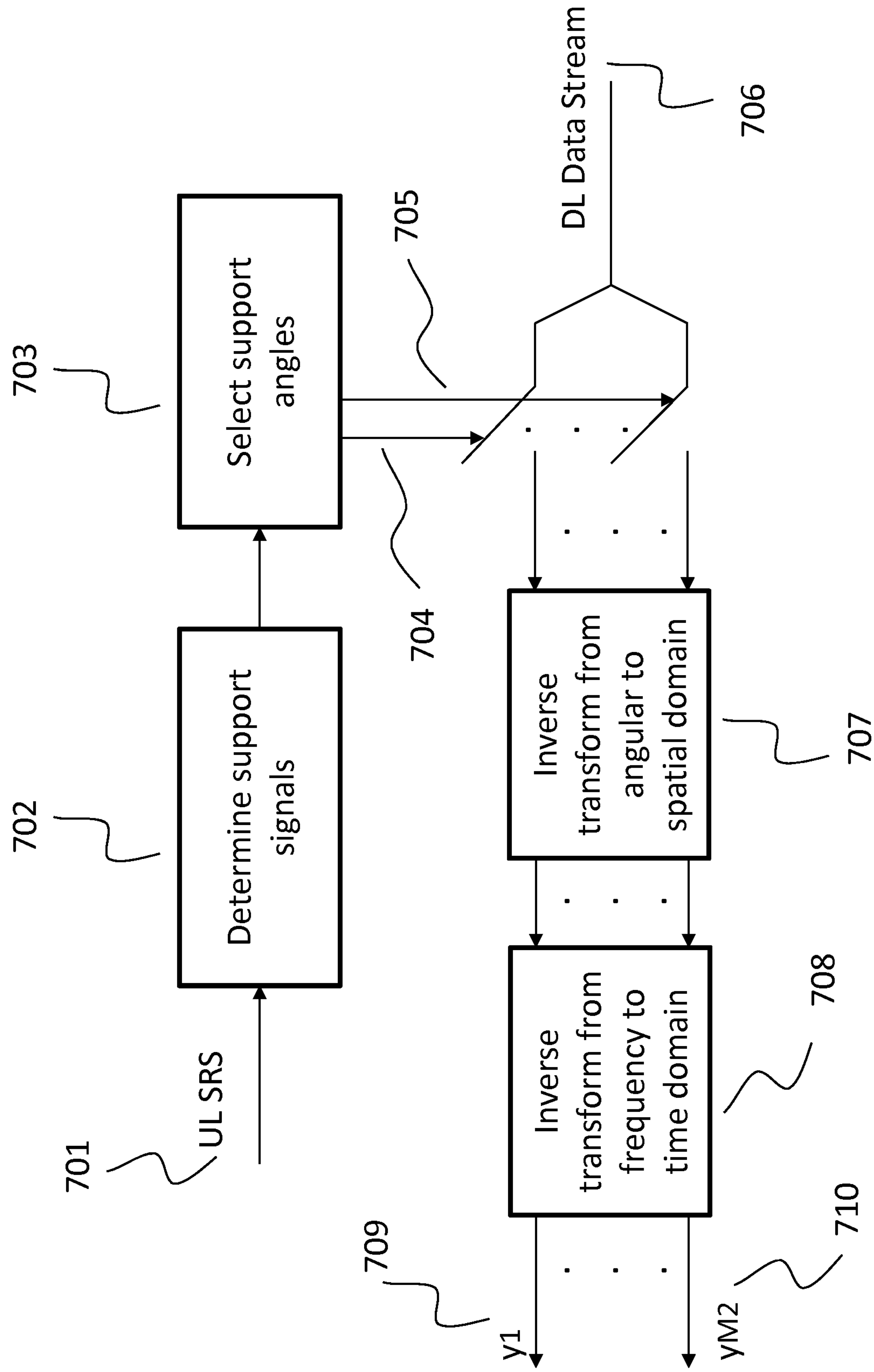
UL SRS
701
Determine support signals
702
Select support angles
703
704
705
DL Data Stream
706
Inverse transform from angular to spatial domain
707
Inverse transform from frequency to time domain
708
y1
709
yM2
710

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/074323

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S3/74 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)
G01S H04B H04L H04W

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.
X	WO 02/061969 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]) 8 August 2002 (2002-08-08) page 8 - page 18	1-15
X	US 6 489 923 B1 (BEVAN DAVID DAMIAN NICHOLAS [GB] ET AL) 3 December 2002 (2002-12-03) column 3, line 62 - column 3, line 67 column 4, line 15 - column 4, line 21 column 4, line 28 - column 4, line 37 column 4, line 44 - column 4, line 63 column 5, line 20 - column 5, line 23 column 5, line 62 - column 6, line 3 column 10, line 32 - column 11, line 25 figures 1, 2	1-15

-/--

[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

"E" earlier application or patent but published on or after the international filing date

"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
14 July 2015	22/07/2015

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	Skraparlis, D

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/074323

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MOLISCH A F ET AL: "FFT-Based Hybrid Antenna Selection Schemes for Spatially Correlated MIMO Channels", IEEE COMMUNICATIONS LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 8, no. 1, 1 January 2004 (2004-01-01), pages 36-38, XP011105837, ISSN: 1089-7798, DOI: 10.1109/LCOMM.2003.822512 Last three paragraphs of Section III beginning from point 3 -----	1-15
X	US 2005/287962 A1 (MEHTA NEELESH B [US] ET AL) 29 December 2005 (2005-12-29) paragraph [0011] - paragraph [0012] paragraph [0025] - paragraph [0026] paragraph [0036] - paragraph [0038] paragraph [0047] - paragraph [0049] paragraph [0152] - paragraph [0155] -----	1-15
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