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(54) Network node and method

(57) A wireless telecommunications network method and wireless telecommunications network node are disclosed. The method comprises providing a plurality of codebooks, each codebook identifying a phase shift to be applied to each signal to be transmitted by each of a plurality of antenna elements arranged in a plurality of pairs, each pair of antenna elements being spaced apart by a distance greater than a half wavelength of a carrier frequency, each codebook identifying a phase shift to be applied to each signal to generate a plurality of beams, each of which has a different angle of departure. In this way, a codebook is provided which enables different beams to be generated concurrently, each with a different angle of departure. This enables the channel conditions at the receiver to be improved using these different codebooks since beams are generated with the different angles of departure in order to better suit the different conditions experienced by the different beams.

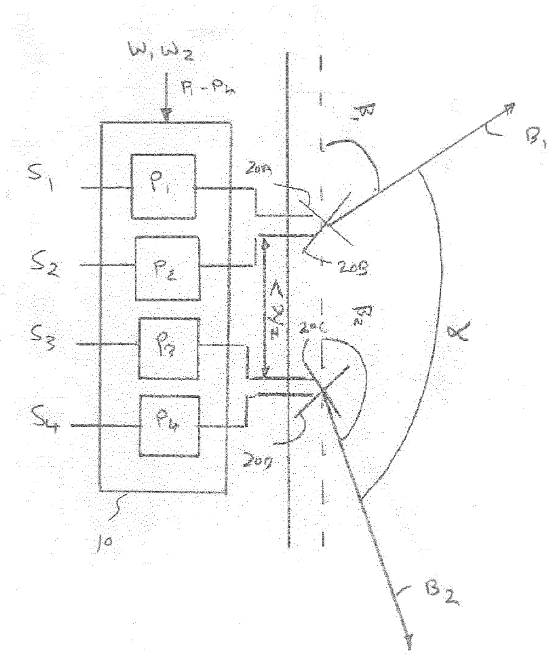

Figure 1

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Description

BACKGROUND

[0001] The present invention relates to a wireless telecommunications network method and wireless telecommunications network node.

FIELD OF THE INVENTION

[0002] Base stations in wireless communication systems provide wireless connectivity to user equipment within a geographic area, or cell, associated with the base station. The wireless communication links between the base station and each of the user equipment typically include one or more downlink (or forward) channels for transmitting information from the base station to the user equipment and one or more uplink (or reverse) channels for transmitting information from the user equipment to the base station. Multiple-input-multiple-output (MIMO) techniques may be employed when the base station and, optionally, the user equipment include multiple antennas. For example, a base station that includes multiple antennas can transmit multiple independent and distinct signals to multiple user equipment concurrently and on the same frequency band.

[0003] For example, consider a cellular system with M antennas at the base station and N antennas at the user equipment. In such communication systems, the radio channel between the base station and the user equipment can be described in terms of NxM links. Each link typically has a time-varying complex gain (i.e. amplitude and phase). This channel state information is measured by the user equipment and fed back to the base station in order to allow the base station to adapt characteristics of the signals transmitted to the user equipment to match it in the most appropriate way to the prevailing channel state.

[0004] In order to reduce the amount of feedback, typically both the base station and the user equipment are configured with the same set of codebooks which define typically phase shifts applied to signals feeding the antennas. The receiver measures characteristics of the signals and estimates which of the set of codebooks would best improve the characteristics of the received signals, and an indication of this codebook is fed back to the transmitter. The transmitter can then apply the phase shifts identified by the indicated codebook to the signals feeding the antennas in order to improve the characteristics of the received signals. Existing techniques typically utilise two codebooks which together provide the required phase shifts. One codebook relates to wideband or long-term channel properties, whilst the other codebook (which is indicated more frequently) relates to sub-band or short-term channel properties.

[0005] Although these techniques can improve received signals, they have their own shortcomings. Accordingly, it is desired to provide an improved technique for improving received signals.

SUMMARY

[0006] According to a first aspect, there is provided a wireless telecommunications network method, comprising: providing a plurality of codebooks, each codebook identifying a phase shift to be applied to each signal to be transmitted by each of a plurality of antenna elements arranged in a plurality of pairs, each pair of antenna elements being spaced apart by a distance greater than a half wavelength of a carrier frequency, each codebook identifying a phase shift to be applied to each signal to generate a plurality of beams, each of which has a different angle of departure.

[0007] The first aspect recognises that a problem with current codebook structures provided by the standards is that they assume closely-spaced (typically a half wavelength spacing) of the antenna elements of the antenna array and so also assume that the angle of departure (or grid of beam) for each of the transmitted beams should be identical in order to improve the characteristics of the channels being received by the user equipment. However, the first aspect also recognises that when more widely-spaced antenna elements are utilised within the antenna array, this assumption may not be correct and that the angle of departure of the different beams may need to be different in order to improve the reception characteristics of the channels due to the reduction in correlation as the antenna elements become more widely spaced and differing propagation characteristics experienced by the different beams.

[0008] Accordingly, a wireless telecommunications network node method may be provided. The method may comprise the step of providing, provisioning or configuring a plurality of codebooks. Each of these codebooks may identify phase shifts that may be applied to those signals which are to be transmitted by each of a plurality of different antenna elements. The antenna elements may be arranged in pairs. Each of the pairs of antenna elements may be spaced apart or separated by a distance which is greater than a half wavelength of a carrier signal. Each of the codebooks then identifies phase shifts that maybe applied to those signals in order to generate different beams, each of which has a different angle of departure. In this way, a codebook is provided which enables different beams to be generated concurrently, each with a different angle of departure. This enables the channel conditions at the receiver to be improved using these different codebooks since beams are generated with the different angles of departure in order to better suit the different conditions experienced by the different beams.

[0009] In one embodiment, the plurality of codebooks identify a phase shift to be applied to each signal to generate the plurality of beams, each of the plurality of beams being spatially divergent with respect to each other. By having different angles of departure, it will be appreciated that the beams concurrently generated may not be parallel, but m ay be spatially divergent.

[0010] In one embodiment, a subset of the plurality of codebooks identify a phase shift to be applied to each signal to generate a plurality of beams, each of the plurality of beams being spatially orthogonal with respect to each other. Accordingly, beams that are orthogonal (that is to say, they are transmitted at 90° to each other), may be generated using a subset of the codebooks. It will be appreciated that another subset generates beams that are not spatially orthogonal.

[0011] In one embodiment, each codebook comprises a product of one of a plurality of first codebooks and one of a plurality of second codebooks. Accordingly, the codebooks may use existing functionality already provided by the standards, which generates precoding vectors from the product of a first codebook and a second codebook.

[0012] In one embodiment, the first codebook comprises one of plurality of identity matrices and diagonal matrices. Again, the codebooks may use existing functionality already provided by the standards.

[0013] In one embodiment, the first codebook comprises one of plurality of matrices having entries arranged in a number of rows and a number of columns corresponding to the plurality of antenna elements.

[0014] In one embodiment, the first codebook comprises one of plurality of matrices W1, where

$$W_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j2n\pi/16} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{j2n\pi/16} \end{bmatrix} \quad where \;\; n \in [0,...,15].$$

[0015] In one embodiment, the second codebook comprises a vector having a number of entries corresponding to the plurality of antenna elements arranged in one of a column and a row.

[0016] In one embodiment, each entry of the product of the first and second codebook is associated with a final phase shift to be applied to each signal transmitted by a corresponding antenna element.

[0017] In one embodiment, wherein the second codebook comprises one of plurality of matrices W2, where

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ -e^{j2m\pi/8} \end{bmatrix} \quad where \;\; m \in [0,...,7].$$

[0018] It will be appreciated that this embodiment W2 may function as a rank 1 matrix.

[0019] In one embodiment, the second codebook comprises one of the plurality of matrices W2, where rank 2 and other higher rank codebooks of W2 are transformed from the rank 1 codebook of W2 by applying a householder transformation to a function of W2. It will be appreciated that for MIMO spatial multiplexing where the MIMO can transmit 2,3, or 4 data streams simultaneously, W2 is a rank 2,3,or 4 matrix (W2 has 2,3,4 column vectors). To obtain a rank 2 or higher rank codebook of W2, it is possible to utilise the rank 1 W2 (mentioned above) at first and then extend it to other ranks by a householder transformation.

[0020] In one embodiment, the method comprises evaluating which of the plurality of first and second codebooks are estimated to provide a desired characteristic of the beams and signalling an indication of which of the plurality of first and second codebooks are estimated to provide the desired characteristic of the beams.

[0021] In one embodiment, the step of signalling the indication comprises signalling a value of m and n.

[0022] In one embodiment, the step of signalling the indication comprises signalling a value of m more frequently than signalling a value of n.

[0023] In one embodiment, spatially orthogonal beams are generated using the first codebook having a value of n of one of 0 and 8 and the second codebook having any value of m.

[0024] In one embodiment, spatially non-orthogonal beams are generated using the first codebook having a value of n between 0 and 15 other than 0 and 8 and the second codebook having any value of m.

[0025] In one embodiment, each pair of antenna elements are spaced apart by a plurality of wavelengths of the carrier frequency.

[0026] In one embodiment, the plurality of antenna elements comprise four antenna elements arranged in two pairs.

[0027] In one embodiment, each pair of antenna elements comprise two cross polarised antenna elements.

[0028] According to a second aspect, there is provided a wireless telecommunications network node, comprising: providing logic operable to provide a plurality of codebooks, each codebook identifying a phase shift to be applied to each signal to be transmitted by each of a plurality of antenna elements arranged in a plurality of pairs, each pair of antenna elements being spaced apart by a distance greater than a half wavelength of a carrier frequency, each codebook identifying a phase shift to be applied to each signal to generate a plurality of beams, each of which has a different angle of departure.

[0029] In one embodiment, the plurality of codebooks identify a phase shift to be applied to each signal to generate the plurality of beams, each of the plurality of beams being spatially divergent with respect to each other.

[0030] In one embodiment, a subset of the plurality of codebooks identify a phase shift to be applied to each signal to generate a plurality of beams, each of the plurality of beams being spatially orthogonal with respect to each other.

[0031] In one embodiment, each codebook comprises a product of one of a plurality of first codebooks and one of a plurality of second codebooks.

[0032] In one embodiment, the first codebook comprises one of plurality of identity matrices and diagonal matrices.

[0033] In one embodiment, the first codebook comprises one of plurality of matrices having entries arranged in a number of rows and a number of columns corresponding to the plurality of antenna elements.

[0034] In one embodiment, the first codebook comprises one of plurality of matrices W1, where

$$W_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j2n\pi/16} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{j2n\pi/16} \end{bmatrix} \quad where \;\; n \in [0,...,15] \quad .$$

[0035] In one embodiment, the second codebook comprises a vector having a number of entries corresponding to the plurality of antenna elements arranged in one of a column and a row.

[0036] In one embodiment, each entry of the product of the first and second codebook is associated with a final phase shift to be applied to each signal transmitted by a corresponding antenna element.

[0037] In one embodiment, the second codebook comprises one of plurality of matrices W2, where

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ -e^{j2m\pi/8} \end{bmatrix} \quad where \;\; m \in [0,...,7].$$

[0038] In one embodiment, the second codebook comprises one of the plurality of matrices W2, where rank 2 and other higher rank codebooks of W2 are transformed from the rank 1 codebook of W2 by applying a householder transformation to a function of W2.

[0039] In one embodiment, the network node comprises evaluation logic operable to evaluate which of the plurality of first and second codebooks are estimated to provide a desired characteristic of the beams and signalling logic operable to signal an indication of which of the plurality of first and second codebooks are estimated to provide the desired characteristic of the beams.

[0040] In one embodiment, the signalling logic is operable to signal a value of m and n.

[0041] In one embodiment, the signalling logic is operable to signal a value of m more frequently than signalling a value of n.

[0042] In one embodiment, spatially orthogonal beams are generated using the first codebook having a value of n of one of 0 and 8 and the second codebook having any value of m.

[0043] In one embodiment, spatially non-orthogonal beams are generated using the first codebook having a value of n between 0 and 15 other than 0 and 8 and the second codebook having any value of m.

[0044] In one embodiment, each pair of antenna elements are spaced apart by a plurality of wavelengths of the carrier frequency.

[0045] In one embodiment, the plurality of antenna elements comprise four antenna elements arranged in two pairs.

[0046] In one embodiment, each pair of antenna elements comprise two cross polarised antenna elements.

[0047] According to a third aspect, there is provided a computer program product operable, when executed on a computer, to perform the method steps of the first aspect.

[0048] Further particular and preferred aspects are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in combinations other than those explicitly set out in the claims.

[0049] Where an apparatus feature is described as being operable to provide a function, it will be appreciated that this includes an apparatus feature which provides that function or which is adapted or configured to provide that function.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050] Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 illustrates an arrangement of a transmitter according to one embodiment.

DESCRIPTION OF THE EMBODIMENTS

Overview

[0051] Before discussing the embodiments in any more detail, first an overview will be provided. As mentioned above and illustrated in Figure 1, current standards specify techniques which utilise codebooks W_1W_2 to feed back the different phase shifts P_1 to P_4 required to be applied by a phase shifter 10 to signals S_1 to S_4 transmitted from antenna elements 20A to 20D in order to form different beams B_1 and B_2. The current standards assume certain characteristics of the arrangement of the antenna elements and the resultant required characteristics of the formed beams. For example, the current codebooks assume that the antenna array is made of closely spaced (for example, half wavelength spaced) antenna elements which generate beams having an identical angle of departure from the antenna array. Whilst these codebooks are suitable for such antenna arrays, they are generally unsuitable for more widely spaced arrays where the antenna elements are spaced apart by greater than half a wavelength, typically between around 4 and 10 wavelengths. This is because with such widely spaced antenna elements, correlation decreases and propagation characteristics vary more than with the closely spaced antenna elements. In other words, as the distance between antenna elements increases, the correlation between the beams decreases, and so different angles of departure may be required in order to improve channel conditions, given the effects of the different paths through which the beams will travel due to differing environmental conditions experienced by the beams. Accordingly, with widely spaced antenna elements, improved channel conditions may be achieved if the angles of departure of the beams are not identical. However, it is also desirable to avoid the complete replacement of the existing codebook arrangement, techniques and functionality in order to accommodate additional codebooks for these more widely spaced antennas.

[0052] Accordingly, embodiments provide an arrangement where codebooks are provided, provisioned or configured for antenna arrays which have antenna elements spaced apart by a distance which is greater than half a wavelength. These different codebooks provide phase shifts which, when applied to different signals, generate beams having different angles of departure. This enables user equipment to evaluate, based on measurements made regarding the received channel signals, which of the different codebooks would provide the most desirable channel signals when the different phase shifts are applied to the signals transmitted by the antenna elements and beams are formed with different angles of departure.

[0053] Hence, existing codebook feedback arrangements may be utilised, such as using a two-stage codebook structure which feeds back sub-band or short-term channel properties frequently using one codebook and wideband or long-term channel properties less frequently using another codebook. In addition, the wideband or long-term channel property codebook may be identical for both closely spaced and widely spaced antenna elements, but the codebook of the sub-band or short-term channel property for widely spaced antenna elements differs, as will be explained in more detail below.

Channel State Evaluation

[0054] As already mentioned above, in order to improve the properties of the channels between a base station and user equipment, user equipment will typically perform measurements of the characteristics of the channels being received. The user equipment is provided with a set of codebooks which define different combinations of phase shifts that can be applied at the base station to the signals being transmitted from its antenna array. The user equipment can evaluate all or a sub-set of these codebooks in order to estimate how those phase shifts would improve the characteristics of the channels being received. The identity of the most appropriate codebooks can then be fed back to the base station in order that the base station may utilise the phase shifts specified within those codebooks in order to improve the conditions of the channels being received by the user equipment.

[0055] Using codebooks rather than transmitting information relating to the channel conditions is useful, since this reduces the quantity of feedback required between the user equipment and the base station. However, the use of codebooks is also constraining, since if these are not provisioned or configured appropriately, then optimal improvements to the channel conditions may not be possible.

Codebook Structure - Closely Spaced Antenna Elements

[0056] For a typical cross-polarised or co-polarised antenna array with a half-wavelength spacing, a two-stage codebook structure W_1W_2 is provided. W_1 provides wideband or long-term channel properties, whilst W_2 provides sub-band or short-term channel properties. The two-stage codebook structure is used in order to balance overhead and accuracy of channel state information feedback. Typically, W_1 is fed back relatively infrequently, such as, for example, every 100 ms, whilst W_2 is fed back more frequently, such as, for example, every 5 ms.

[0057] W_1 will typically be a diagonal matrix with n bits to capture the angle of departure or grid of beam for a closely spaced antenna array which may be either cross-polarised or co-polarised:

$$W_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j2n\pi/16} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{j2n\pi/16} \end{bmatrix} \quad where \;\; n \in [0,...,15].$$

[0058] W_2 can be a vector with m bits to capture the phase shift between polarisations:

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ e^{j2m\pi/8} \end{bmatrix} \quad where \;\; m \in [0,...,7].$$

[0059] In other words, varying the value of n will change the angle of departure of both beams transmitted by the four antenna elements so that both beams are together directed at the same one of 16 different angles of departure, specified by the value n. Likewise, the phase shift between the two beams may be one of eight different phase shifts specified by the value m. Hence, the value n may be transmitted using four bits, typically every 100ms, whilst the value m may be transmitted using three bits every 5ms. This helps to generate the two beams with the same required angle of departure and different phase shift in order to improve the channel conditions at the user equipment.

[0060] However, this configuration of codebooks is optimised for a calibrated antenna array with correlated antenna elements (typically having a half wavelength spacing and propagation with a single dominant angle of departure path (for example, line of sight). Given that different configuration antenna arrays may be provided, it is desirable to modify the codebook such that it contains code words which can be used for different antenna spacing between antenna arrays (XX array) with multiple wavelength spacing such as, for example, four or 10 wavelengths, which allows for multiple path propagation with more freedom at the same time.

Codebook Structure - Widely Spaced Antenna Elements

[0061] Whilst it is possible to retain W_1 in its configuration mentioned above, W_2 is modified to:

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ -e^{j2m\pi/8} \end{bmatrix} \; where \; m \in [0,...,7].$$

[0062] With this modified W_2, W_1W_2=[1 $e^{j2n\pi/16}$ $e^{j4m\pi/16}$ $-e^{j(4m+2n)\pi/16}$].

[0063] With this arrangement, two orthogonal co-phasing or precoding vectors for two polarisations can be found when n = 0,8 and any m. That is to say, the two beams formed when n = 0,8 will be spatially orthogonal (i.e. the two beams will transmit with a 90° angle of separation α between them). It will be appreciated that the angle of departure β is the angle at which the beam extends from the surface of the antenna array.

[0064] W_1 may be configured either as an identity matrix or a diagonal matrix (1, -1, 1, -1) representing long term channel characteristics of a full transmission element widely-spaced antenna array. Other non-orthogonal co-phasing vectors or pre-coding vectors for two polarisations can be found with other combination values of n and m.

[0065] Therefore, with the modified arrangement of W_2 this codebook can reuse the codebook design structure that currently exists for closely spaced antenna arrays with very limited modification of design in order to support widely spaced antenna arrays. Simply transmitting values of n and m in accordance with current procedures can be used to generate beams with varying angles of departure β and angles of separation α in order to improve the channel conditions at the user equipment.

<u>Codebook Structure - Combined Widely Spaced and Closely Spaced Antenna Elements</u>

[0066] It will be appreciated that the codebook W_2 may include vectors suitable for both closely spaced and widely spaced antennas, for example the codebook may comprise the union of both

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ -e^{j2m\pi/8} \end{bmatrix} \; where \; m \in [0,...,7] \text{ and } W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ e^{j2m\pi/8} \end{bmatrix} \; where \; m \in [0,...,7].$$

[0067] When both the standard W_2 matrix and the modified W_2 matrix are provided, the selection between the two codebooks may be indicated by higher level signalling from the base station to the user equipment (since the base station may be aware of which type of antenna array is being utilised), or may be signalled from the user equipment to the base station based on its evaluation of both the standard and modified codebook W_2, together with feedback for the W_1 code word selection, or together with feedback for the W_2 code word selection.

[0068] Accordingly, it can be seen that embodiments provide a technique where W_1 is semi-statically measured and fed back from the user equipment where W_1 is used to quantise the phase shift within an antenna pair showing the same polarisation. The standard W_1 codebook arrangement can be applied. W_2 is defined according to the following principles: for a code word represented by W_1W_2 user equipment can feed back two different phase shift/co-phasing vectors corresponding to different polarisations, even though they share the same long-term quantisation of W_1; for a code word represented by W_1W_2, two different phase shift/co-phasing vectors can be orthogonal or non-orthogonal. This arrangement provides a codebook that can give improved MIMO performance for widely-spaced, cross-polarised antenna configurations, which is an increasingly common base station antenna configuration. This arrangement can be implemented with only minimal changes to existing standards.

[0069] A person of skill in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Herein, some embodiments are also intended to cover program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. The embodiments are also intended to cover computers programmed to perform said steps of the above-described methods.

[0070] The functions of the various elements shown in the Figures, including any functional blocks labelled as "processors" or "logic", may be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, explicit use of the term "processor" or "controller" or "logic" should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, network processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), read only memory (ROM) for storing software, random access memory (RAM), and non volatile storage. Other hardware, conventional and/ or custom, may also be included. Similarly, any switches shown in the Figures are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the implementer as more specifically understood from the context.

[0071] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

[0072] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

Claims

1. A wireless telecommunications network method, comprising:

   providing a plurality of codebooks, each codebook identifying a phase shift to be applied to each signal to be transmitted by each of a plurality of antenna elements arranged in a plurality of pairs, each pair of antenna elements being spaced apart by a distance greater than a half wavelength of a carrier frequency, each codebook identifying a phase shift to be applied to each signal to generate a plurality of beams, each of which has a different angle of departure.

2. The method of claim 1, wherein said plurality of codebooks identify a phase shift to be applied to each signal to generate said plurality of beams, each of said plurality of beams being spatially divergent with respect to each other.

3. The method of claim 1 or 2, wherein a subset of said plurality of codebooks identify a phase shift to be applied to each signal to generate a plurality of beams, each of said plurality of beams being spatially orthogonal with respect to each other.

4. The method of any preceding claim, wherein each codebook comprises a product of one of a plurality of first codebooks and one of a plurality of second codebooks.

5. The method of claim 4, wherein said first codebook comprises one of plurality of identity matrices and diagonal matrices.

6. The method of claim 4 or 5, wherein said first codebook comprises one of plurality of matrices having entries arranged in a number of rows and a number of columns corresponding to said plurality of antenna elements.

7. The method of any one of claims 4 to 6, wherein said first codebook comprises one of plurality of matrices W1, where

$$W_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j2n\pi/16} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & e^{j2n\pi/16} \end{bmatrix} \quad where \;\; n \in [0,...,15].$$

8. The method of any one of claims 4 to 7, wherein said second codebook comprises a vector having a number of entries corresponding to said plurality of antenna elements arranged in one of a column and a row.

9. The method of any one of claims 4 to 8, wherein each entry of the product of the first and second codebook is associated with a final phase shift to be applied to each signal transmitted by a corresponding antenna element.

10. The method of any one of claims 4 to 9, wherein said second codebook comprises one of plurality of matrices W2, where

$$W_2 = \begin{bmatrix} 1 \\ 1 \\ e^{j2m\pi/8} \\ -e^{j2m\pi/8} \end{bmatrix} \quad where \;\; m \in [0,...,7].$$

11. The method of any one of claims 4 to 9, wherein said second codebook comprises one of the plurality of matrices W2, where rank 2 and other higher rank codebooks of W2 are transformed from the rank 1 codebook of W2 by applying a householder transformation to a function of W2.

12. The method of any one of claims 4 to 11, comprising evaluating which of said plurality of first and second codebooks are estimated to provide a desired characteristic of said beams and signalling an indication of which of said plurality of first and second codebooks are estimated to provide said desired characteristic of said beams.

13. The method of any one of claims 4 to 12, wherein spatially orthogonal beams are generated using said first codebook having a value of n of one of 0 and 8 and said second codebook having any value of m and wherein spatially non-orthogonal beams are generated using said first codebook having a value of n between 0 and 15 other than 0 and 8 and said second codebook having any value of m.

14. A wireless telecommunications network node, comprising:

providing logic operable to provide a plurality of codebooks, each codebook identifying a phase shift to be applied to each signal to be transmitted by each of a plurality of antenna elements arranged in a plurality of pairs, each pair of antenna elements being spaced apart by a distance greater than a half wavelength of a carrier frequency, each codebook identifying a phase shift to be applied to each signal to generate a plurality of beams, each of which has a different angle of departure.

15. A computer program product operable, when executed on a computer, to perform the method steps of any one of claim 1 to 13.

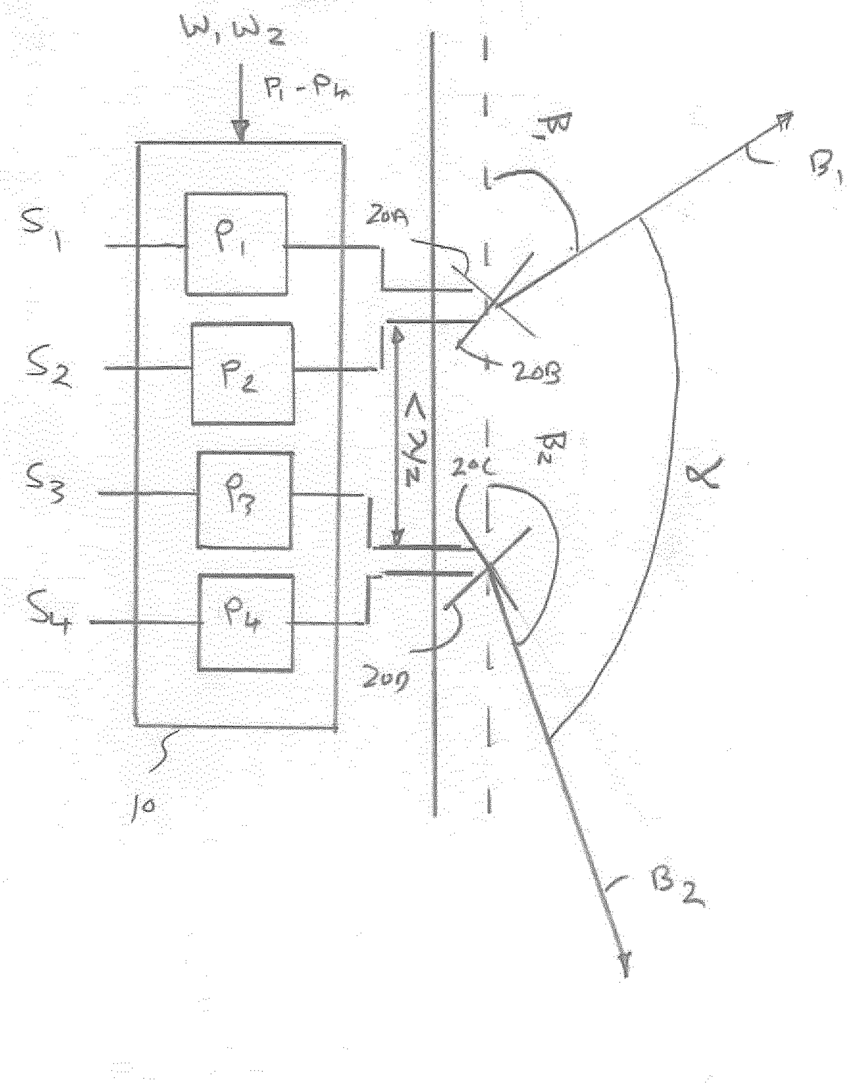

Figure 1

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 13 30 5259

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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