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(54) Title of the Invention: **Method and apparatus for antenna selection in wireless communications systems**
Abstract Title: **Transmit antenna selection in a multi-carrier, multi-antenna transceiver using signal metrics associated with signals received by the transceiver**

(57) The invention applies to a wireless transceiver comprising a plurality of antennas and operable to transmit data on a plurality of subcarriers from one or more of said plurality of antennas over a communication channel. The invention lies in selecting the antennae which are to be used for transmission. The transceiver receives signals via each of the antennas, and determines the number of subcarriers that can be allocated to each of the antennas, for data transmission, on the basis of received signal metrics associated with said received signals (steps S1-0 to s1-6). Preferably, this determination involves, for each antenna, plotting a graph of the number of sub-carriers received as function of the power of received signals and applying linear regression. Transmit antenna selection is performed on the basis of the number of subcarriers which can be allocated to each antenna (steps s1-6 to s1-13). This enables unused RF chains to be switch-off. Transmit antenna selection can be performed without carrying out FFT processing of received signals.
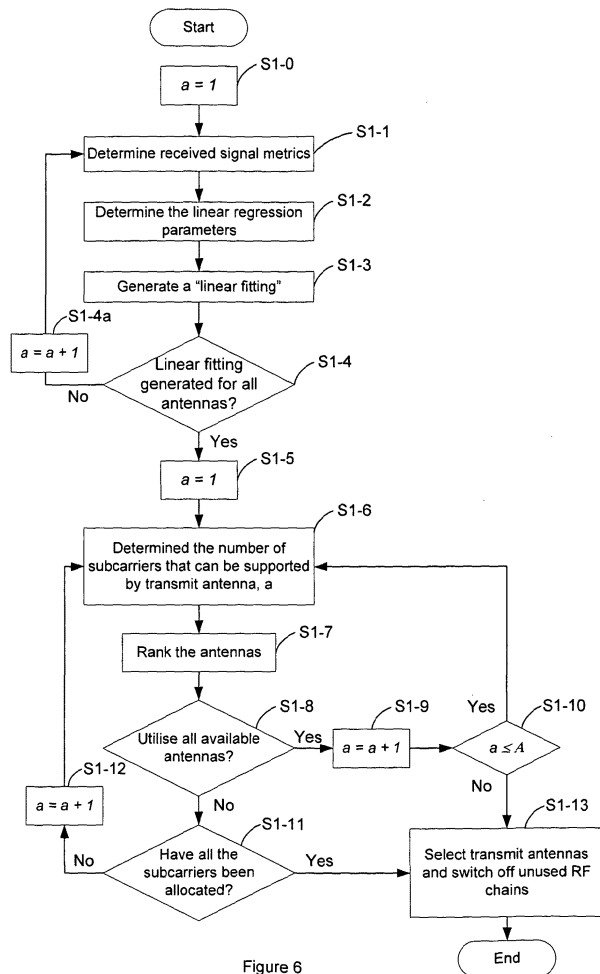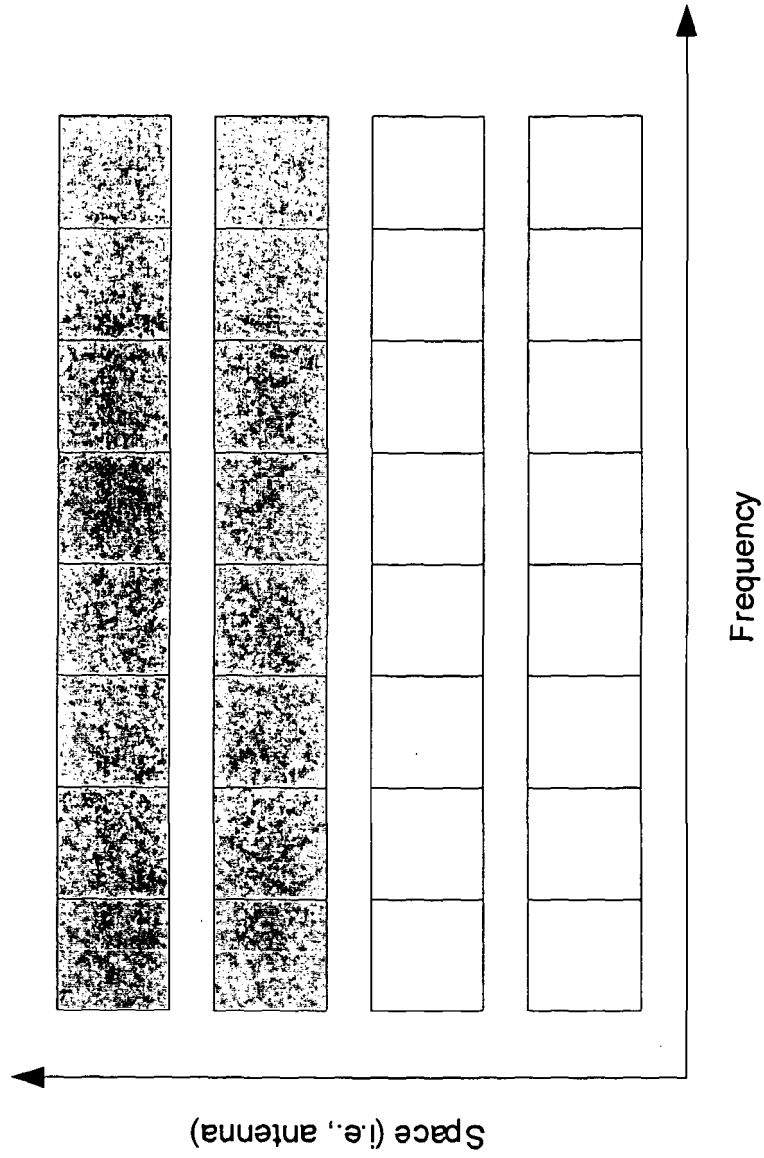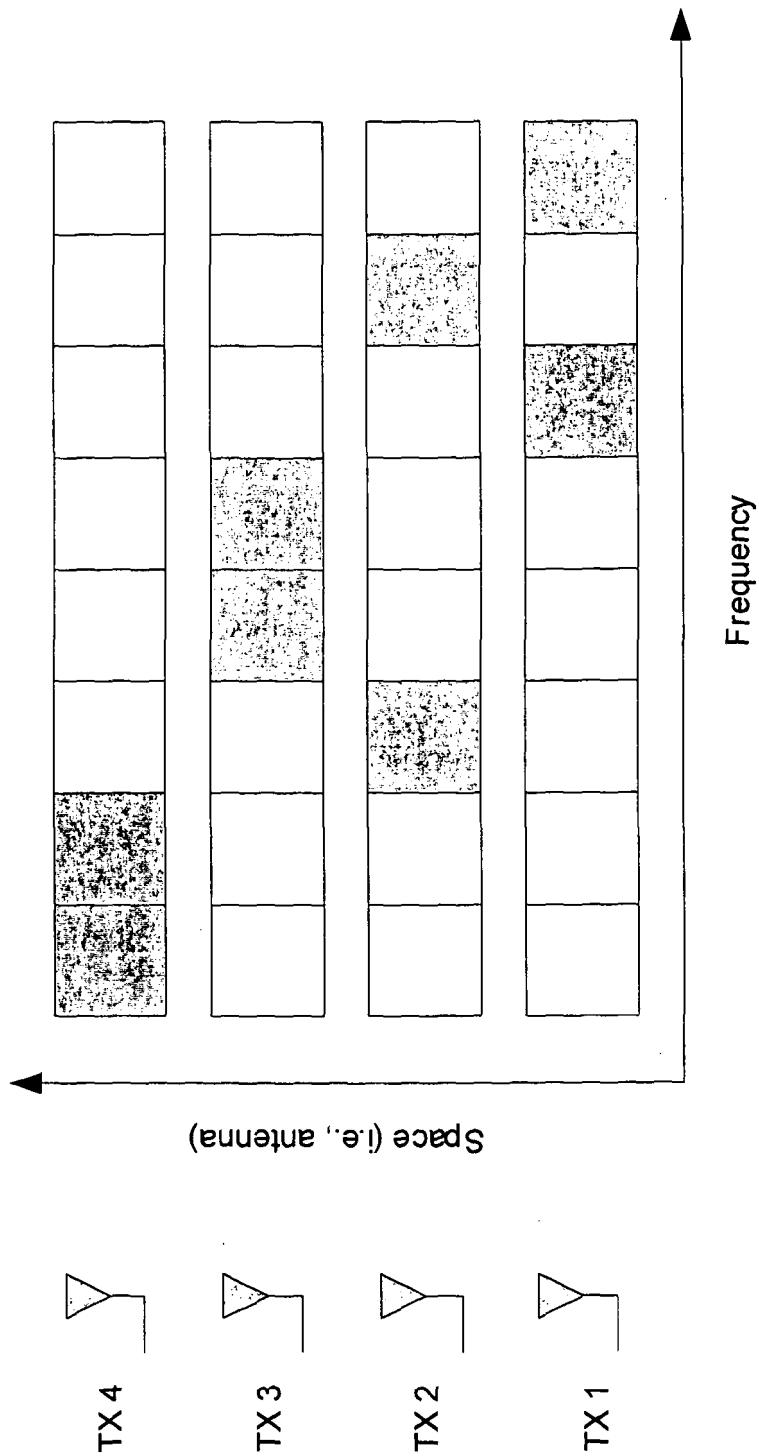
Figure 6

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Figure 1

Frequency

Space (i.e., antenna)

TX 4

TX 3

TX 2

TX 1

Figure 2

Figure 3

Figure 4

FROM RF
CHAINS

30

A/D

32

FFT

24

TO DATA
SOURCE/
SINK

Figure 5

```
                    ( Start )
                        |
                        v    ┌─ S1-0
                   ┌─────────┐
                   │  a = 1  │
                   └─────────┘
                        |
                        v                  ┌─ S1-1
          ┌─────────────────────────────┐
     ┌───>│ Determine received signal metrics │
     │    └─────────────────────────────┘
     │                  |
     │                  v                  ┌─ S1-2
     │    ┌─────────────────────────────┐
     │    │  Determine the linear regression │
     │    │          parameters         │
     │    └─────────────────────────────┘
     │                  |
     │                  v                  ┌─ S1-3
     │    ┌─────────────────────────────┐
     │    │   Generate a "linear fitting"    │
     │    └─────────────────────────────┘
     │                  |
  ┌─ S1-4a              v
 ┌─────────┐      ◇ Linear fitting      ◇  ┌─ S1-4
 │ a = a + 1│<────  generated for all
 └─────────┘    No   antennas?
                        |
                        v  Yes
                   ┌─────────┐  ┌─ S1-5
                   │  a = 1  │
                   └─────────┘
                        |
                        v                  ┌─ S1-6
          ┌─────────────────────────────┐
     ┌───>│    Determined the number of    │<───────┐
     │    │ subcarriers that can be supported │     │
     │    │     by transmit antenna, a     │       │
     │    └─────────────────────────────┘         │
     │                  |                          │
     │                  v          ┌─ S1-7         │
     │        ┌─────────────────┐                  │
     │        │  Rank the antennas  │              │
     │        └─────────────────┘                  │
     │                  |                          │
     │  ┌─ S1-8         v         ┌─ S1-9   Yes ┌─ S1-10
     │  ◇ Utilise all available ◇ ──> ┌───────┐ ──>  ◇ a ≤ A ◇
     │     antennas?        Yes   │ a = a + 1│
   ┌─ S1-12                       └───────┘         │ No
 ┌─────────┐        |                                v  ┌─ S1-13
 │ a = a + 1│       | No                   ┌──────────────────┐
 └─────────┘        v        ┌─ S1-11      │ Select transmit antennas │
     │  No   ◇ Have all the ◇ ──────────> │  and switch off unused RF  │
     └──────   subcarriers been   Yes     │        chains          │
              allocated?                   └──────────────────┘
                                                     |
                                                     v
                                                 ( End )
```
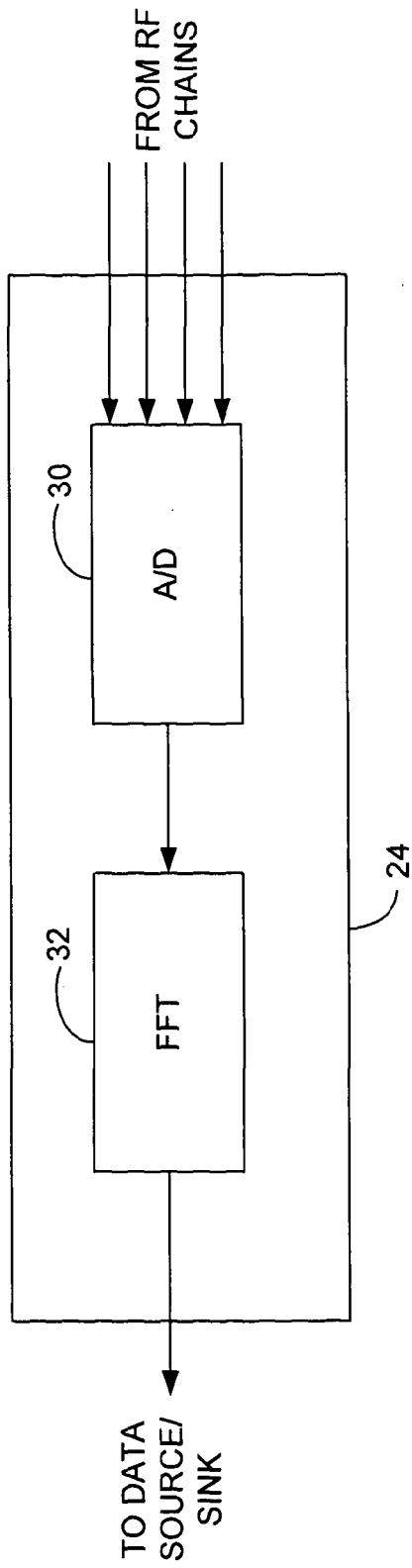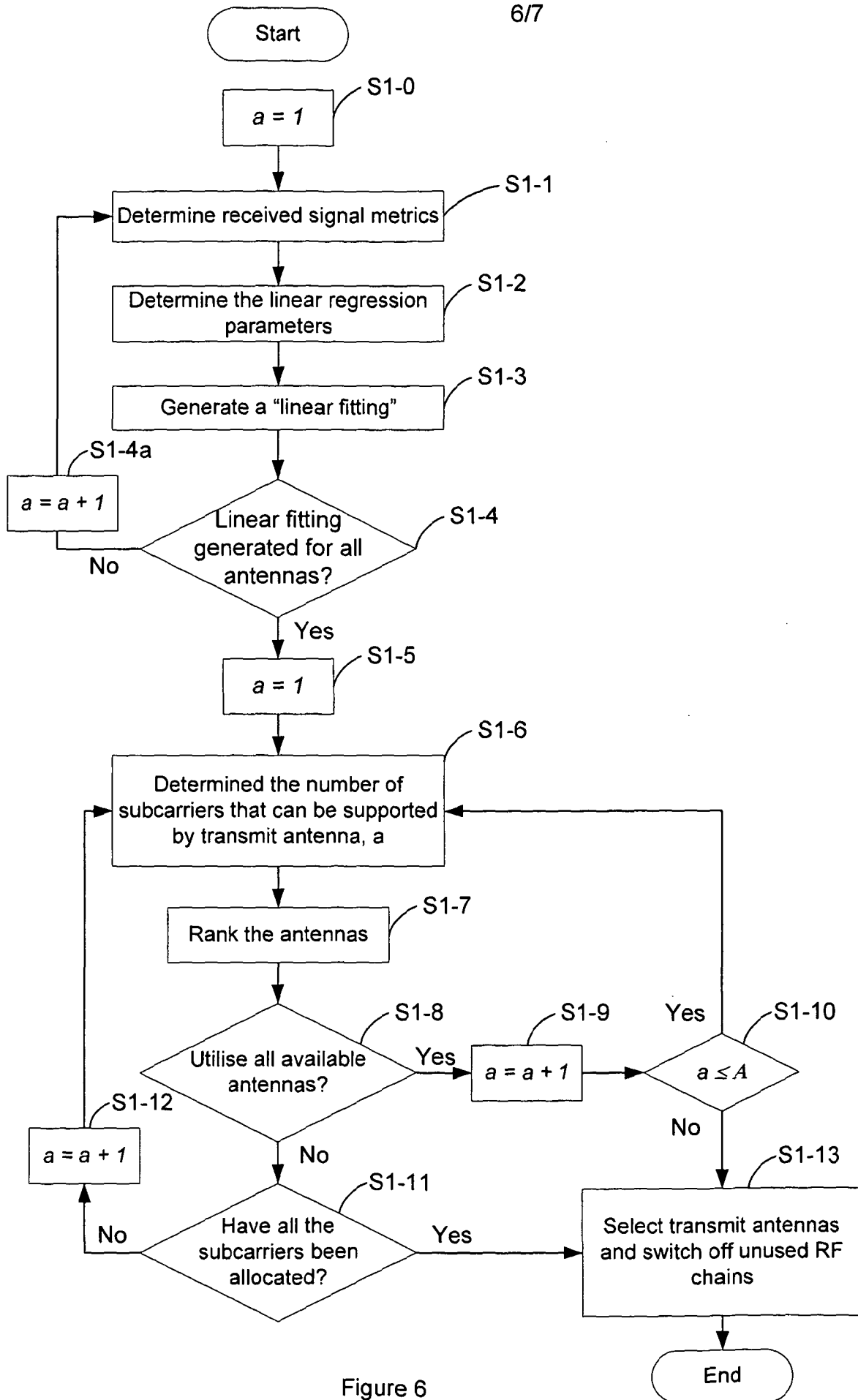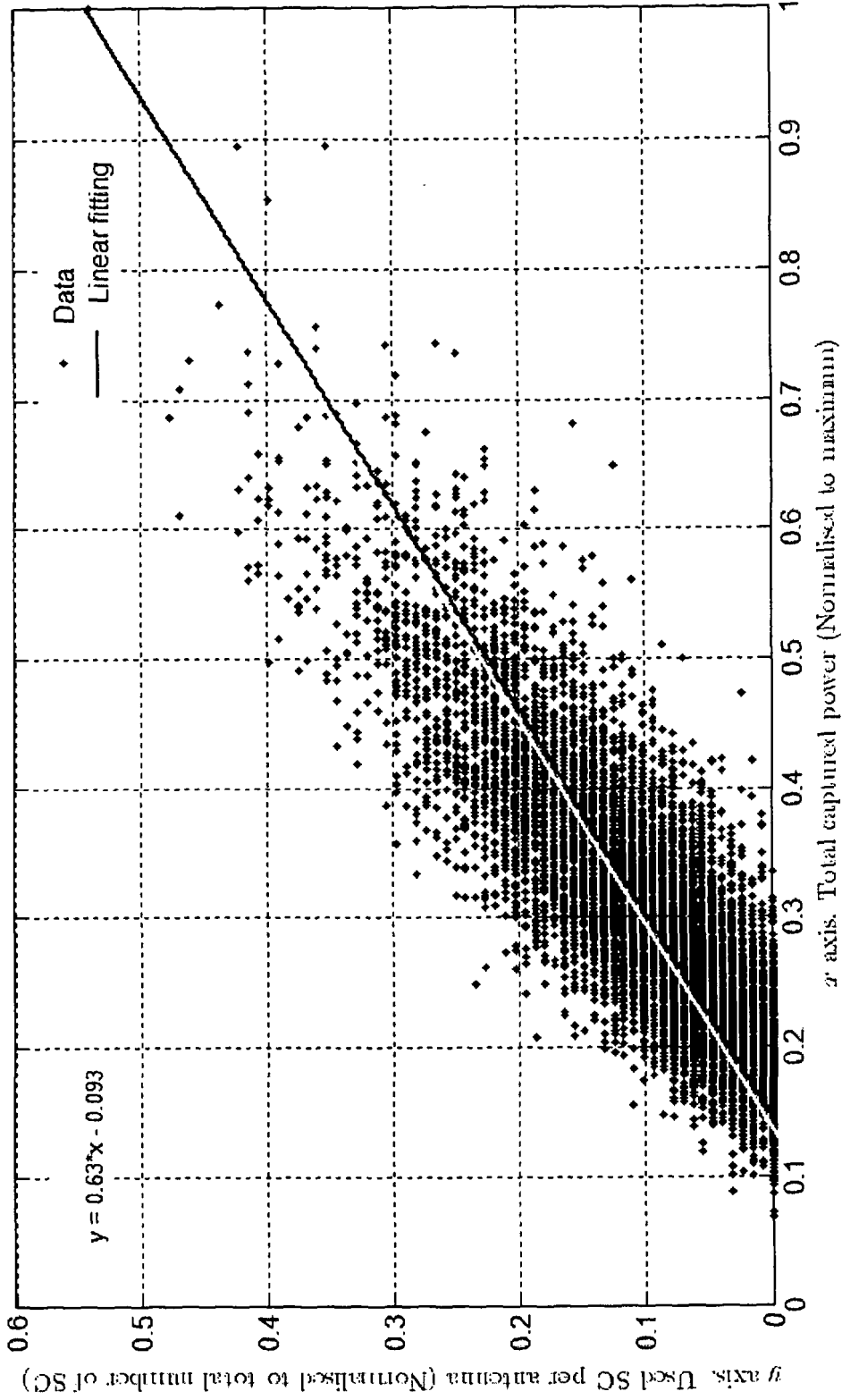
Figure 6

Figure 7

METHOD AND APPARATUS FOR ANTENNA SELECTION IN WIRELESS COMMUNICATIONS SYSTEMS

Field

5   Embodiments described herein relate generally to antenna selection in wireless communications systems transmitting frequency multiplexed signals.

Background

Antenna selection in orthogonal frequency division multiplexing (OFDM) systems is a

10   powerful technique for exploiting spatial diversity using multiple antennas at a transmitter and/or receiver. Typically, the selection of transmit antennas is performed after the received signals have been digitalised and transformed into a frequency domain using a fast Fourier transform (FFT) module. One of the disadvantages of using this approach is the latency of the process when the antenna selection is being

15   performed. Furthermore, analogue to digital (A/D) converters, decoding modules and RF chains in a transceiver are required to remain powered on at all times, which leads to unnecessary energy wastage.

Description of the drawings

20   Embodiments will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates the concept of bulk antenna selection;

25   Figure 2 illustrates the concept of per-tone antenna selection;.

Figure 3 illustrates the selection of transmit antennas based on a measured gain of each antenna in each of the subcarriers;

30   Figure 4 is a simplified schematic illustration of a transceiver device according to an embodiment;

Figure 5 is a schematic diagram of a receiver driver illustrated in Figure 4;

Figure 6 shows a flow diagram of an antenna selection procedure according to an embodiment; and

Figure 7 is a graph illustrating an example of a linear regression.

Detailed description

Specific embodiments will be described in further detail in the following paragraphs on the basis of the attached figures. It will be appreciated that this is by way of example only, and should not be viewed as presenting any limitation on the scope of protection sought.

Antenna selection method in OFDM can be considered to fall into two categories: (1) bulk selection, whereby one or more antennas out of a total available set are used for transmission and/or reception for all frequencies, and (2) per-subcarrier selection, which provides an additional degree of freedom that allows the antenna selection to differ across the utilised bandwidth. Both techniques have advantages and disadvantages. For example, bulk selection requires very little channel state information (CSI) feedback and exploits fewer radio frequency (RF) chains then per-subcarrier selection. However, per-subcarrier selection is capable of achieving much higher coding gains than bulk selection, i.e., the bit-error rate (BER) for per-subcarrier selection is significantly lower than for bulk selection.

These two techniques are illustrated for transmit antenna selection diagrammatically in Figure 1 and Figure 2. In Figures 1 and 2 each illustrated segment represents a subcarrier, with a row of contiguous segments/subcarriers indicating the subcarriers associated with the particular antenna shown next to it. The shading denotes spatial/spectral regions that are used for transmission on the associated antenna. Blank areas indicate sub carriers that are not used for transmission on the associated antenna.

In Figure 1 transmitters TX 3 and TX 4 both transmit on all frequencies. Thus, only two RF chains are required for this scenario. In contrast, Figure 2 shows all transmitters conveying information; however, only one transmitter is active on any given subcarrier. This is the so-called per-subcarrier antenna selection approach, which requires four RF

chains. Note that both these selection schemes can equally be performed at the receiver instead of the transmitter, or indeed at both the transmitter and the receiver. Per-subcarrier selection has been shown to perform exceptionally well. However, its implementation requires a large number of RF circuitry, which can draw a considerable
5   amount of system resources (e.g., power) and reduce battery life in portable devices.

In the most general case, antenna selection can be performed such that a single antenna is chosen for transmission out of M available antenna, or a subset of L antenna are chosen out of M available antenna. The former approach is herein
10   labelled "single-antenna selection", while the latter is termed "subset selection". Both approaches can be employed in bulk selection or per-subcarrier selection scenarios.

If channel information is available at a transmitter, one method of selecting the best antennas for transmission is by measuring the gain of each antenna and selecting the
15   antenna that provides the best gain at each subcarrier for data transmission. An example of this method is illustrated in Figure 3. The lower graph in Figure 3 illustrates the measured antenna gain at each of the antennas of a four-antenna transmitter over a group of subcarriers. The x-axis in that graph represents a group of subcarriers (20 to 50) in an OFDM symbol while the y-axis represents the measured antenna gain at
20   each of the antennas over the group of sucarriers. The circle in the graph denotes antennas that have been selected for transmission over the subcarriers. As illustrated in the upper graph in Figure 3, transmit antennas TX 2, TX 3, and TX 4 have been selected for transmission over subcarriers 21-29, 30-45, and 46-50 respectively. In this example, transmit antenna, TX 1, which experiences low gains over the subcarriers,
25   has not been selected for transmission.

According to one embodiment there is provided a wireless communication device comprising a plurality of antennas and operable to transmit data on a plurality of subcarriers from one or more of said plurality of antennas over a communication
30   channel, the device comprising a receiver configured to receive signals via each of said plurality of antennas, a processor configured to determine the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of received signal metrics associated with said received signals; and an antenna selector configured to select one or more of said plurality of antennas for
35   transmitting data on said plurality of subcarriers based on said determination.

The received signal metrics may include any one of the following:

- total received energy of said received signals;
- peak received power of said received signals; and
- root mean square (RMS) delay spread of said received signals.

The processor may be further configured to determine the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of a function defining a relationship between said received signal metrics and subcarriers that can be allocated to said one or more of said plurality of antennas.

The function may include a linear regression defining said relationship, and is expressible in the form:

$$y = \alpha + \beta x$$

where α is the intersection point and β is the slope factor.

The processor may be configured to determine the number of subcarriers that can be allocated to each of said plurality of antennas for data transmission

The processor may be further configured to arrange said plurality of antennas in descending order by the number of subcarriers that can be allocated to each of said plurality of antennas.

The antenna selector may be configured to select a set of antennas from said arranged antennas, such that the total number subcarriers allocated to said set of antennas is equal to or greater than said plurality of subcarriers.

In one embodiment, the wireless communication device may further comprise radio frequency (RF) modules connected to each of said plurality of antennas, and said processor is operable to switch off said RF modules corresponding to antennas other than said selected antennas.

According to another embodiment, there is provided a method of operating a wireless communication device comprising a plurality of antennas and operable to transmit data

on a plurality of subcarriers from one or more of said plurality of antennas over a communication channel, the method comprising receiving signals via each of said plurality of antennas, determining the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of received

5   signal metrics associated with said received signals, and selecting one or more of said plurality of antennas for transmitting data over said plurality of subcarriers based on said determination.

One embodiment provides a computer program product comprising computer

10   executable instructions which, when executed by a computer, cause the computer to perform a method as set out above. The computer program product may be embodied in a carrier medium, which may be a storage medium or a signal medium. A storage medium may include optical storage means, or magnetic storage means, or electronic storage means.

15

The described embodiments can be incorporated into a specific hardware device, a general purpose device configure by suitable software, or a combination of both. Aspects can be embodied in a software product, either as a complete software implementation, or as an add-on component for modification or enhancement of

20   existing software (such as a plug in). Such a software product could be embodied in a carrier medium, such as a storage medium (e.g. an optical disk or a mass storage memory such as a FLASH memory) or a signal medium (such as a download). Specific hardware devices suitable for the embodiment could include an application specific device such as an ASIC, an FPGA or a DSP, or other dedicated functional

25   hardware means. The reader will understand that none of the foregoing discussion of embodiment in software or hardware limits future implementation of the invention on yet to be discovered or defined means of execution.

Figure 4 illustrates a schematic transceiver device 20 comprising a transmitter driver 22

30   operable to receive data from data sink/source 26 for transmission on the antennas TX 1 to TX 4 via the respective RF chains 29a to 29d of the device 20. A receiver driver 24 receives and processes signals received on the same antennas, and provides data to the data source/sink 26 and channel state information to the transmitter driver 22. An array of switches 28 is provided to allow the antennas to be selected for both

35   transmitting and receiving. As shown in Figure 4, the RF chains 29a, 29b, 29c, and

29d are connected to the switches 28. An array of switches 30 is also provided between the RF chains and the transmitter and receiver drivers to enable the device to select the RF chains to be used for both transmitting and receiving.

5   Figure 5 shows a simplified illustration of the receiver driver 24 of the transceiver device 20. As shown in Figure 5, the receiver driver 24 includes an analogue to digital converter (A/D) module 30 and a fast Fourier transform (FFT) module 32. The A/D converter 30 transforms the received analogue signals into digital samples which are then converted into its frequency domain using the FFT module. Subsequently, further

10   modules (not shown) are used for post-processing of the decoded data as in any other OFDM system. The post-processed data are used to determine which of the antennas are to be used for data transmission. In such a configuration, the number of RF chains, A/D modules, and FFT modules need to be equivalent to the number of antennas.

15   It is noted that a number of advantages can be achieved if the antenna selection is performed in the time domain, i.e. before the received signals are converted into digital frequency domain. Hence, an embodiment described herein provides a method of performing antenna selection based on analogue signals in the time domain.

20   Figure 6 illustrates the process of selecting transmit antennas according to an embodiment. The transceiver device 20 performs antenna selection according to the following procedure:

Step S1-0:   Initialise the transmit antenna index, $a = 1$.

25

Step S1-1:   Determine received signal metrics from the received analogue signals. Examples of the received signal metrics include total received energy, peak received power, root mean square (RMS) delay spread and so on. In this example, the total received energy is used to determine the received signal metrics. Alternatively, a

30   number of received signal metrics can also be determined and combined to produce a combined received signal metrics.

A linear regression can be determined based on the received signal metrics, and is expressible in the form:

35

$$y = \alpha + \beta x \qquad\qquad (1)$$

where α and β are regression parameters and are known as the intersection point and the slope factor respectively.

Alternatively, a multiple linear regression can be determined based on a number received signal metrics, and is expressible in the form:

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m \qquad\qquad (2)$$

It will be appreciated by those skilled in the art that the multiple linear regression is a line fitting represented by an intersection point and m number of slope factors, where m is the number of received signal metrics. Essentially, the multiple linear regression provides extra dimension(s) for selecting the transmit antennas, taking into account of other factors such as noise and interference.

Accordingly, the regression parameters can be determined, in step S1-2, as follows:

$$\beta = \frac{\sum_{i=1}^{n} \left(x_1 - \overline{x} \right)\left(y_i - \overline{y} \right)}{\sum_{i=1}^{n} \left(x_i - \overline{x} \right)^2} \qquad\qquad (3)$$

$$a = \overline{y} - \beta \overline{x} \qquad\qquad (4)$$

where n is the total number of measurements, x_i is the measured parameter, y_i is the number of data subcarriers for the ith measurement, and $\overline{x}$ is the mean value of x.

Step S1-3:   Generate a "linear fitting" (or commonly referred to as a linear regression) which will be used for estimating the number of data subcarriers that a given antenna can support. An example of the linear regression is illustrated in Figure 7. The linear regression is generated using a least squares linear fit that minimises the square of the distance between every data point and a line that provides the best fit. Essentially, the overall solution minimises the sum of squared residuals, where the

residual is the difference between an observed value and the value provided by the model. As shown in Figure 7, the x-axis represents the normalised total received power, and the y-axis represents the number of subcarriers, normalised to the total number of subcarriers, that can be supported by each antenna. The linear regression can be generated prior to the device 20 being deployed. In such a case, the linear regression is generated based on statistics of previous received signals. Alternatively, the linear regression can be generated and updated continuously in "real-time", when the device is being deployed.

Step S1-4: Determine whether the linear regression has been generated for each of the antennas. If yes, perform step S1-5. Otherwise, perform step S1-4a and repeat steps S1-1 to S1-3.

Step S1-5: Reset the transmit antenna index, $a = 1$.

Step S1-6: Determine the number of subcarriers that can be supported by transmit antenna, a, using the respective linear regression generated in step S1-3. To do this, signals received by each of the transmit antennas are compared with the linear regression to determine the number of subcarriers that can be supported by the transmit antenna. By way of an example, consider a situation in which there are 128 subcarriers to be supported and 4 transmit antennas are provided. The transmit antennas, TX 1 to TX 4, may be capable of supporting the required subcarriers in the following manner:

TX 1: 25 subcarriers
TX 2: 35 subcarriers
TX 3: 70 subcarriers
TX4: 50 subcarriers

In this case, the transceiver will therefore select antennas TX 3, TX 4, and TX 2 for transmission, as these antennas are able to support data transmission for a total of 155 subcarriers.

Step S1-7: Rank the transmit antennas. In this example, the transmit antennas are ranked in descending order by the number of subcarriers supported by each of the

antennas. Following from the above example, the antennas can be ranked in the following order: TX 3, TX 4, TX 2 and TX 1. However, it will be appreciated that the transmit antennas can also be ranked in ascending order, and any other manner depending on the application.

Step S1-8: Alternatively, the transceiver can decide whether all the available antennas are to be utilised.

If yes, the following steps will be performed:

Step S1-9: $a = a + 1$

Step S1-10: Determine whether all the transmit antennas have been allocated, $a \leq A$, where A is the total number of available transmit antennas.

and repeat steps S1-6 to S1-7.

Otherwise, perform step S1-11 to determine whether all the subcarriers have been allocated.

Repeat steps S1-6 to S1-8 if there are more subcarriers to be allocated to the antennas. In this case, the transceiver will simply allocate the subcarriers to the transmit antennas until all the 128 subcarriers have been allocated. Following from the above example, although TX 4 is able to support 50 subcarriers, antennas TX 1, TX 2, and TX 3 will instead be selected for transmission as these antennas are able to support 130 subcarriers. Hence, the allocation of subcarriers (i.e. steps S1-6 to S1-8) will terminate at TX 3.

Step S-13: Select the antennas that have been allocated with subcarriers for transmission, and switch off the respective RF chains of the antennas that have not been allocated with any subcarriers. In another embodiment, instead of switching off the RF chains, the clock rate at which the unused RF chains operate can be reduced. In either case, the overall processing power of the transceiver can be reduced. It is further noted that the FFT modules and the A/D modules that are connected to the unused RF chains can also be powered off to further reduce power consumption.

Thus, the described embodiment provides the advantages of providing an early decision as to which antennas can be used for transmission and switching off unused RF chains, thereby reducing processing time and power.

5   It will be appreciated that the above described method can also be applied at a receiver to select antennas for reception.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the
10   inventions. Indeed, the novel devices, methods, and products described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the
15   scope and spirit of the inventions.

CLAIMS:

1.   A wireless communication device comprising a plurality of antennas and operable to transmit data on a plurality of subcarriers from one or more of said plurality of antennas over a communication channel, the device comprising

a receiver configured to receive signals via each of said plurality of antennas;

a processor configured to determine the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of received signal metrics associated with said received signals; and

an antenna selector configured to select one or more of said plurality of antennas for transmitting data on said plurality of subcarriers based on said determination.

2.   A device according to claim 1, wherein said received signal metrics include any one of the following:

total received energy of said received signals;

peak received power of said received signals; and

root mean square (RMS) delay spread of said received signals.

3.   A device according to claim 1 or claim 2, wherein said processor is further configured to perform said determination on the basis of a function defining a relationship between said received signal metrics and subcarriers that can be allocated to said one or more of said plurality of antennas;

4.   A device according to claim 3, wherein said function includes a linear regression defining said relationship, and is expressible in the form:

$$y = \alpha + \beta x$$

where α is the intersection point and β is the slope factor.

5. A device according any one of the preceding claims, wherein said processor is further configured to arrange said plurality of antennas in descending order by the number of subcarriers that can be allocated to each of said plurality of antennas.

6. A device according to claim 5, wherein said antenna selector is configured to select a set of antennas from said arranged antennas, such that the total number subcarriers allocated to said set of antennas is equal to or greater than said plurality of subcarriers.

7. A device according to claim 6, further comprising radio frequency (RF) modules connected to each of said plurality of antennas, and said processor being operable to switch off said RF modules corresponding to antennas other than said selected antennas.

8. A method of operating a wireless communication device comprising a plurality of antennas and operable to transmit data on a plurality of subcarriers from one or more of said plurality of antennas over a communication channel, the method comprising:

receiving signals via each of said plurality of antennas;

determining the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of received signal metrics associated with said received signals;

selecting one or more of said plurality of antennas for transmitting data on said plurality of subcarriers based on said determination.

9. A method according to claim 8, wherein said received signal metrics include any one of the following:

total received energy of said received signals;

peak received power of said received signals; and

root mean square (RMS) delay spread of said received signals.

10. A method according to claim 8 or claim 9, further comprising determining the number of subcarriers that can be allocated to one or more of said plurality of antennas for data transmission on the basis of a function defining a relationship

between said received signal metrics and subcarriers that can be allocated to said one or more of said plurality of antennas;

11. A method according to claim 10, wherein said function includes a linear regression defining said relationship, and is expressible in the form:

$$y = \alpha + \beta x$$

where α is the intersection point and β is the slope factor.

12. A method according to any one of claims 8 to 11, further comprising arranging said plurality of antennas in descending order by the number of subcarriers that can be allocated to each of said plurality of antennas.

13. A method according to claim 12, further comprising selecting a set of antennas from said arranged antennas, and wherein the total number subcarriers allocated to said set of antennas is equal to or greater than said plurality of subcarriers.

14. A method according to claim 13, wherein said wireless communication device further comprising radio frequency (RF) modules connected to each of said plurality of antennas, and the method further comprising switching off said RF modules corresponding to antennas other than said selected antennas.

15. A computer program product comprising computer executable instructions operable to configure a general purpose programmable communications device to perform a method according to any one of claims 8 to 14.

INTELLECTUAL
PROPERTY OFFICE
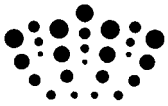
| Application No: | GB1108776.4 | | **Examiner:** | Dr John Cullen |
| Claims searched: | 1-15 | | **Date of search:** | 24 August 2011 |

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	---	WO2006/093468 A1 (MATSUSHITA)
A	---	JP2004343562 A (SHARP)
A	---	GB2475307 A (TOSHIBA)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

H04B; H04L

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, TXTE, INSPEC, XPI3E, XPIEE, XPESP

International Classification:

Subclass	Subgroup	Valid From
H04B	0007/06	01/01/2006
H04L	0005/00	01/01/2006