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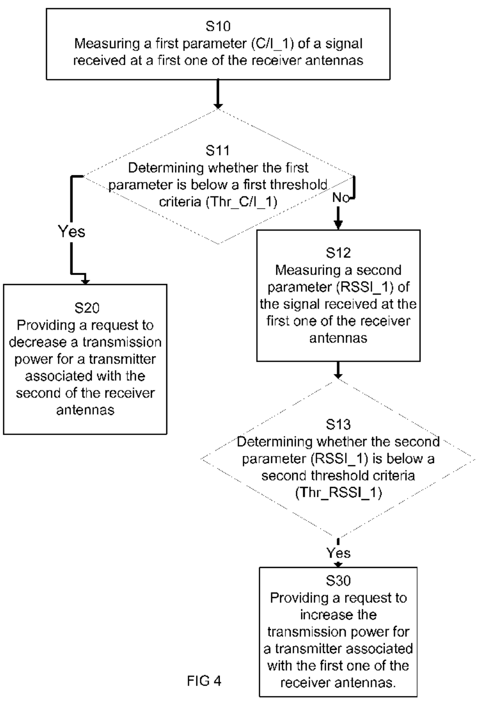


FIG 4

(57) **Abstract:** Methods and arrangements for adaptive power control are provided. A MIMO system, comprises at least two spatial receiver antennas (21-1, 21-2,.., 21-M) and at least two spatial transmitter antennas (11-1, 11-2,.., 11-N). A processor units determines whether first signal quality parameter associated with a first receiver antenna is below a first threshold criteria (Thr_C/I_l); and in response to it measures a second parameter or attempts to decrease a transmission power of a transmitter associated with a second receiver antenna. The processor unit may also increase the transmission power of the transmitter associated with the first receiver.

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# Improved adaptive transmit power control for Line of Sight MIMO system

## TECHNICAL FIELD

The present disclosure relates to the field of Multiple-Input Multiple-Output, MIMO, wireless communication. More particularly, the claimed subject matter pertains to transmit power control.

## BACKGROUND

In radio communication, Multiple-Input Multiple-Output, MIMO, is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to e.g. exploit multipath propagation or provide for line of sight communication. MIMO has become an essential element of wireless communication standards including IEEE 802.11n, IEEE 802.11ac, HSPA+, WiMAX, and Long Term Evolution and Long Term Evolution Advanced and recently 5G.

LoS-MIMO, Line-of-Sight Multi-input Multi-output, technology offers the possibility to significantly increase the transmission throughput of e.g. point-to-point microwave radio links for next generation wireless backhaul networks. This type of MIMO system employs fmultiple transmitter antennas and multiple receiver antennas in line-of-sight conditions, where all highly directive transmitter antennas operate at the same carrier frequency.

A well-conditioned MIMO channel relies on diversity of phase shifts provided by proper spatial separation of antennas. In general, optimal antenna separation increases with increasing hop length and decreasing carrier frequency. In practice, the antennas are often separated by at least a number of meters, even several tens of meters. Due to the spatial separation different antennas in the system may experience different environmental conditions that affect transmission and reception properties. For example, a couple of antennas might be exposed to heavy rain whereas other antennas comprised in the same system are positioned where they are somewhat protected from rainfall.

Hence, there is a need to enhance the robustness of the LoS MIMO receiver against channel variations induced by atmospheric impacts and other sources, thereby to improve the availability and optimize and guarantee the throughput of LoS MIMO systems.

SUMMARY

In the present disclosure methods, non-transitory computer readable media, receiver, transmitter, arrangement and an adaptive power control is presented, which provides a robust LoS MIMO communication in order to maintain a high throughput and keep the communication up and running even if the environmental circumstances are altered.

This object is obtained by a method in a receiver arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas. The method comprises the steps of:

- Measuring a first parameter of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- Determining whether the first parameter is below a first threshold criteria;
- In response to determining that the first parameter is below the first threshold criteria:
  - Providing a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- In response to determining that the first parameter is not below the first threshold criteria:
  - Measuring a second parameter of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
  - Determining whether the second parameter is below a second threshold criteria;
  - In response to determining that the second parameter is below the second threshold criteria;
    - Providing a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

The present invention provides an improvement of the MIMO performance in a time-varying environment. To do so one step is to provide an adequate level of the first parameter in all MIMO links to keep them up and functional. In the next step one can regulate a second signal quality parameter to guarantee a desired level of throughput.

The method in accordance with the present disclosure proposes a power control mechanism to reduce the difference in signal quality parameter between the MIMO sub-channels, and thereby improve the robustness of the MIMO receiver. The improvement particular of the C/I ratio and/or other signal quality parameters of the MIMO system can achieve higher throughput even in varying environment conditions.

In an aspect providing a request to increase the transmission power of a transmitter associated with the first one of the at least two spatial receiver antennas comprises the steps of

- Determining whether the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas is below a third threshold criteria and in response to determining that the transmission power is below the third threshold criteria:
  - Sending a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

Hence, the power can be increased if the power of the respective transmitter is not yet at maximum, thereby improving the RSSI.

In another aspect, providing a request to decrease the transmission power for the transmitter associated with the second of the at least two spatial receiver antennas comprises the step of

- Determining whether the transmission power for the transmitter is below the third threshold criteria; and
- In response to determining that the transmission power is not below the third threshold criteria:
  - Providing a request to decrease transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas; and
- In response to determining that the transmission power is below the third threshold criteria :
  - Sending a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

It has been found, that the overall performance of the MIMO system can still be maintained, even if the transmission power of the transmitter is at maximum. In such case, the power of the transmitter associated with the second of the at least two spatial receiver antennas may be decreased, thus reducing the interference portion of a C/I ratio in the first receiver. Hence, by increasing the transmission power or decreasing the transmission power for the other transmitter, the overall C/I ratio can be improved.

In another aspect, the method further comprises to determine whether decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas. If a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas, then a request is provided to set a fourth threshold criteria associated with the second of the at least two spatial receiver antennas to a lower threshold value which matches the current feasible throughput. This enables the receiver of the MIMO system to determine if a decrease in the transmission power of the transmitter associated with the second receiver deteriorates the throughput. Proper measures can then be taken to save power and avoid introducing unnecessary interference, hence improving the overall performance of the MIMO system.

Yet another aspect relates to the second parameter measured in accordance with the proposed method. In response to determining that the second parameter is not below the second threshold criteria, it is determined whether the second parameter is below a predetermined higher value of the second threshold criteria. In response to determining that the second parameter is below a predetermined higher value of the second threshold criteria, a request is provided to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

In some instances the method further comprises in response to determining that the second parameter is not below a predetermined higher value of the second threshold criteria:

- Setting the second threshold criteria to the next predetermined higher value; and
- In response to setting the second threshold criteria to the next predetermined higher value:
  - based upon a counter associated with a fourth threshold criteria of said second one of the at least two receivers being above a predetermined value, setting the fourth threshold

criteria to the next lower predetermined value and decrementing a counter associated with the second threshold criteria of said second one of the at least two receivers by one; or

- based upon the counter associated with the fourth threshold criteria being below a predetermined value, setting the fourth threshold criteria to the next higher predetermined value and incrementing a counter associated with the fourth threshold criteria.

This aspect allows taking previous executions of the proposed method into account to reflect previous changes of the respective threshold levels. Hence, the method can “reset” previous changes of threshold levels when the environment for the receiver changes.

In yet another aspect, it may be determined that the transmission power is not below the third threshold criteria. In response to such determination, it may be determined whether a data throughput is below a predetermined level and in response to determining that the data throughput is below a predetermined level:

- Setting the second threshold criteria for the first one of the at least two spatial receiver antennas to a next lower threshold value which matches the current feasible throughput and
- Decrementing a counter associated with the second threshold criteria for the first one of the at least two spatial receiver antennas by one.

The object is also obtained by a method in a transmitter arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial transmitter antennas. Said method comprises:

- Determining whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria;
- in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria:
  - Increasing the transmission power level for the first transmitter antenna.

In an aspect, a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas may be received; and

- in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is not below the third threshold criteria:
  - providing a request to decrease transmission power of the second transmitter.

The proposed method allows in a transmitter arrangement of a MIMO system to increase or decrease the transmission power associated with a transmitter. This may improve likewise the C/I ratio and other signal quality parameters of the MIMO system thus achieving higher throughput even in varying environment conditions.

In another aspect of the proposed method, providing a request to decrease transmission power for the second transmitter comprises:

- Determining whether the MIMO system can provide a higher data throughput compared to a MIMO system of a lower order including a feasible SISO system; and
- in response to determining that the MIMO system can provide a higher data throughput decreasing the transmission power for the second transmitter.

In case it is determined that the MIMO system cannot provide a higher data throughput compared to a feasible MIMO system of a lower order, a request is provided to switch from the current MIMO system to a MIMO system of a lower order. In this regard , it is understood that a MIMO system is of the order N if it comprises N transmitters and N receivers., in short “N x N”. A MIMO system of one order lower has N-1 transmitters and N or N-1 receivers represented by “N-1 x N-1” or “N-1 x N”. Generally a MIMO system of a lower order has N-x transmitters and between N-x and N receivers. A 1 x 1 system is also called Single Input, Single Output, SISO system.

This will achieve certain flexibility, because MIMO functionality will only be kept if a respective throughput can be maintained. Otherwise, the method may cause to switch the transmitter to an appropriate MIMO or SISO system or take other appropriate measures.

In another aspect, determining that a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria comprises receiving a request to increase the transmission power level for the first transmitter antenna.

The object is also obtained by a method for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas, said method comprising:

- Measuring a first parameter of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- Determining whether the first parameter is below a first threshold criteria;
- In response to determining that the first parameter is not below the first threshold criteria:
  - o Measuring a second parameter of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
  - o Determining whether the second parameter is below a second threshold criteria;
- In response to determining that the second parameter is below the second threshold criteria or in response to determining that the first parameter is below the first threshold criteria:
  - o Determining whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria;
  - o In response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria:
    - ▪ Increasing the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

The proposed method for adaptive power control of a MIMO system enables a higher flexibility in maintaining the desired throughput. The transmission power of the respective transmitters is increased or decreased based on the measurement of certain signal quality parameter. This may improve likewise the C/I ratio and other signal quality parameters of the MIMO system thus achieving higher throughput even in varying environment conditions.

In an aspect, the method comprise in response to determining that the first parameter is below the first threshold and that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria:

- Providing a request to decrease transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

In another aspect providing a request to decrease transmission power may comprise to determine whether the MIMO system can provide a higher data throughput compared to a to a MIMO system of lower order including a feasible SISO system; and in response to determining that the MIMO system is able to provide a higher data throughput, the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas is decreased.

The overall performance of the MIMO system can still be maintained, even if the transmission power of the transmitter is at maximum. In such case, the power of the transmitter associated with the second of the at least two spatial receiver antennas may be decreased, thus reducing the interference portion of the measured C/I ratio in the first receiver. Hence by increasing the transmission power or decreasing the transmission power for the other transmitter, the overall C/I ratio can be improved.

If however it is determined that the MIMO system cannot provide a higher data throughput, the adaptive power control causes switching from MIMO system to a MIMO system of a lower order including a single input, single output, SISO system.

Thus flexibility even under various environmental conditions is maintained. The method will attempt to maintain MIMO functionality depending on the maximum available data throughput, but has also the option to switch to a MIMO system of lower order if appropriate. In another aspect in response to determining that the MIMO system can provide a higher data throughput, it is determined whether a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver antennas. In response to determining that a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver, a fourth threshold of the second one of the at least two spatial receivers is set to a lower value which matches the current throughput.

This takes into account that different transmitters can cause co-channel interferences effects in different receivers of the MIMO system. Changing threshold values balance the different measurement parameters like C/I and RSSI against each other to achieve a stable high data throughput.

Another aspect is related to the second parameter. For instance, in response to determining that the second parameter is below the second threshold criteria and in response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria, it can be determined whether a data throughput is below a predetermined level. In response to determining that the data throughput is below a predetermined level, the second threshold criteria for the first one of the at least two spatial receiver antennas is set to a lower threshold value which matches the current throughput.

In yet another aspect, the method in response to determining that the data throughput is below a predetermined level further comprises:

- Determining whether a fifth parameter associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria; and
- In response to determining that the fifth parameter is below the maximal value of the fourth threshold:
  - Determining whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value; and in response that the power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below the sixth threshold value:
    - Setting the fourth threshold criteria to the next higher value.

The aspect provides an attempt to set the MIMO system and their respective parameters and thresholds to a state, in which the undesired low data throughput can be corrected. This is done in accordance with the present proposal by determining whether the transmission power of the transmitter associated with the second of the at least two receivers can be reduced, enabling some headroom for an improvement of the first parameter.

In some aspects and in response to determining that the second parameter is not below the second threshold criteria, the method comprises:

- o Determining whether the second parameter is below a predetermined higher value of the second threshold criteria; and
- o In response to determining that the second parameter is below a predetermined higher value of the second threshold criteria;
- ▪ Decreasing the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

Decreasing the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas may be suitable, if enough head room for such decrease is determined. Decreasing the transmission power of one transmitter may improve the first parameter of all receivers not associated with said transmitter and save power.

In another aspect, in response to determining that the second parameter is not below a predetermined higher value of the second threshold criteria, the method comprises:

- o Setting the second threshold criteria to the next predetermined higher value; and
- o In response to setting the second threshold criteria to the next predetermined higher value:
- ▪ based upon a counter associated with a fourth threshold criteria of said second one of the at least two receivers being above a predetermined value, setting the fourth threshold criteria to the next lower predetermined value and decrementing a counter associated with the second threshold criteria of said second one of the at least two receivers by one; or
- ▪ based upon the counter associated with the fourth threshold criteria being below a predetermined value, setting the fourth threshold criteria to the next higher predetermined value and incrementing a counter associated with the fourth threshold criteria.

The object is also obtained by a receiver arrangement in a Multiple Input Multiple Output, MIMO system, comprising at least the following:

- at least two spatial receiver antennas;
- a measurement unit coupled to the at least two spatial receiver antennas and configured to measure at least a first parameter and a second parameter different from the first

parameter at the respective ones of the at least to two spatial receiver antennas, said parameters characterizing a signal quality;

- a processor unit coupled to the measurement unit and configured to:
- determine whether the first parameter is below a first threshold criteria;
- in response to determine that the first parameter is below the first threshold criteria:
  - to provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas;
- in response to determine that the first parameter is not below the first threshold criteria:
- to determine whether the second parameter is below a second threshold criteria;
- in response to determine that the second parameter is below the second threshold criteria:
- to provide a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

The receiver arrangement comprises a form of a power control mechanism to reduce the C/I difference between the MIMO sub-channels, and thereby improve the robustness of the MIMO receiver. The improvement of the C/I ratio and/or other signal quality parameters of the MIMO system can achieve higher throughput even in varying environment conditions.

In some aspects, providing the request to increase the transmission power of a transmitter associated with the first one of the at least two spatial receiver antennas can comprise:

- to determine whether the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas is below a third threshold criteria and in response to determining that the transmission power is below the third threshold criteria:
- to send a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

In a further aspect, to provide a request to decrease the transmission power for the transmitter associated with the second of the at least two spatial receiver antennas can comprises to determine whether the transmission power for the transmitter is below the third threshold criteria. In response to determine that the transmission power is not below the third threshold criteria a request to decrease transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas is provided. In response to determine that the transmission power is below the third threshold criteria, a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas is send.

Hence, the power can be increased if the power of the respective transmitter is not yet at maximum, thereby improving the first parameter associated with the signal quality, and particular the C/I ratio. It has been found, that the overall performance of the MIMO system can still be maintained, even if the transmission power of a transmitter is not at maximum. In such case, the power of the transmitter associated with the second of the at least two spatial receiver antennas may be decreased, thus reducing the interference portion of the measured C/I ratio in the first receiver. Hence by increasing the transmission power or decreasing the transmission power for the other transmitter, the overall performance of the MIMO system can be maintained or even improved.

In another aspect, the processor unit is further configured to:

- determine whether a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas; and
- in response to determine that a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas to:
  - provide a request to set a fourth threshold criteria associated with the second of the at least two spatial receiver antennas to a lower threshold value which matches the current feasible throughput.

This enables the receiver of the MIMO system to determine if a decrease in the transmission power of the transmitter associated with the second receiver deteriorates the throughput. Proper measures can then be taken to save power and avoid introducing unnecessary interference and hence improve the overall perrformance.

Another aspect relates to in response to determine that the second parameter is not below the second threshold criteria. In such case, processor unit is configured to determine whether the second parameter is below a predetermined higher value of the second threshold criteria. In response to determine that the second parameter is below a predetermined higher value of the second threshold criteria, the processor unit is configured to provide a request to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

In yet another aspect wherein it is determined that the second parameter is not below a predetermined higher value of the second threshold criteria, the processor unit is configured to set the second threshold criteria to the next predetermined higher value. In response to the setting of the second threshold criteria to the next predetermined higher value, the processor unit can be configured to, based upon a counter associated with a fourth threshold criteria of said second one of the at least two receivers being above a predetermined value, set the fourth threshold criteria to the next lower predetermined value and to decrement a counter associated with the second threshold criteria of said second one of the at least two receivers by one; or based upon the counter associated with the fourth threshold criteria being below a predetermined value, to set the fourth threshold criteria to the next higher predetermined value and to increment a counter associated with the fourth threshold criteria.

This aspect allows taking previous executions into account to reflect previous changes of the respective threshold levels. Hence, the arrangement can “reset” previous changes of threshold levels when the environment for the receiver changes.

In an aspect, the processor unit may be configured to in response to determine that the transmission power is not below the third threshold criteria:

- determine whether a data throughput is below a predetermined level and in response to determine that the data throughput is below a predetermined level to:
  - set the second threshold criteria for the first one of the at least two spatial receiver antennas to a next lower threshold value which matches the current feasible throughput; and
  - decrement a counter associated with the second threshold criteria for the first one of the at least two spatial receiver antennas by one.

The object is also obtained by a transmitter arrangement in a multiple input-multiple output, MIMO system, comprising at least the following:

- at least two spatial transmitter antennas each associated with a respective one of at least two spatial receiver antennas;
- a processor unit configured to:
  - determine, in response to a received request to increase transmission power for the first transmitter, whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria;
  - in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria:
    - increase the transmission power level for the first transmitter antenna.

In an aspect wherein the processor unit is further configured to

- receive a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- in response to determine that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is not below the third threshold criteria, to:
  - provide a request to decrease transmission power of the second transmitter.

The proposed method allows in a transmitter arrangement of a MIMO system to increase or decrease the transmission power associated with a transmitter. This may improve likewise the C/I ratio and other signal quality parameters of the MIMO system thus achieving higher throughput even in varying environment conditions.

In another aspect the processor unit is further configured to determine whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of lower order; and in response to determine that the MIMO system can provide a higher data throughput to decrease the transmission power for the second transmitter. This is particularly suitable in response to a request to decrease transmission power for the second transmitter.

In another aspect, it may not always be possible to provide a higher data throughput compared to a feasible MIMO system of lower order. In response to determine that the MIMO system cannot provide a higher data throughput compared to a feasible MIMO system of lower order, the processor unit may be configured to provide a request to switch the current N x N MIMO system to a MIMO system of a lower order, like for instance N-1 x N-1 system or an N-1 x N system. Such system can be a single input, single output, SISO system.

In another aspect, the processor unit may determine that a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria. The processor unit may be configured to receive a request to increase the transmission power level for the first transmitter antenna.

The object is further obtained by an arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system. Said MIMO system comprises at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas are associated with a respective one of the at least two receiver antennas. The arrangement now comprises:

- a measurement unit coupled to the at least two spatial receiver antennas and configured to measure at least a first parameter and a second parameter different from the first parameter at the respective ones of the at least to two spatial receiver antennas , said parameters characterizing a signal quality;
- a processor unit coupled to the measurement unit and configured to:
  - determine whether the first parameter meets a first threshold criteria;
  - in response to determining that the first parameter is not below the first threshold criteria to:
    - determine whether the second parameter is below a second threshold criteria;
  - in response to determine that the second parameter is below the second threshold criteria or in response to determine that the first parameter is below the first threshold criteria to:
    - determine whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria;

- in response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria to:
  - increase the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

The arrangement for adaptive power control of a MIMO system enables a higher flexibility in maintaining the desired throughput. The transmission power of the respective transmitters is increased or decreased based on the measurement of certain signal quality parameter. This may improve likewise the C/I ratio and other signal quality parameters of the MIMO system thus achieving higher throughput even in varying environment conditions.

In an aspect, wherein in response to determine that the first parameter (C/I_1) is below the first threshold and that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria, the arrangement may be configured to provide a request to decrease transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

Such a request to decrease transmission power may comprises determine whether the MIMO system can provide a higher data throughput compared to MIMO system of lower order or a feasible SISO system; and in response to determine that the MIMO system can provide a higher data throughput decrease the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

The overall performance of the MIMO system can still be maintained, even if the transmission power of the transmitter is at maximum. In such case, the power of the transmitter associated with the second of the at least two spatial receiver antennas may be decreased, thus reducing the interference portion of a C/I ratio in the first receiver. Hence, by increasing the transmission power or decreasing the transmission power for the other transmitter, the overall performance of the MIMO system can be maintained or even improved.

If however it is determined that the MIMO system cannot provide a higher data throughput, the adaptive power control causes switching from MIMO system to another MIMO system of a lower order. It may also switch to a single input, single output, SISO system.

Thus flexibility even under various environmental conditions is maintained. The method will attempt to maintain MIMO functionality depending on the maximum available data throughput, but has also the option to switch to SISO if appropriate. In another aspect in response to determining that the MIMO system can provide a higher data throughput, it is determined whether a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver antennas. In response to determining that a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver, a fourth threshold of the second one of the at least two spatial receivers is set to a lower value which matches the current throughput.

This takes into account that different transmitters can cause interferences effects in different receivers of the MIMO system. Changing threshold values balance the different measurement parameters like C/I and RSSI against each other to achieve a stable high data throughput

In another aspect, the processor unit is configured in response to determine that the second parameter is below the second threshold criteria and in response to determine that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria to:

- o determine whether a data throughput is below a predetermined level and in response to determine that the data throughput is below a predetermined level to:
- ▪ set the second threshold criteria for the first one of the at least two spatial receiver antennas to a lower threshold value which matches the current throughput.

In some aspects the processor unit may determine that the data throughput is below a predetermined level further. The processor unit may be configured to:

- determine whether a fifth parameter associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria; and
- in response to determine that the fifth parameter is below the maximal value of the fourth threshold to:

- determine whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value; and in response that the power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below the sixth threshold value to:
  - set the fourth threshold criteria to the next higher value.

On the other hand the processor unit may determine in some aspects that the second parameter is not below the second threshold criteria. The processor unit may be configured to:

- determine whether the second parameter is below a predetermined higher value of the second threshold criteria; and
- in response to determine that the second parameter is below a predetermined higher value of the second threshold criteria;
  - to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

Some other aspects relate to the second parameter. In an aspect, the processor unit configured to determine that the second parameter is not below a predetermined higher value of the second threshold criteria, may further be configured to:

- set the second threshold criteria to the next predetermined higher value; and
- in response to the setting of the second threshold criteria to the next predetermined higher value:
  - based upon a counter associated with a fourth threshold criteria of said second one of the at least two receivers being above a predetermined value, to set the fourth threshold criteria to the next lower predetermined value and to decrement a counter associated with the second threshold criteria of said second one of the at least two receivers by one; or
  - based upon the counter associated with the fourth threshold criteria being below a predetermined value, to set the fourth threshold criteria to the next higher predetermined value and to increment a counter associated with the fourth threshold criteria.

These and other aspects provide a possibility to set the MIMO system and their respective parameters and thresholds to a state, in which the undesired low data throughput can be corrected. This is done in accordance with the present proposal by determining whether the transmission power of the transmitter associated with the second of the at least two receivers can be reduced, enabling some headroom for an improvement of the first parameter.

Many different aspects and features disclosed above with respect to the arrangements can also be applied to the following receiver, transmitter arrangement and the adaptive power control.

The object is further obtained by a receiver arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas, said arrangement comprising:

- A first measurement module arranged to measure a first parameter of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- A first decision module arranged to determine whether the first parameter is below a first threshold criteria;
- In response to determining that the first parameter is below the first threshold criteria:
  - A first provider module arranged to provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- In response to determining that the first parameter is not below the first threshold criteria:
  - A second measurement module arranged to measure a second parameter of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
  - A second decision module arranged to determine whether the second parameter is below a second threshold criteria;
  - In response to determining that the second parameter is below the second threshold criteria:
    - A second provider module configured to provide a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

The object is further obtained by a transmitter arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system comprising at least two spatial transmitter antennas comprising:

- A decision module configured to determine  whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria;
- in response to determine that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria:
    - A regulator module configured to increasing the transmission power level for the first transmitter antenna.

Finally, the object is obtained by an adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas, said method comprising:

- A first measuring module configured to measure a first parameter of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- A first decision module configured to determine whether the first parameter meets a first threshold criteria;
- In response to determine that the first parameter is not below the first threshold criteria:
    - A second measuring module configured to measure a second parameter of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
    - A second decision module configured to determine whether the second parameter is below a second threshold criteria;
- In response to determine that the second parameter is below the second threshold criteria or in response to determine that the first parameter is below the first threshold criteria:
    - A third decision module configured to determine whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria;

- In response to determine that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria:
  - A regulator module configured to increase the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

In an aspect of the above methods, transmitters, receivers and arrangements, the first parameter may comprise a carrier to interference ratio and the second parameter may comprise RSSI value. It has been found that these two parameters provide sufficient information to achieve an improvement in the overall performance of a MIMO system through the adaptive transmit power control ATPC .

In another aspect, a counter for each of the respective threshold criteria and/or other parameters may be provided. These counters may reflect and count any changes of the criteria or parameters they are associated with. For instance in the above arrangement, a processor unit may be configured to comprise a counter for each of the respective first and second threshold criteria and incrementing upon a change in the first and second threshold criteria to a higher value and decrementing upon a change in the first and second threshold criteria to a lower value. Further counters associated with the threshold values or any parameter which can be set can be implemented in the arrangement.

All of the above methods can be stored as executable programs on a non-transitory computer readable medium. For instance, a non-transitory computer readable medium may store a program causing a receiver arrangement to execute the methods in the receiver arrangement, in the transmitter arrangement, for the adaptive power control or any combination thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular description of the example embodiments, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the example embodiments.

Figure 1 shows an example of LoS MIMO system with precoding and interference cancellation.

Figure 2 is a schematic overview of an N*M MIMO system.

Figure 3A to 3B illustrate the effect of wet snow on C/I and phase error.

Figure 4 discloses a method in a receiver arrangement according to some aspects.

Figure 5 shows a method in a receiver arrangement according to some further aspects.

Figure 6 illustrates a method a receiver arrangement according to some aspects.

Figure 7 shows some further aspects of a method in a receiver arrangement.

Figure 8 illustrates some further aspects of a method in a receiver arrangement.

Figure 9 shows a method in a receiver arrangement according to some other aspects.

Figure 10 discloses a method in a transmitter arrangement according to some other aspects.

Figure 11 illustrates some further aspects of a method in a transmitter arrangement.

Figure 12 discloses some aspects for adaptive power control of a MIMO system.

Figure 13 illustrate aspects for adaptive power control of the MIMO system.

Figure 14 show aspects of the method for adaptive power control of the MIMO system.

Figure 15 illustrates some further aspects of the method for adaptive power control.

Figure 16 show further aspects of the method for adaptive power control.

Figure 17 disclose some aspects of a receiver arrangement.

Figure 18A to 18C show some aspects to illustrate C/I effect in a MIMO system.

Figure 19 illustrate some aspects of a relationship between received power and data throughput.

Figure 20 illustrate an example of the power adaptive control method and functionality according to some aspects.

Figure 21 shows further aspects of the power adaptive control as of Figure 20.

Figure 22 discloses some aspects of non-transitory computer readable medium.

Figure 23 discloses a receiver arrangement in a MIMO system according to some aspects.

Figure 24 discloses a transmitter arrangement in a MIMO system according to some aspects.

Figure 25 discloses a MIMO system and adaptive power control functionality according to some aspects.

Figure 26 discloses a receiver arrangement in a MIMO system according to some other aspects.

Figure 27 discloses a transmitter arrangement in a MIMO system according to some other aspects.

Figure 28 discloses a MIMO system and adaptive power control functionality according to some further aspects.

DETAILED DESCRIPTION

Aspects of the present disclosure will be described more fully hereinafter with reference to the accompanying drawings. The methods, non-transitory computer readable medium and apparatus disclosed herein can, however, be realized in many different forms and should not be construed as being limited to the aspects set forth herein. Like numbers in the drawings refer to like elements throughout.

The terminology used herein is for the purpose of describing particular aspects of the disclosure only, and is not intended to limit the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

Some of the example embodiments presented herein are directed towards improvement of robustness such that a stable throughput level of a MIMO system is maintained. As part of the development of the example embodiments presented herein, a problem will first be identified and discussed.

The presented systems and methods disclose how to ensure a high throughput in situations where e.g. environmental influences degrade the performance of the communication channels in a Line of Sight Multiple-Input Multiple-Output, LoS MIMO, system. This is achieved by allowing the transmitted power of the interference producing antennas to be reduced.

To facilitate the understanding of the proposed technique aspects of LoS MIMO communications are further discussed. Specifically, focus is kept on how to maintain the performance of the system at all times.

The power present in a received radio signal can be measured. Applying some signal processing to the measured signal to determine which portion belongs to the wanted signal provides an estimation referred to as the received signal strength indicator, RSSI. The RSSI is the relative received signal strength in a wireless environment, the higher the RSSI number, the stronger the signal. The signal processing to estimate the RSSI value in a MIMO system is different from the ones used in SISO systems.

Further, C/I ratio are a measure that compares the level of a received carrier signal to the level of interference. It is defined as the ratio of carrier power to the interference power, often expressed in decibels. A positive value similar to the SNR figures indicates a higher carrier level than the interference level.

Throughout the text examples with 2x2 MIMO systems are given in order to increase readability and reduce the complexity unless where otherwise noted. The examples presented with respect to a 2x2 MIMO system should in no way been seen as limited, and the systems can easily be scaled up to any NxM MIMO system. Likewise the expression two receivers or two transmitters is not to be seen as restricting the system to such two receviers and transmitters, respectively. It shall also include at least two receivers and at least two transmitters

Interference is one of the problems encountered in MIMO systems. One way of deciding if interference is acceptable or not is to compare the carrier-to-interference, C/I, ratio to a threshold value. The C/I ratio is the ratio, expressed in dB, between a desired carrier (C) and an interfering carrier (I) received by the same receiver. In other words, at the receiver antennas, the carrier-to-interference ratio is referred to the power ratio between the main data signal (the signal from the corresponding transmitter antenna) and the interference signal. Very often the interference signal contains noise and the signal from the non-corresponding transmitter antenna. As a result thereof, for a MIMO system to stay functional and provide the desired throughput two conditions are required, namely an acceptable level of C/I and an acceptable level of RSSI.

There are different ways of reducing co-channel intereference of a MIMO system. One known alternative is a cancellation-based NxN MIMO system, i.e. interference cancellation of a zero-forcing MIMO receiver. An example is a 2x2 MIMO system. Here each data stream is individually transmitted from each transmit TX antenna, i.e. no precoding is present. The two receive (RX) antennas receive mixed signals from the both TX antennas. E.g. RX1 receives the wanted data stream from TX1 and an interference signal from TX2. To remove the interference and recover the wanted data stream, the received signals from the both RX antennas are used. At the first receiver, RX1, the signal received at the second antenna, RX2, is first rotated and then added to the signal from the first antenna, RX1. In other words, in RX1 the received wanted data stream from TX1 and the interference signal from TX2 are added to a rotation of the received wanted data from TX2 in RX2 and a rotation of the interference signal from TX1 received in RX2. Utilizing a proper rotation phase, the interference signal from TX2 is removed. The similar cancellation mechanism is also applied at the second receiver.

The overall MIMO system performance can be further improved if the transmitter has knowledge about the state of the MIMO channel and can apply a pre-coding strategy accordingly. The singular-value-decomposition, SVD, based pre-coder is known to achieve the MIMO channel capacity. In short, the solution given by singular value decomposition of the channel matrix is a unitary rotation matrix which maps the signals to the subspace spanned by the eigenvectors of the channel matrix. Figure 1 demonstrates an example where SVD-based pre-coder is used in a 2x2 MIMO system. The first data stream, a1, and the second data stream, a2, are properly mixed (pre-coded). In this example, 0.5a1 is added to 0.5a2 and transmitted from the first transmitter antenna TX1, see Figure 1a. Moreover, -0.5a1 (corresponding to 180 degree phase shift) is added to 0.5a2 and transmitted from the second transmitter antenna TX2, see Figure 1e.

The received signals are viewed for the first receiver RX1 in Figure 1b and for the second receiver RX2 in Figure 1f, respectively. In Figures 1b and 1f all the signals received from TX1 and TX2 are viewed as separate vectors. In order to ease the understanding, vector sums of the received signals are shown in Figures 1c and 1g. The same cancellation strategy as described in relation to zero-forcing MIMO is applied, that is to say adding the rotated signal from the other antenna. In this example it means that the signal received at RX2 (Figure 1g) is added (zero rotation) to the signal received at RX1 (Figure 1c). The result is shown in Figure 1d where the contribution from a2 is cancelled. In order to retrieve a2, the signal received at RX1 (Figure 1c) is rotated and added to the signal received at RX2 (Figure 1g). The result is shown in Figure 1h where the contribution from a1 is now cancelled.

The carrier-to-interference ratio is still referred to the power ratio between the two data streams. In the example of Figure 1, the carrier-to-interference (C/I) ratio at RX1 is same as the interference-to-carrier, I/C, ratio at RX2, which means a high C/I ratio at RX1 will lead to low C/I ratio at RX2.

If there are more than two antennas, I(interference) will be the received power from all interference antennas. Increased interference power can come from one interference antenna or all interference antennas. The performance will be limited by the total interference power.

In practical implementation, the phase estimate for interference cancellation could be affected by a number of factors, the phase noise from the oscillator, the thermal noise level, the interference signal level and etc. At a low C/I ratio, it may be difficult to recover the weak sub-channel, since the interference level is too high or the carrier too low. In particular, the LoS MIMO carrier recovery is sensitive to C/I difference as modulation increases. This is due to the fact that the decision region becomes smaller, e.g. the constellations points in 256QAM are positioned much closer to each other than they are in a 16QAM constellation diagram. Hence, large QAM modulation is more sensitive to phase error, and less tolerant to low C/I ratio. Examples of C/I limits for different modulation formats:

| *Modulation* | *Minimunm C/I ratio before MIMO out of lock* |
|---|---|
| 4QAM | -18 dB |
| 16QAM | -15 dB |
| 64QAM | -12 dB |
| 256QAM | -7 dB |
| 1024QAM | -6 dB |

For example, the carrier recovery breaks down at C/I=-6dB for 1024QAM.

A typical scenario will be described with reference to Figures 2 and 3. Figure 2 illustrates a MIMO system comprising N transmitting TX antennas 11-1,11-2,11-3,...,11-N and M receiving RX antennas 21-1,21-2,21-3,...,21-M.

Hence, in LoS MIMO systems, the full rank MIMO channel is ensured by proper antenna separation. In general, optimal antenna separation increases with increasing hop length and decreasing carrier frequency. The optimal antenna distance could be from several meters to several tens of meters.

The very first effect of large antenna separation is that different sub-channels may experience different levels of flat or multipath fading. In other words, the correlation of MIMO sub-channels decreases when the spatial separation increases. Different receivers may experience extremely different ratio of signal to noise (SNR) and C/I.

Due to the large antenna separation, it is also unrealistic to synchronize the multiple transmit/receiver local oscillators, LOs, which means all LOs are free-running. Hence, the MIMO carrier recovery becomes more challenging (due to the increased number of unknown oscillator signals) compared with tracking synchronized oscillator signals. The phase tracking performance is also very sensitive to degraded channel conditions, e.g. when C/I ratio becomes low, which may degrade the performance of the MIMO system even more. If the phase tracking in MIMO is not correct then the interference cancellation as previously described will fail. Hence, unsynchronized LOs and low C/I ratio are challenging conditions for LoS MIMO carrier recovery. When using high modulation formats, the phase tracking becomes extremely sensitive to C/I variations, for example a difference of more than 6dB according to table 1 between the carrier and the interference could fail the MIMO phase tracker when operating at 1024QAM.

Assume that one of the RX antennas in Figure 2 is exposed to wet snow whereas the others RX antennas are to some extent shielded. The most exposed RX antenna will exhibit a worsened C/I ratio. This is further illustrated in Figures 3a and b, where a corresponding 2x2 MIMO system measuring result serves as an example. One antenna was covered by snow, but not the second one. Figure 3a shows the C/I in dB for the receiving antennas RX1 and RX2 as a function of time. The C/I starts to increase when the snow starts to collect on one antenna. RX1 is the reception antenna exposed to snow, i.e. RX1 is receiving the weak sub-channel. As previously described, the LoS MIMO carrier recovery is sensitive to low C/I ratio which is visualized in Figure 3b where the phase error is shown as a function of the time. The snow has the effect that the phase error of the weak channel (where the signal is received by RX1) becomes large and carrier recovery becomes difficult.

There are different attempts to increase the robustness of antenna systems.

In e.g. Single Input Single Output, SISO, scenarios, the receiver Radio Signal Strength Indicator, RSSI, level is used to control the transmit power level and to maximize the throughput. Moreover, the adaptive transmit power control is mainly governed by Means Square Error, MSE, of the recovered signal. However, this solution is not applicable to a MIMO scenario where the received signal is a combination of different signal streams collected from uncorrelated sub-channels. Lack of correlation between different sub-channels implies that different transmitters may need different adjustments to be applied to their transmitted powers. An attempt to solve the issue in NxN LoS MIMO has been addressed by WO/2014/037035 where automatic transmit power control is utilized. However, the described solution does not take the transmit power limitation into account. The solution basically assumes there is infinite possibility to increase the transmit powers. In addition, the solution forces an equal C/I ratio to all receivers which is an unnecessary condition leading to a higher power consumption.

The inventors have realized that by regulating the C/I ratio and the RSSI for each individual channel in a MIMO system, when it is needed, the performance of carrier recovery can be improved. The robustness of the MIMO receiver and the total throughput can be increased. The power consumption per throughput can be reduced.

The proposed solution is an adaptive transmit power control mechanism which is based on system parameters such as MSE, C/I ratios, modulation formats, and throughput which complements the previous work. The ultimate goal of the mechanism is to adjust the transmit powers so that the system availability and throughput are maximized. Within the solution, the C/I ratios are kept within an acceptable range where the MIMO carrier recovery can take place.

Further, if the C/I of one link falls below the limit, the power control system forces the corresponding transmitter to increase its TX power. However, if maximum TX power is reached while the corresponding C/I ratio is still below the limit, the MIMO transmitter with the highest C/I may reduce the TX power accordingly in order to regulate C/I ratios and to prevent failure in MIMO carrier recovery. However, the transmitter reduces its TX power, if and only if the action can maximize the total throughput. This is often the case since point-to-point microwave links have often designed with a large fading margin; therefore, it may still be possible to send MIMO streams with high rates, even when the TX power is reduced.

In addition to C/I regulation, the current solution maximizes the total throughput by continuous monitoring and exchange of the information between different links. If throughput of one channel reduces where there is no chance to compensate for it, then it might be possible to increase the throughput of the other links to maximize the total capacity. This can be done by increasing the transmit power in the healthy links to increase the channels capacity and consequently the throughput; or by decreasing the power in the low throughput channel to decrease the interference in healthy links; or combination of both methods. This strategy may be even seen as a power consumption optimization which leads lower power consumption per throughput.

The proposed methods and arrangement will now be described in more detail referring to Figures 4-28.

Figure 4 shows according to some aspect a method in a receiver arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system. Said MIMO system comprises at least two spatial receiver antennas. The method comprises in step S10 measuring a first parameter (C/I_1) of a signal received at a first one of the receiver antennas. Said parameter can be in some aspects a carrier to interference ratio of said first receiver. In step S11 it is determined whether the first parameter is below first threshold criteria (Thr_C/I_1). If the determination results in that the first parameter is below first threshold criteria, a request is provided in S20 to decrease a transmission power for a transmitter associated with the second of the receiver antennas. If the first parameter is not below first threshold criteria, the method continues with steps S12, namely measuring a second parameter (RSSI_1) of the signal received at the first one of the receiver antennas. The second parameter can include a received signal strength indicator, RSSI in some aspects. The S13 determines whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). If that is the case the method continues with step S30, providing a request to increase the transmission power for a transmitter associated with the first one of the receiver antennas.

The above method therefore proposes to control the power of one or more transmitters, each of those associated with a respective receiver in a MIMO system by measuring a first parameter in a first receiver and in response to its result either decrease the power of the transmitter(s) associated with the other receivers or increase the power for the transmitter associated with the first receiver. It has been found that data throughput can be maintained or even improved by reducing the transmitter causing interference in a receiver of a MIMO system or alternatively increasing received carrier power. A combination of both approaches as proposed in here and the following improves the overall performance for a MIMO system.

Figure 5 shows some further aspects of step S30, providing a request to increase the transmission power. It can be determined in S301, whether the transmission power for the transmitter associated with the first one of the receiver antennas is below a third threshold criterion (TX1_maxPower). In response to a positive determination, that is the transmission power for the transmitter associated with the first one of the receiver antennas is below the third threshold criteria, a request is sent to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas. This aspect of sending a request may be suitable, when transmitter and receiver are spaced apart. The request or command can be sent via a microwave link or other communication channel. It can be part of a feedback control loop.

According to some further aspects shown in Figure 6 with respect to step S20, providing a request to decrease a transmission power for a transmitter associated with the second of the receiver antennas, it can be determined in S201, whether the transmission power for the transmitter is below the third threshold criteria (TX1_maxPower). If the determination results that the transmitter is below the third threshold criteria, a request to increase transmission power for the transmitter associated with the first one of the receiver antennas is sent, like the one in Figure 5, step S302. If the determination results that the transmitter is not below the third threshold criteria, a request to decrease transmission power for the transmitter associated with a second one of the receiver antennas is generated, S21. Optionally it can subsequently be determined in step S202, whether decreasing transmission power for the transmitter associated with a second one of the receiver antennas results in a lower data throughput in a second of the receiver antennas.in response to such determination and if decreasing transmission power for the transmitter associated with a second one of the receiver antennas results in a lower data throughput, a request to set a fourth threshold criteria (Thr_RSSI_2) associated with the second of the receiver antennas to a lower threshold value is provided.

Figure 7 deals with some aspects related to the results of the measurement of the second parameter. In S13, it is determined whether the second parameter (RSSI_1) is below second threshold criteria (Thr_RSSI_1). IF the determination indicates that the second parameter is below second threshold criteria, the method continues with S30, providing a request to increase the transmission power for a transmitter associated with the first one of the receiver antennas. If, however the second parameter is not below second threshold criteria, optional step S131 is performed, determining whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1). This step evaluates if there exists a possibility to change the requirements of the system to use a higher value of second threshold criteria (Thr_RSSI_1) in order to reset some of the previouse changes applied to the default settings. Consequently, if step 131 results that second parameter is below a predetermined higher value of the second threshold criteria, a request is provided in S132 to decrease the transmission power for the transmitter associated with the first one of the receiver antennas.

Figure 8 consequently illustrates some steps performed, when it is determined in S131 that the second parameter is not below a predetermined higher value of the second threshold criteria. The method then continues with S133, Setting the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value and determining whether a counter (Counter_RSSI_2) related to the second parameter associated with the second receiver is above a predetermined value. Depending on such determination, the fourth threshold criteria (Thr_RSSI_2) related to the second threshold criteria associated with the second receiver is set to the next lower predetermined value in S134 and the above counter (Counter_RSSI_2) decremented by one, or fourth threshold criteria (Thr_RSSI_2) is set to the next higher predetermined value in S136 and the above counter (Counter_RSSI_2) incremented by one.

Referring back to step S30, some further aspects are illustrated in Figure 9. As disclosed before, step S301 determines whether the transmission power for the transmitter associated with the first one of the receiver antennas is below a third threshold criteria (TX1_maxPower). If that is the case, a request is sent in S302 to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas. If the transmission power of the transmitter associated with the first one of the receiver antennas is not below a third threshold criterion, the method continues with S303, determining whether a data throughput is below a predetermined level. In case data throughput is below a predetermined level, the second threshold criteria (Thr_RSSI_1) for the first one of the receiver antennas is set to a next lower threshold value in S304 and subsequently a counter (Counter_RSSI_1) associated with the second threshold criteria (Thr_RSSI_1) for the first one of the receiver antennas decremented by one in S305.

Some further aspects illustrated in Figure 10 are related to a transmitter arrangement of a MIMO System. The transmitter arrangement controls inter alia the power level for the transmitter. It may optionally receive respective control commands coming from a respective receiver arrangement of the MIMO system of from some other control unit. In optional step S20a a request is received by the transmitter arrangement to decrease a transmission power for a transmitter associated with the second receiver antennas. In response to such request it is then determined in S201 whether the transmission power for a first transmitter antenna is below the third threshold criteria (TX1_maxPower).

If S201 results in that the transmission power for a first transmitter antenna is not below the third threshold criteria, S401 forwards the request to decrease transmission power of the second transmitter as the power for the first or any other transmitter cannot be increased. Alternatively, the method continues with S302a by increasing the transmission power level for the first transmitter antenna. Optionally, the transmitter arrangement can also at any stage a receive (S30a) request to increase the transmission power level for the first transmitter antenna as indicated here in step S30a.

These steps reflect the aspect that the transmitter arrangement either increases the power of the transmitter associated with the receiver for which the request in S20a was received or reduces the power for all or some of the other transmitters.

Figure 11 illustrates some further aspects to step S401 as in the previous figure. Providing a request to decrease transmission power of the second transmitter may include optional step S402, determining whether the MIMO system can provide a higher data throughput compared to a MIMO system of a lower order or even a feasible SISO system. If the MIMO system can provide a higher data throughput compared to a MIMO system of a lower order, the system should stay in said MIMO system with its functionality. Consequently, step 405 is performed, that is the transmission power for the second transmitter is decreased. If a higher throughput cannot or no longer be provided or maintained, then a request is generated to switch from MIMO system to a MIMO system of a lower order or even down to a single input, single output, SISO system with similar throughput.

Figure 12 now refers to some aspect for an adaptive power control functionality in a MIMO system, said MIMO system comprising at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas. Similar to the previous aspects, step S10 is performed by measuring a first parameter (C/I_1) of a signal received at a first one of the receiver antennas. In some aspects the first parameters can comprise a carrier to interference ratio measured at the first receiver. In step S11 it is determined whether the first parameter is below first threshold criteria (Thr_C/I_1). If the first parameter is not below first threshold criteria, the method continues with step S201 as explained further below.

If the first parameter is not below first threshold criteria, the method continues with step S12, comprising measuring a second parameter (RSSI_1) of the signal received at the first one of the receiver antennas. Subsequently, step S13 determines whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). If this is the case the method continues with step S201, which performs the same task as method step S301. In method steps S201 it is determined, whether a transmission power level for the transmitter associated with the first of the receiver antennas is below a third threshold criteria (TX1_maxPower). In response to determining that the transmission power level for the transmitter associated with the first of the receiver antennas is below the third threshold criteria (TX1_maxPower), the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas is increased in step S302a. If the transmission power level for the transmitter associated with the first of the receiver antennas is not below a third threshold criteria and the first parameter is below a first threshold criteria (Thr_C/I_1), step S401 is performed and a request to decrease transmission power of the second transmitter is provided.

Step S401 is illustrated with further optional aspects in Figure 13. Providing a request to decrease transmission power of the second transmitter comprises in step S402 Determining whether the MIMO system can provide a higher data throughput compared to a feasible SISO system. Upon such determination, the method continues with S404a. S404a switches from MIMO system to a single input, single output, SISO system or with steps S405 and S407. In step S405 performed in response to determining that the MIMO system can provide a higher data throughput compared to a feasible SISO system, the transmission power for the second transmitter is decreased. Subsequently it is in S407 determining whether a decrease of the transmission power of the transmitter associated with a second of the receiver antennas results in a lower throughput through the second of the two receiver antennas. If this is the case, a fourth threshold (Thr_RSSI_2) of the second one of the at least two spatial receivers is set to a lower value which matches the current throughput.

Some further aspects with respect to processing the measurement of the second parameter are disclosed in Figure 14. As already inficated in Figure 12, step S13 determines, whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). If this is the case, it is subsequently determined whether the transmission power level for the transmitter associated with the first of the receiver antennas is below a third threshold criteria (TX1_maxPower). A request in step S302a is provided to increase transmission power of the first transmitter if it is determined that the transmission power level for the transmitter associated with the first of the receiver antennas is below the third threshold criteria. If it is determined that the transmission power level for the transmitter associated with the first of the receiver antennas is not below the third threshold criteria, optional step S501 determines whether a data throughput of the first receiver RX1 is below a predetermined level. If it is found that the throughput is below the predetermined level, the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas is set to a lower threshold value.

Figure 15 relates to some optional aspects in response to determining whether a data throughput is below a predetermined level. If the data throughput is below the predetermined level, it is also determined whether a fifth parameter (Thr_RSSI_2) associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria (Thr_RSSI_2_max). This step can be performed in parallel or subsequently to setting the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas is to a lower threshold value as described with resepct to Figure 14. If that is the case, the method continues with a further determination step S504, namely determining whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value (Tx2_maxPower). The fourth threshold criteria (Thr_RSSI_2) is set to the next higher value if the result in S504 indicate that the power level of the transmitter is below a sixth threshold value.

Figure 16 returns back to step S13 illustrating some aspects, when the determining step S13 indicates that the second parameter is not below the second threshold criteria. The method continues with step S131, determining whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1). If this is the case, the transmission power for the transmitter associated with the first one of the receiver antennas is decreased in S132a.

The regulation of the first parameter, particular the C/I regulation and the proposed exemplary methods maximize the total throughput by continuous monitoring and exchange of the information between different links. If throughput of one channel reduces where there is no chance to compensate for it, then it might be possible to increase the throughput of the other links to maximize the total capacity. This can be done by increasing the transmit power in the “healthy” or less disturbed links to increase the channels capacity and consequently the throughput; or by decreasing the power in the low throughput channel to decrease the interference in healthy links; or combination of both methods. This strategy may be even seen as a power consumption optimization which leads lower power consumption per throughput.

Figure 17 shows a general illustration of an arrangement with an adaptive power control in an exemplary MIMO system. The MIMO system comprises two transmitter antennas TX1, TX2 and two receiver antennas RX1, RX2 spatially apart from each other and corresponding to a 2x2 MIMO system. The MIMO system can have more antennas and a higher complexity, for instance it can be a 3x3, 4x4 or generally N x N system, wherein N is the number of antennas. The adaptive power control unit is arranged in the receiver portion of the system in this example. It can be of course separated from receiver and transmitter portion or placed in the transmitter portion. The adaptive power control may inter alia control the transmission power for each of the transmitter antennas TX1, TX2 in the transmitter portion. The receiver portion comprises a measurement unit with a C/I estimator and an RSSI estimator coupled to the adaptive power control to provide the carrier to interference ratio to the adaptive power control. The adaptive power control may receive further measurements, e.g. MSE, received power and the like. The MIMO streams are often assigned a channel index which can be used to identify the degraded MIMO path. Based on the estimated parameters, the TX power level for the degraded path can be changed, i.e. increased to strengthen the carrier portion. Alternatively the TX power level for all the other transmitters can be reduced to decreases the interference portion of the degraded path. Using a suitable combination, the power levels and modulation formats can be optimized such that the total data throughput is maximized. The maximum C/I value for each modulation can be stored in a table in a digital signal processing (DSP) unit.

Figure 18A to 18C illustrate some aspects related to the effect of interference cause by a transmitter not associated with the receiver, the resulting C/I value and the consequences when increasing or decreasing the power of those transmitters. Transmitter TX1 is associated with receiver RX1 and transmitter TX2 is associated with receiver RX2. TX1 is also blocked or attenuated indicated by the blob on the transmitter antenna. Further it is assumed for Figure 18A and 18B that transmitter TX1 has reached the maximum allowed TX power which is $P_{TX}$. Figure 18A illustrates the situation without an adaptive power control. From the view of receiver

RX1, the antenna receives the signal from TX1 and an interference signal from TX2. However, the signal from TX1 is attenuated resulting in a reduce C/I by –x[dB]. Likewise that interference signal from TX1 in receiver RX2 is improved by x[dB].

In order to regulate the C/I ratio in both receivers RX1 and RX2 and improve C/I in RX1, one can reduce the transmission power from TX2. This is the situation in Figure 18B, in which transmission power of TX2 is reduced by y[dB]. As the transmission from TX2 is responsible for the interference in RX1, the C/I ratio in receiver RX1 is improved resulting in –x+y[dB]. On the other hand, the received power in RX2 is reduced resulting in a C/I ratio of x-y[dB]. Alternatively it may be possible to increase the power of TX1 in case $P_{TX}$ is not the maximal power. This is illustrated in Figure 18C. One could start to increase the transmission power at TX1 until the maximum of $P_{TX} + z$ is reached. If the C/I is still not good enough, the TX power at TX2 should be reduced by amount of $y$.

The example in **Error! Reference source not found.** to demonstrate in accordance with some aspects the trade-off between received power in RX2 and the carrier to interference ratio C/I in RX1 for various modulation formats. The relation between the received power and modulation format for each C/I value resembles a staircase function. The dashed line represents the received power at RX2 for each modulation format to obtain C/I=0 at TX1, while the solid the curve represents the received power required for each modulation at C/I=-7dB. As can be found from the figure, to increase the C/I ratio at RX1 for any specific modulation, one should move from more negative C/I curve to the more positive C/I curves; which involves reduction of TX2 power.

Figure 20 and 21 show a more detailed view of the method for adaptive power control in a MIMO system including some additional aspects. The method illustrated in Figures 20 and 21 can be used for a MIMO system with 2 transmitters and 2 receivers, referred to a 2x2 MIMO system. It can however be expanded to an NxN system. The figures show the workflow and method steps for optimizing the setting for the first receiver of the two receivers in the MIMO system. The same steps are applied to the 2$^{nd}$ receiver. Consequently, changes of the transmission power in one transmitter affect both receivers, and particular the carrier to interference ratio of both receivers. Hence, the exemplary method presented herein applied by one receiver within a MIMO system include steps changing threshold values for the other receiver or the transmitter of said system. To avoid unstable situations, e.g. by increasing or decreasing constantly a transmission power due to contradicting targets, the exemplary method also includes several counters associated with certain parameter or threshold values. The counters are decremented or incremented based on the changes of the respective parameters or threshold values. The counters enable the method to provide some form of history knowledge to avoid ambiguous or unstable operations of the MIMO systems.

As can be recognized from the flowchart, the process starts with the measurement of the carrier to interference ratio C/I in the first receiver. The parameter is referred to as (C/I_1). If the C/I level is less than a pre-determined and permitted threshold (Thr_C/I_1) for underlying modulation scheme, then the first priority is to regulate the C/I ratio. To do so, the method determines if it is possible to increase the power in TX1 or not. This can be simply done by evaluating the output power of the transmitter associated with the first receiver, in the present example transmitter TX1. For simplicity purposes, one can simply look at the power settings, it is not required to actually measure the output power. If the power is not at a maximum (or any other defined level), a command of power increase will be sent to TX1. In other words, the method will cause the transmission power of the first transmitter to increase. However, it can happen that the output power is already at the maximum level and a further increase of the transmission power is not possible. As explained above, it may still be possible to maintain data throughput of the MIMO system. By instead of increasing the power of TX1, reducing the power of TX2. For this purpose, it is evaluated if the MIMO system can be maintained or even provide higher throughput. If the throughput cannot be maintained, it may be more suitable to switch back to an appropriate SISO system. If, on the other side the determination results in an indication that the throughput can at least be maintained, the adaptive power control system will issue a command to decrease the power for the transmitter TX2.

If the issued reduction in the transmission power on transmitter TX2 leads to a lower throughput in receiver RX2, the adaptive power control system will set a lower (Thr_RSSI_2) accordingly to optimize the power consumption under this circumstance and to decrease the emitted interference towards other receivers. In addition, the reduction in the threshold value of the RSSI parameter for the second transmitter will be tracked with a counter (Counter_RSSI_2) and the occurrence of low (C/I_1) leading to reduced threshold value (Thr_RSSI_2) of the RSSI parameter for the second transmitter is kept in a counter named (Counter_low_C/I_1). Tracking of those criteria provides knowledge of the history and enables the method to reset the adaptive power control system to default settings when it is applicable.

On the other hand, referring back to the result of the measurement of the first parameter (C/I_1), the determination can result in that the estimated C/I level is in accordance with the requirements, that is the first parameter (C/I_1) is not smaller than the pre-set threshold value (Thr_C/I_1). The method will then progress to the next step which is measurement of received signal strength (RSSI_1) on the first receiver. The received signal strength is estimated by a digital signal processing unit, in hardware, software or both and provides information about the strength of carrier or wanted signal but not in the combination with the accompanied interference. The measured value (RSSI_1) is then compared with a predetermined second threshold value (Thr_RSSI_1). The second threshold value (Thr_RSSI_1) is a threshold which guarantees a specific MSE and throughput in RX1. If (RSSI_1) is below the required level, that is the received signal strength may be too low, the system is required to take some action. Two possible scenarios may occur.

In a first scenario, the transmission power level for the first transmitter TX1 is below the predetermined level and the adaptive power control will issue a command to increase the power level for the first transmitter TX1. The increase of the power of the first transmitter will increase the carrier portion thus increase the carrier to interference ratio in the first transmitter and also increase the received signal strength indicator (RSSI_1) thereby preserving the throughput. It may happen that due to the increase in TX1 power, the received signal strength (RSSI_1) will become larger. This setup will be disclosed in larger detail in Figure 21.

Referring back to Figure 20, in the second scenario, no further increase in TX1 is applicable. Under these circumstances, the throughput of receiver RX1 is measured and used to see if it is below the required throughput. Very often, MIMO systems include a certain margin and also each combination of modulation scheme/coding can be employed within a range of MSE (and correspondingly RSSI) with a hysteresis nature. This means that a desired throughput in a receiver may still be preserved, even though associated RSSI value is lower than the specified threshold. If the throughput of receiver RX1 is maintained, no further action is necessary. Otherwise, a lower throughput modulation/coding scheme is used which requires lower received signal strength indicator for the first receiver. Consequently, the proposed approach has the opportunity to decrease the threshold value for the received signal strength indicator for the first receiver (Thr_RSSI_1) to a lower level to optimize the power consumption and to reduce the emitted interference towards other transmitters. As a consequence, the adaptive power control needs to keep track of those changes to be able to reset them at a later stage. Hence, the adaptive power control provides a counter (Counter_RSSI_1) associated with the received signal strength indicator for the first receiver to indicate any changes and decrements the counter by one.

Since in the latter scenario the RX1 throughput and consequently the total throughput has decreased, the adaptive power control can initiate a procedure to increase the data throughput in the link between the second transmitter TX2 and receiver RX2 if there is any room left for it. This is done by setting first evaluating whether the threshold value (Thr_RSSI_2) of the received signal strength of the second receiver is at a maximal value (Thr_RSSI_2 _max). If this is the case a further improvement is not possible. If however the threshold value (Thr_RSSI_2) is below the maximal value, it is evaluated, whether the transmission power in the second transmitter is at maximum level or can further be increased. In case the transmission power of the second transmitter TX2 can be increased, the adaptive power control set the threshold value (Thr_RSSI_2) for the second receiver to the next higher value. To keep track of the changes the counter (Counter_RSSI_2) for the received signal strength for the second receiver is incremented and another counter (Low_throughput_1) reflecting the low throughput of in the first receiver is decremented by one. With this approach the adaptive power control mechanism when executing the method for the first receiver sets revised conditions for the second receiver.

Referring now to Figure 21 illustrating further aspect of the method for adaptive power control. If the measured received signal strength (RSSI_1) for the first receiver is not below the threshold value (Thr_RSSI_1) but not as large as next higher threshold value (Thr_RSSI_1) for the received signal strength for the first receiver, the adaptive power control system will instruct the first transmitter TX1 to decrease its transmission power. On the other hand, the measured received signal strength (RSSI_1) for the first receiver could also be equal to or above the next higher threshold value (Thr_RSSI_1) for the received signal strength for the first receiver. In such case there is an opportunity to reset some of the changes applied to default criteria. For this purpose, the values for the counter (Counter_low _C/I_2) associated with the occurrence of low carrier to interference ratio in the second receiver and a subsequent decrease of transmission power in the first transmitter and the counter for the received signal strength changes (Counter_RSSI_1) associated with the first receiver are evaluated. If the first counter is not below zero and the second counter is below zero, the threshold value (Thr_RSSI_1) for the received signal strength for the first receiver is set to the next higher value. Accordingly, the counter (Counter_RSSI_1) associated with the threshold value is incremented by one.

In a next step, two evaluations are performed to check whether the threshold for the received signal strength (Thr_RSSI_2) can be adapted. The first evaluation concerns the counter (Counter_low_C/I_1) associated with the occurrence of low carrier to interference ratio in the first receiver. When such counter (Counter_low_C/I_1) is above 0, it is confirmed whether the counter (Counter_ RSSI_2) for the received signal strength is below zero and subsequently the threshold value (Thr_RSSI_2) for the received signal strength for the second receiver is set to the next higher threshold. Likewise, the counter (Counter_RSSI_2) for the received signal strength of the second receiver is incremented and the counter (Counter_low_C/I_1) associated with the occurrence of low carrier to interference ratio in the first receiver decremented.

If however, the counter (Counter_low_C/I_1) associated with the occurrence of low carrier to interference ratio in the second receiver is not above 0, the adaptive power control determines whether the first receiver had a low throughput (Low_ throughput_1> 0). If that is not the case the method steps out. Otherwise, the adaptive power control confirms that the counter (Counter_ RSSI_2) for the received signal strength is above zero and subsequently sets the threshold value (Thr_RSSI_2) of the received signal strength for the second receiver is set to the next lower threshold. Likewise, the counter (Counter_RSSI_2) for the received signal strength of the second receiver is decremented and the counter (Low_ throughput_1) associated with the occurrence of low throughput in the first receiver decremented.

Some further aspects are illustrated in Figure 22A to Figure 22C. The above methods in the receiver, transmitter and adaptive power control system can be implemented in hardware, software or a combination thereof. Figure 22A to Figure 22C show a respective non-transitory storage medium, like a non-volatile memory for example comprising computer program code, which when executed by a processor causes the processor to conduct, perform or cause the method steps and aspects disclosed previously. The computer program code can be stored on a hard-disk, a flash memory, ROM, DVD or any other non-volatile memory. It is possible to store only parts of the computer program code in a non-volatile memory, while other parts can be stored separately in another non-volatile memory. Likewise it is possible that the computer program code is executed on one or more processor, including hardware processors, like CPU's, FPGA's, Asics and the like as well as in virtual machines on virtual processors running on a host system.

Figure 23 shows some aspects of a receiving arrangement (20) in a Multiple Input Multiple Output, MIMO system. The arrangement comprises at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and a measurement unit (22) coupled to the at least two spatial receiver antennas. The measurement unit is configured to estimate at least a first parameter (C/I_1) and a second parameter (RSSI_1) different from the first parameter at the respective ones of the at least to two spatial receiver antennas. The parameters characterize a signal quality and can include for example a carrier to interference ratio and an RSSI value. A processor unit (23) is coupled to the measurement unit (22) and configured to determine whether the first parameter (C/I_1) is below a first threshold criteria (Thr_C/I_1). In response to such determination, the processor unit can either provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas or determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). If that is the case a request is provided to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

Figure 24 shows some aspects of a transmitter arrangement (10) in a multiple input-multiple output, MIMO system. The transmitter arrangement 10 comprises at least two spatial transmitter antennas (11-1, 11-2, .., 11-N), each associated with a respective one of at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and a processor unit (13) configured to:

- determine, in response to a received request to increase transmission power for the first transmitter, whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria (TX1_maxPower);
- in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower):
  - increase the transmission power level for the first transmitter antenna.

The transmitter arrangement is often located apart from the receiver arrangement, but coupled together via a common control unit (not shown in here).

Figure 25 shows a  MIMO system (30) with an adaptive power control comprises at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and at least two spatial transmitter antennas (11-1, 11-2, .., 11-N), wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas. The arrangement also comprises a measurement unit (32) coupled to the at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and configured to measure at least a first parameter (C/I_1) and a second parameter (RSSI_1) different from the first parameter at the respective ones of the at least to two spatial receiver antennas, said parameters characterizing a signal quality. The parameter can be in some aspects a carrier to interference ratio or a received signal strength indicator. The arrangement comprises one or more a processor units (33) coupled to the measurement unit and configured to determine whether the first parameter meets a first threshold criterion

(Thr_C/I_1). In response to determining that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1) to, the processor unit is configured to determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). In response to determine that the second parameter is below the second threshold criteria (Thr_RSSI_1) or in response to determine that the first parameter is below the first threshold criteria (Thr_C/I_1) to the one or more processor unit determines whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower). In response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria (TX1_maxPower) the processor unit increases the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

The processor unit described above can be hardware or software, a single unit or a plurality of devices acting together to perform the specific functions. The measurement unit as disclosed above can be a single unit or comprise multiple measurement units and multiple processor units. The measurement units can comprise one or more sensor either implemented as hardware sensors, software sensors, a combination thereof, as well as estimators or other signal processing units.

Some further aspects are disclosed in Figures 26 to 28. Figure 26 shows a receiver arrangement (200) for adaptive power control of a Multiple Input Multiple Output, MIMO system with at least two spatial receiver antennas. The arrangement comprises a first measurement module (Sx10) arranged to measure and estimate a first signal quality parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas. The first decision module (Sx11) is arranged to determine whether the first parameter is below a first threshold criteria (Thr_C/I_1). The arrangement also comprises a first provider module (Sx20). The first provider module (Sx20) is arranged, in response to determining that the first parameter (C/I_1) is below the first threshold criteria, to provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas. The receiver arrangement also comprises a second measurement module (Sx12). The second measurement module (Sx12) is arranged in response to determining that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1) to measure a second parameter (RSSI_1) of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter. Finally a second decision module is provided and arranged to determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1). In response to determining that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1), a second provider module (Sx30) is configured to provide a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

Figure 27 show some aspects of a transmitter arrangement (100) for adaptive power control of a Multiple Input Multiple Output, MIMO system comprising at least two spatial transmitter antennas, a decision module and a regulator module. The decision module (Sx301) configured to determine whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria (TX1_maxPower). The regulator module (Sx302a) is configured to increasing the transmission power level for the first transmitter antenna in response to determination that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower).

Figure 28 illustrates some aspects of a MIMO system or an adaptive power control of a MIMO system. The MIMO system comprises at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas. The adaptive power control comprises a first measuring module (Sx10), a first decision module (Sx11), a second measuring module (Sx12), a second decision module (Sx13), a third decision module (Sx201, Sx301) and a regulator module (Sx302a). The first measuring module (Sx10) is configured to measure a first parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality. The first decision module (Sx11) is configured to determine whether the first parameter meets a first threshold criterion (Thr_C/I_1). The second measuring module (Sx12) is configured to measure a second parameter (RSSI_1) of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter, in response to determining that the first parameter is not below the first threshold criteria (Thr_C/I_1). The second decision module (Sx13) is configured to determine whether the second parameter is below a second threshold criterion (Thr_RSSI_1). The third decision module (Sx201, Sx301) is configured to determine whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower) in response to determining that the second parameter is below the second threshold criteria (Thr_RSSI_1) or in response to determine that the first parameter is below the first threshold criteria (Thr_C/I_1). Finally, the regulator module (Sx302a) is configured to increase the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas in response to determine that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria (TX1_maxPower).

While the previous aspects and examples have been illustrated for a MIMO system, with two transmitters and receivers, respectively, it is apparent for the skilled person that the proposed principles can be extended and applied to any MIMO system having a plurality of transmitters and receivers, in particular to a 3x3, 4x4 or larger system.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

Throughout the present disclosure, the expression “measurement” or to “measure” a parameter was used. In this regard it is pointed out that the used expression are not limited to the actual measurement as such but also include all kind of additional signal processing associated with the measurement. In particular, a measurement can comprise the actual physical measurement of a signal accompanied by some signal processing resulting in an estimation of a signal parameter. It is apparent from this view that a measurement unit may also referred to as estimator and likewise the term “measure” is equivalent to the expression “estimate”.

It should be noted that the word “comprising” does not necessarily exclude the presence of other elements or steps than those listed and the words “a” or “an” preceding an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several “means”, “units” or “devices” may be represented by the same item of hardware.

CLAIMS

1. A method in a receiver arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas said method comprising:

- Measuring (S10) a first parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- Determining (S11) whether the first parameter is below a first threshold criteria (Thr_C/I_1);
- In response to determining that the first parameter (C/I_1) is below the first threshold criteria:
    - Providing (S20) a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- In response to determining that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1):
    - Measuring (S12) a second parameter (RSSI_1) of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
    - Determining (S13) whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1);
    - In response to determining that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1):
        - Providing (S30) a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

2. The method according to claim 1, wherein the first parameter comprises one of carrier to interference ratio and signal to noise ratio and/or the second parameter comprises RSSI value.

3. The method according to any of claims 1 to 2, wherein providing (S30) a request to increase the transmission power of a transmitter associated with the first one of the at least two spatial receiver antennas comprises the steps of

- Determining (S301) whether the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower) and in response to determining that the transmission power is below the third threshold criteria (TX1_maxPower):
    - Sending (S302) a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

4. The method according to any of claims 1 to 3, wherein providing (S20) a request to decrease the transmission power for the transmitter associated with the second of the at least two spatial receiver antennas comprises the step of

- Determining (S201) whether the transmission power for the transmitter is below the third threshold criteria (TX1_maxPower);
- In response to determining that the transmission power is not below the third threshold criteria (TX1_maxPower):
    - Providing (S21) a request to decrease transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas; and
- In response to determining that the transmission power is below the third threshold criteria (TX1_maxPower):
    - Sending (S302) a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

5. The method according to claim 4, further comprising:

- Determining (S202) whether decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas; and
- In response to determining that a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas:

- Providing (S203) a request to set a fourth threshold criteria (Thr_RSSI_2) associated with the second of the at least two spatial receiver antennas to a lower threshold value which matches the current feasible throughput.

6. The method according to any of claims 1 to 5, further comprising:

- In response to determining (S13) that the second parameter is not below the second threshold criteria (Thr_RSSI_1):
  - Determining (S131) whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1);
  - In response to determining (S131) that the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1);
    - Providing (S132) a request to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

7. The method according to claim 6, further comprising in response to determining (S131) that the second parameter (RSSI_1) is not below a predetermined higher value of the second threshold criteria (Thr_RSSI_1):
   - Setting (S133) the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value; and
   - In response to setting (S133) the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value:
     - based upon a counter (Counter_RSSI_2) associated with a fourth threshold criteria (Thr_RSSI_2) of said second one of the at least two receivers being above a predetermined value, setting (S134) the fourth threshold criteria (Thr_RSSI_2) to the next lower predetermined value and decreasing (S135) a counter (Counter_RSSI_2) associated with the second threshold criteria of said second one of the at least two receivers by one; or
     - based upon the counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) being below a predetermined value,

setting (S136) the fourth threshold criteria (Thr_RSSI_2) to the next higher predetermined value and increasing (S137) a counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) .

8. The method according to claim 3, further comprising in response to determining (S301) that the transmission power is not below the third threshold criteria (TX1_maxPower):
   - o Determining (S303) whether a data throughput is below a predetermined level and in response to determining that the data throughput is below a predetermined level:
     - ▪ Setting (S304) the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas to a next lower threshold value which matches the current feasible throughput and
     - ▪ Decreasing (S305) a counter (Counter_RSSI_1) associated with the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas by one.

9. The method according to claims 1 to 8, comprising:
   - Providing a counter for each of the respective first and second threshold criteria and counting any changes in the first and second threshold criteria.

10. A method in a transmitter arrangement for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial transmitter antennas comprising:
    - Determining (S201) whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria (TX1_maxPower);
    - in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower):

- Increasing (S302a) the transmission power level for the first transmitter antenna.

11. The method according to claim 10, further comprising:
    - Receiving (20a) a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
    - in response to determining (201) that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is not below the third threshold criteria (TX1_maxPower):
        - providing (S401) a request to decrease transmission power of the second transmitter.

12. The method according to claim 11, wherein providing (S401) a request to decrease transmission power for the second transmitter comprises:
    - Determining (S402) whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of lower order; and
    - in response to determining (S402) that the MIMO system can provide a higher data throughput decreasing (S405) the transmission power for the second transmitter.

13. The method according to claim 12, further comprising in response to determining (S402) that the MIMO system cannot provide a higher data throughput compared to a feasible MIMO system of lower order :
    - providing (S404) a request to switch from MIMO system to the MIMO system of lower order.

14. The method according to any of claims 10 to 13, wherein determining (S201) that a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower) comprises:
    - Receiving (S30a) a request to increase the transmission power level for the first transmitter antenna.

15. A method for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas, said method comprising:
    - Measuring (S10) a first parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
    - Determining (S11) whether the first parameter is below a first threshold criteria (Thr_C/I_1);
    - In response to determining (S11) that the first parameter is not below the first threshold criteria (Thr_C/I_1):
        - Measuring (S12) a second parameter (RSSI_1) of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
        - Determining (S13) whether the second parameter is below a second threshold criteria (Thr_RSSI_1);
    - In response to determining (S13) that the second parameter is below the second threshold criteria (Thr_RSSI_1) or in response to determining (S11) that the first parameter is below the first threshold criteria (Thr_C/I_1):
        - Determining (S201, S301) whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower);
        - In response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria (TX1_maxPower):
            - Increasing (S302a) the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

16. The method according to claim 15, wherein the first parameter comprises carrier to interference ratio and the second parameter comprises RSSI value.

17. The method according to any of claims 15 to 16, further comprising in response to determining (S11) that the first parameter (C/I_1) is below the first threshold (Thr_C/I_1) and that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria (TX1_maxPower):
    - o Providing (S401) a request to decrease transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

18. The method of claim 17, wherein providing (S401) a request to decrease transmission power comprises:
    - Determining (S402) whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of a lower order; and
    - in response to determining (S402) that the MIMO system can provide a higher data throughput:
        - o decreasing (S405) the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

19. The method according to claim 18, further comprising in response to determining that the MIMO system cannot provide a higher data throughput:
    - Switching (S404a) from MIMO system to the MIMO system of a lower order or to a single input, single output, SISO system.

20. The method according to any of claims 18 to 19, wherein in response to determining (S402) that the MIMO system can provide a higher data throughput:
    - Determining (S407) whether a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver antennas;
    - in response to determining (S407) that a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver:

- Setting (S408) a fourth threshold (Thr_RSSI_2) of the second one of the at least two spatial receivers to a lower value which matches the current throughput.

21. The method according to claims 15 to 20, wherein in response to determining (S13) that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1) and in response to determining (S301) that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria (TX1_maxPower):
    - Determining (S303, S501) whether a data throughput is below a predetermined level and in response to determining that the data throughput is below a predetermined level:
        - Setting (S304, S502) the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas to a lower threshold value which matches the current throughput.

22. The method according to claim 21, in response to determining (S501) that the data throughput is below a predetermined level further comprise:
    - Determining (S503) whether a fifth parameter (Thr_RSSI_2) associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria (Thr_RSSI_2_max) ; and
    - In response to determining (S503) that the fifth parameter is below the maximal value of the fourth threshold (Thr_RSSI_2_max):
        - Determining (S504) whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value (Tx2_maxPower); and in response that the power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below the sixth threshold value (Tx2_maxPower):
            - Setting (S505) the fourth threshold criteria (Thr_RSSI_2) to the next higher value.

23. The method according to any of claims 15 to 22, wherein in response to determining (S13) that the second parameter (RSSI_1) is not below the second threshold criteria (Thr_RSSI_1):
    - Determining (S131) whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1); and
    - In response to determining (S131) that the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1);
        - Decreasing (S132a) the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

24. The method according to claim 23, further comprising in response to determining (S131) that the second parameter (RSSI_1) is not below a predetermined higher value of the second threshold criteria (Thr_RSSI_1):
    - Setting (S133) the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value; and
    - In response to setting (S133) the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value:
        - based upon a counter (Counter_RSSI_2) associated with a fourth threshold criteria (Thr_RSSI_2) of said second one of the at least two receivers being above a predetermined value, setting (S134) the fourth threshold criteria (Thr_RSSI_2) to the next lower predetermined value and decreasing (S135) a counter (Counter_RSSI_2) associated with the second threshold criteria of said second one of the at least two receivers by one; or
        - based upon the counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) being below a predetermined value, setting (S136) the fourth threshold criteria (Thr_RSSI_2) to the next higher predetermined value and increasing (S137) a counter

(Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) .

25. The method according to any of claims 15 to 24, wherein the first parameter comprises carrier to interference ratio and the second parameter comprises RSSI value.

26. The method according to claims 15 to 25, comprising:

providing a counter for each of the respective first and second threshold criteria and counting up upon a change in the first and second threshold criteria to a higher value and counting down upon a change in the first and second threshold criteria to a lower value.

27. A non-transitory computer readable medium storing a program causing a receiver arrangement to execute the methods of any of claims 1-9.

28. A non-transitory computer readable medium storing a program causing a transmitter arrangement to execute the methods of any of claims 10-14.

29. A non-transitory computer readable medium storing a program causing a computer to execute the method for adaptive power control of a Multiple Input Multiple Output, MIMO system of any of claims 15-26.

30. Receiving arrangement (20) in a multiple input-multiple output, MIMO system, comprising:

- at least two spatial receiver antennas (21-1, 21-2, .., 21-M);
- a measurement unit (22) coupled to the at least two spatial receiver antennas and configured to measure at least a first parameter (C/I_1) and a second parameter (RSSI_1) different from the first parameter at the respective ones of the at least to two spatial receiver antennas, said parameters characterizing a signal quality;
- a processor unit (23) coupled to the measurement unit (22) and configured to:
  - determine whether the first parameter (C/I_1) is below a first threshold criteria (Thr_C/I_1);
  - in response to determine that the first parameter is below the first threshold criteria:
    - to provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas;

- in response to determine that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1):
    - to determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1);
    - in response to determine that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1):
        - to provide a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

31. The receiving arrangement (20) according to claim 30, wherein the first parameter comprises carrier to interference ratio and the second parameter comprises RSSI value.

32. The receiving arrangement (20) according to any of claims 30-31, wherein to provide a request to increase the transmission power of a transmitter associated with the first one of the at least two spatial receiver antennas comprises to:
    - determine whether the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas (21-1, 21-2, .., 21-M) is below a third threshold criteria (TX1_maxPower) and in response to determining that the transmission power is below the third threshold criteria (TX1_maxPower):
        - to send a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

33. The receiving arrangement (20) according to any of claims 30-32, wherein to provide a request to decrease the transmission power for the transmitter associated with the second of the at least two spatial receiver antennas (21-1, 21-2, .., 21-M) comprises to
    - determine whether the transmission power for the transmitter is below the third threshold criteria (TX1_maxPower);

- in response to determine that the transmission power is not below the third threshold criteria (TX1_maxPower) to:
  - provide a request to decrease transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas; and
- in response to determine that the transmission power is below the third threshold criteria (TX1_maxPower):
  - send a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

34. The receiving arrangement (20) according to claim 33, wherein the processor unit (23) is further configured to:
    - determine whether a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas (21-1, 21-2, .., 21-M) results in a lower data throughput in a second of the at least two spatial receiver antennas (21-1, 21-2, .., 21-M); and
    - in response to determine that a decreasing transmission power for the transmitter associated with a second one of the at least two spatial receiver antennas results in a lower data throughput in a second of the at least two spatial receiver antennas to:
      - provide a request to set a fourth threshold criteria (Thr_RSSI_2) associated with the second of the at least two spatial receiver antennas to a lower threshold value which matches the current feasible throughput.

35. The receiving arrangement (20) according to any of claims 30-34, wherein in response to determine that the second parameter is not below the second threshold criteria (Thr_RSSI_1), to:

- determine whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1);
- in response to determine that the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1) to:
  - provide a request to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

36. The receiving arrangement (20) according to claim 35, wherein in response to determine that the second parameter (RSSI_1) is not below a predetermined higher value of the second threshold criteria (Thr_RSSI_1), to:

- set the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value; and
- in response to the setting of the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value:
  - based upon a counter (Counter_RSSI_2) associated with a fourth threshold criteria (Thr_RSSI_2) of said second one of the at least two receivers being above a predetermined value, to set the fourth threshold criteria (Thr_RSSI_2) to the next lower predetermined value and to decrease a counter (Counter_RSSI_2) associated with the second threshold criteria of said second one of the at least two receivers by one; or
  - based upon the counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) being below a predetermined value, to set the fourth threshold criteria (Thr_RSSI_2) to the next higher predetermined value and to increase a counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) .

37. The receiving arrangement (20) according to claim 32, , wherein in response to determine that the transmission power is not below the third threshold criteria (TX1_maxPower), to:

- determine whether a data throughput is below a predetermined level and in response to determine that the data throughput is below a predetermined level to:
    - set the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas to a next lower threshold value which matches the current feasible throughput; and
    - decrease a counter (Counter_RSSI_1) associated with the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas by one.

38. The receiving arrangement (20) according to claims 30-37, wherein the processor unit (23) comprises a counter for each of the respective first and second threshold criteria and counting any changes in the first and second threshold criteria.

39. Transmitter arrangement (10) in a multiple input-multiple output, MIMO system, comprising:
    - at least two spatial transmitter antennas (11-1, 11-2, .., 11-N), each associated with a respective one of at least two spatial receiver antennas (21-1, 21-2, .., 21-M);
    - a processor unit (13) configured to:
        - determine, in response to a received request to increase transmission power for the first transmitter, whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria (TX1_maxPower);
        - in response to determining that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower):
            - increase the transmission power level for the first transmitter antenna.

40. Transmitter arrangement (10) according to claim 39, wherein the processor unit (13) is further configured to

- receive a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- in response to determine that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is not below the third threshold criteria (TX1_maxPower), to:
  - provide a request to decrease transmission power of the second transmitter.

41. Transmitter arrangement (10) according to claim 40, wherein to provide a request to decrease transmission power for the second transmitter comprises to:
   - determine whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of a lower order; and
   - in response to determine that the MIMO system can provide a higher data throughput to decrease the transmission power for the second transmitter.

42. Transmitter arrangement (10) according to claim 41, wherein in response to determine that the MIMO system cannot provide a higher data throughput compared to a feasible MIMO system of a lower order, to:
   - provide a request to switch from MIMO system to the MIMO system of a lower order.

43. Transmitter arrangement (10) according to any of claims 39-42, wherein to determine that a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower) comprises:
   - to receive a request to increase the transmission power level for the first transmitter antenna.

44. Arrangement (30) for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and at least two spatial transmitter antennas (11-1, 11-2, .., 11-N),

wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas, said arrangement comprising:

- a measurement unit (32) coupled to the at least two spatial receiver antennas (21-1, 21-2, .., 21-M) and configured to measure at least a first parameter (C/I_1) and a second parameter (RSSI_1) different from the first parameter at the respective ones of the at least to two spatial receiver antennas (), said parameters characterizing a signal quality;
- a processor unit (33) coupled to the measurement unit and configured to:
    - determine whether the first parameter meets a first threshold criteria (Thr_C/I_1);
    - in response to determining that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1) to:
        - determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1);
    - in response to determine that the second parameter is below the second threshold criteria (Thr_RSSI_1) or in response to determine that the first parameter is below the first threshold criteria (Thr_C/I_1) to:
        - determine whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower);
        - in response to determining that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria (TX1_maxPower) to:
            - increase the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

45. Arrangement (30) according to claim 44, wherein the first parameter comprises carrier to interference ratio and the second parameter comprises RSSI value.

46. Arrangement (30) according to any of claims 44-45, wherein in response to determine that the first parameter (C/I_1) is below the first threshold (Thr_C/I_1) and that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria (TX1_maxPower) to:
    - provide a request to decrease transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

47. Arrangement (30) according to claim 46, wherein to provide a request to decrease transmission power comprises to:

- determine whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of lower order; and
- in response to determine that the MIMO system can provide a higher data throughput to:
    - decrease the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas.

48. Arrangement (30) according to claim 47, wherein in response to determine that the MIMO system cannot provide a higher data throughput to:

- switch from MIMO system to a MIMO system of a lower order.

49. Arrangement (30) according to any of claims 47-48, wherein in response to determine that the MIMO system can provide a higher data throughput to:

- determine whether a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver antennas;
- in response to determine that a decrease of the transmission power of the transmitter associated with a second of the at least two spatial receiver antennas results in a lower throughput through the second of the two spatial receiver to:

- set a fourth threshold (Thr_RSSI_2) of the second one of the at least two spatial receivers to a lower value which matches the current throughput.

50. Arrangement (30) according to any of claims 44-49, wherein in response to determine that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1) and in response to determine that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is not below the third threshold criteria (TX1_maxPower) to:

   - determine whether a data throughput is below a predetermined level and in response to determine that the data throughput is below a predetermined level to:
      - set the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas to a lower threshold value which matches the current throughput.

51. Arrangement (30) according to claim 50, wherein to determine that the data throughput is below a predetermined level further comprises to:

- determine whether a fifth parameter (Thr_RSSI_2) associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria (Thr_RSSI_2_max) ; and
- in response to determine that the fifth parameter is below the maximal value of the fourth threshold (Thr_RSSI_2_max) to:
   - determine whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value (Tx2_maxPower); and in response that the power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below the sixth threshold value (Tx2_maxPower) to:
      - set the fourth threshold criteria (Thr_RSSI_2) to the next higher value.

52. Arrangement (30) according to any of claims 44-51, wherein in response to determine that the second parameter (RSSI_1) is not below the second threshold criteria (Thr_RSSI_1) to:

- determine whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1); and
- in response to determine that the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1);
    - to decrease the transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

53. Arrangement (30) according to claim 52, wherein in response to determine that the second parameter (RSSI_1) is not below a predetermined higher value of the second threshold criteria (Thr_RSSI_1), to:

- set the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value; and
- in response to the setting of the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value:
    - based upon a counter (Counter_RSSI_2) associated with a fourth threshold criteria (Thr_RSSI_2) of said second one of the at least two receivers being above a predetermined value, to set the fourth threshold criteria (Thr_RSSI_2) to the next lower predetermined value and to decrease a counter (Counter_RSSI_2) associated with the second threshold criteria of said second one of the at least two receivers by one; or
    - based upon the counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2) being below a predetermined value, to set the fourth threshold criteria (Thr_RSSI_2) to the next higher predetermined value and to increase a counter (Counter_RSSI_2) associated with the fourth threshold criteria (Thr_RSSI_2).

54. Arrangement (30) according to any of claims 44-53, wherein the first parameter comprises carrier to interference ratio and the second parameter comprises RSSI value.

55. Arrangement (30) according to any of claims 44-54, wherein the processor unit (33) is further configured to comprise:

- a counter for each of the respective first and second threshold criteria and counting up upon a change in the first and second threshold criteria to a higher value and counting down upon a change in the first and second threshold criteria to a lower value.

56. A receiver arrangement (200) for adaptive power control of a Multiple Input Multiple Output, MIMO system, said MIMO system comprising at least two spatial receiver antennas, said arrangement comprising:

- A first measurement module (Sx10) arranged to measure a first parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
- A first decision module (Sx11) arranged to determine whether the first parameter is below a first threshold criteria (Thr_C/I_1);
- In response to determining that the first parameter (C/I_1) is below the first threshold criteria:
  - A first provider module (Sx20) arranged to provide a request to decrease a transmission power for a transmitter associated with the second of the at least two spatial receiver antennas; and
- In response to determining that the first parameter (C/I_1) is not below the first threshold criteria (Thr_C/I_1):
  - A second measurement module (Sx12) arranged to measure a second parameter (RSSI_1) of the signal received at the first one of the at least two spatial receiver antennas, the second parameter different from the first parameter;
  - A second decision module (Sx13) arranged to determine whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1);
  - In response to determining that the second parameter (RSSI_1) is below the second threshold criteria (Thr_RSSI_1):

- A second provider module (Sx30) configured to provide a request to increase the transmission power for a transmitter associated with the first one of the at least two spatial receiver antennas.

57. A transmitter arrangement (100) for adaptive power control of a Multiple Input Multiple Output, MIMO system comprising at least two spatial transmitter antennas, comprising:
    - a decision module (Sx301) configured to determine whether a transmission power level for a first transmitter antenna of the at least two spatial transmitter antennas is below a third threshold criteria (TX1_maxPower);
    - in response to determine that the transmission power level for the first transmitter antenna of the at least two spatial transmitter antennas is below the third threshold criteria (TX1_maxPower):
        - A regulator module (Sx302a) configured to increasing the transmission power level for the first transmitter antenna.

58. An adaptive power control of a Multiple Input Multiple Output, MIMO system, (300) said MIMO system comprising at least two spatial receiver antennas and at least two spatial transmitter antennas, wherein each of the at least two transmitter antennas is associated with a respective one of the at least two receiver antennas, said adaptive power control comprising:
    - A first measuring module (Sx10) configured to measure a first parameter (C/I_1) of a signal received at a first one of the at least two spatial receiver antennas, said first parameter characterizing a signal quality;
    - A first decision module (Sx11) configured to determine whether the first parameter meets a first threshold criteria (Thr_C/I_1);
    - In response to determine that the first parameter is not below the first threshold criteria (Thr_C/I_1):
        - A second measuring module (Sx12) configured to measure a second parameter (RSSI_1) of the signal received at the first one of the at least two

spatial receiver antennas, the second parameter different from the first parameter;

  - A second decision module (Sx13) configured to determine whether the second parameter is below a second threshold criteria (Thr_RSSI_1);

- In response to determine that the second parameter is below the second threshold criteria (Thr_RSSI_1) or in response to determine that the first parameter is below the first threshold criteria (Thr_C/I_1):
  - A third decision module (Sx201, Sx301) configured to determine whether a transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below a third threshold criteria (TX1_maxPower);
  - In response to determine that the transmission power level for the transmitter associated with the first of the at least two spatial receiver antennas is below the third threshold criteria (TX1_maxPower):
    - A regulator module (Sx302a) configured to increase the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas.

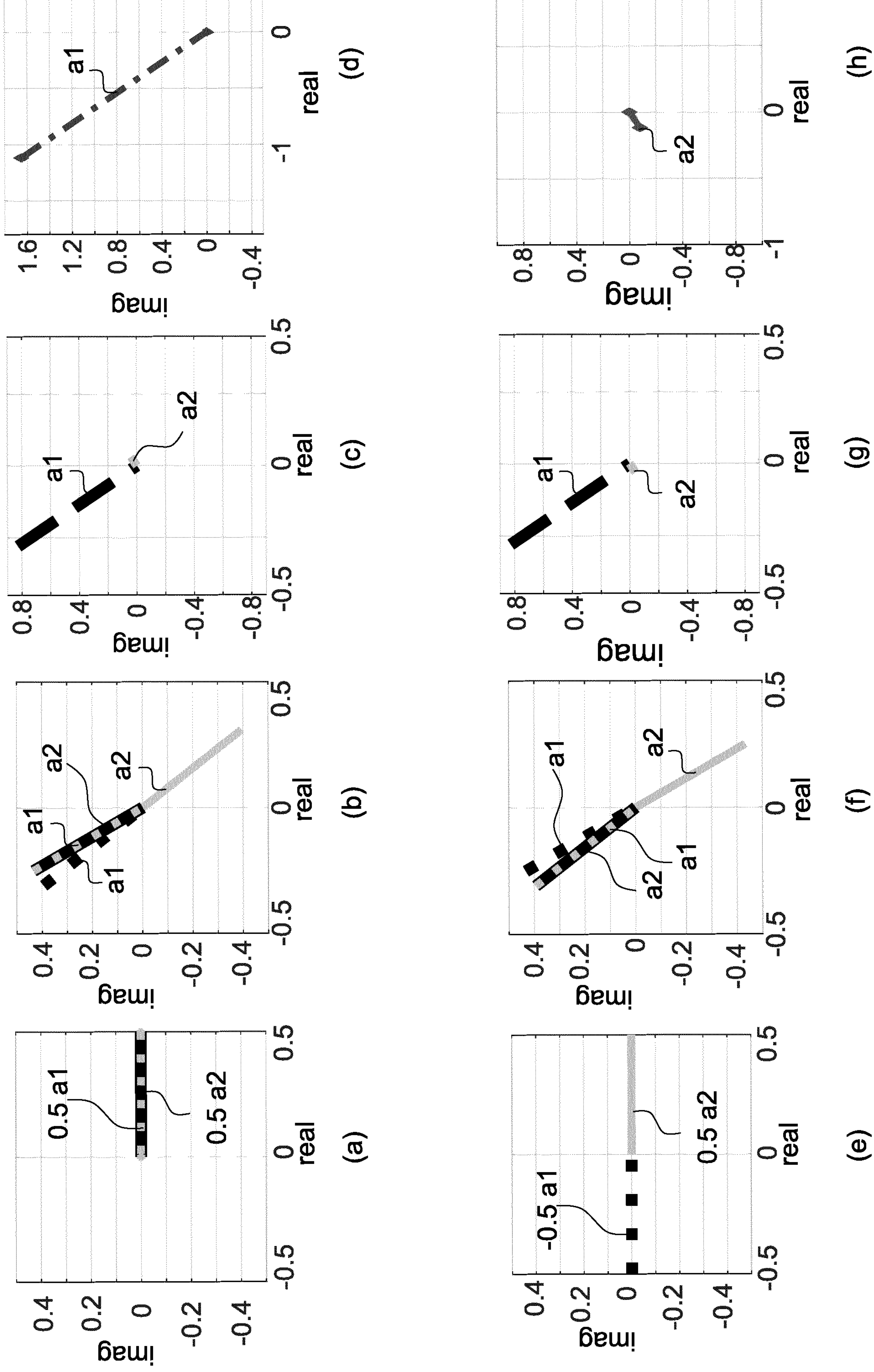



FIG 1

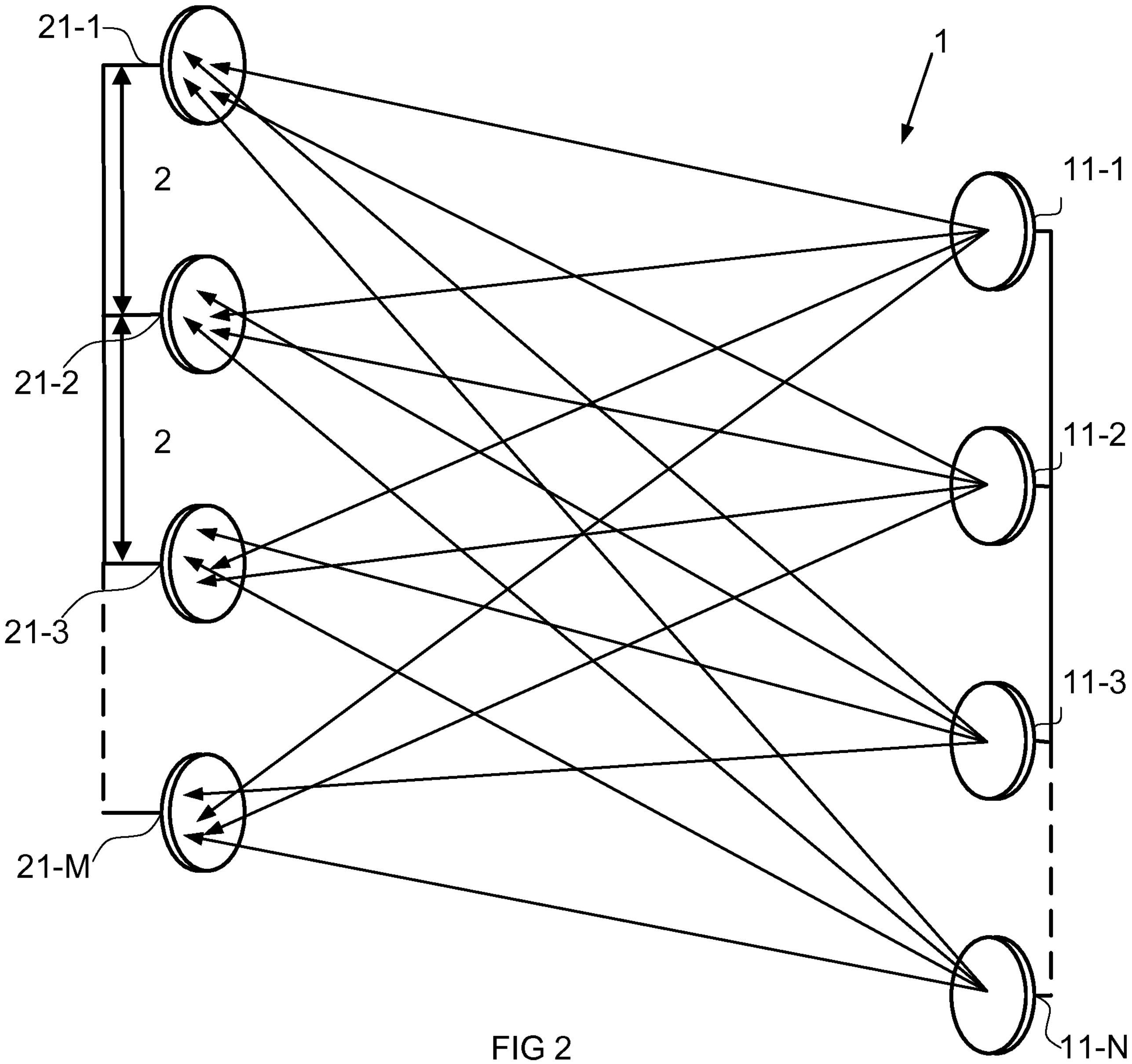
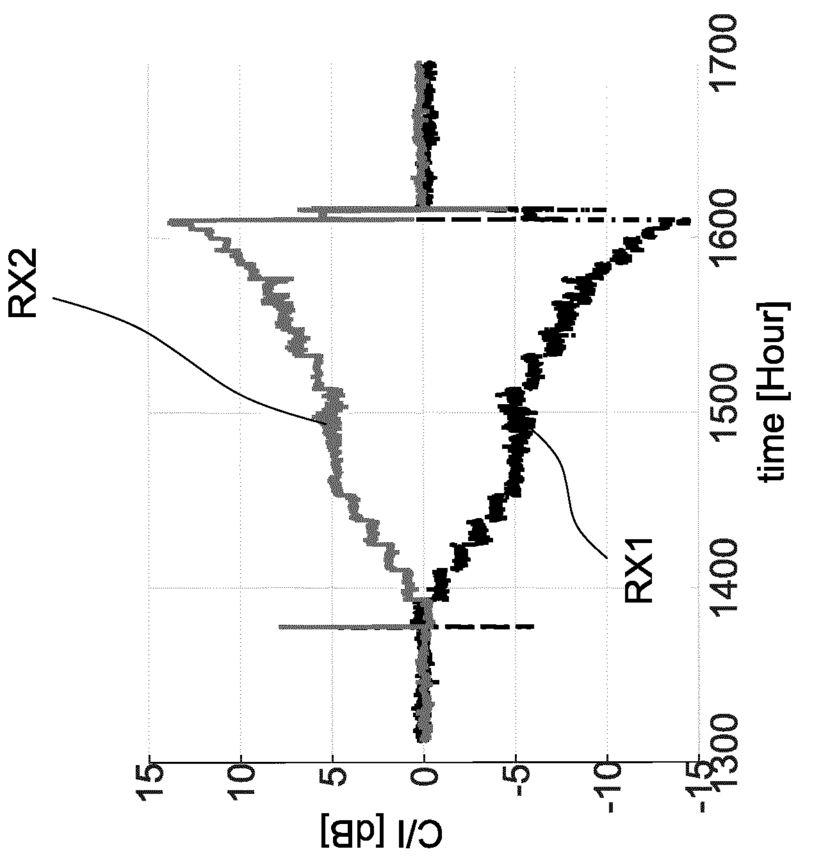
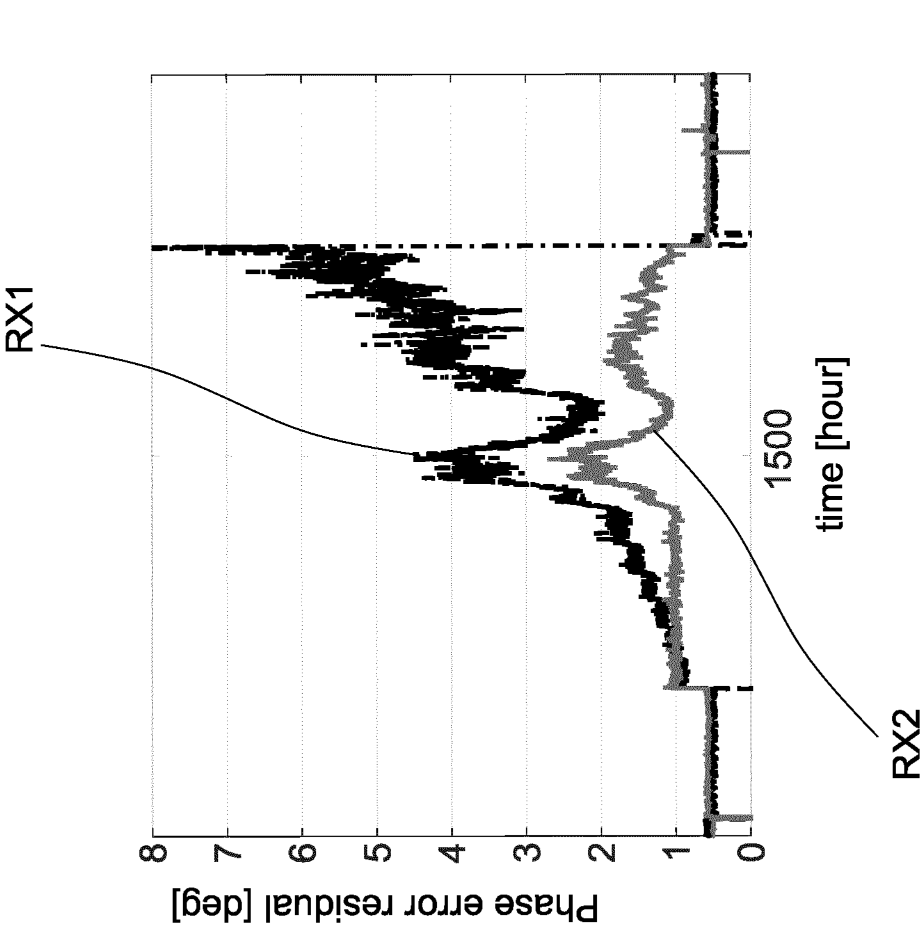



FIG 2



RX2
RX1
C/I [dB]
15
10
5
0
-5
-10
-15
1300
1400
1500
1600
1700
time [Hour]


FIG 3A



RX1
RX2
Phase error residual [deg]
8
7
6
5
4
3
2
1
0
1500
time [hour]


FIG 3B

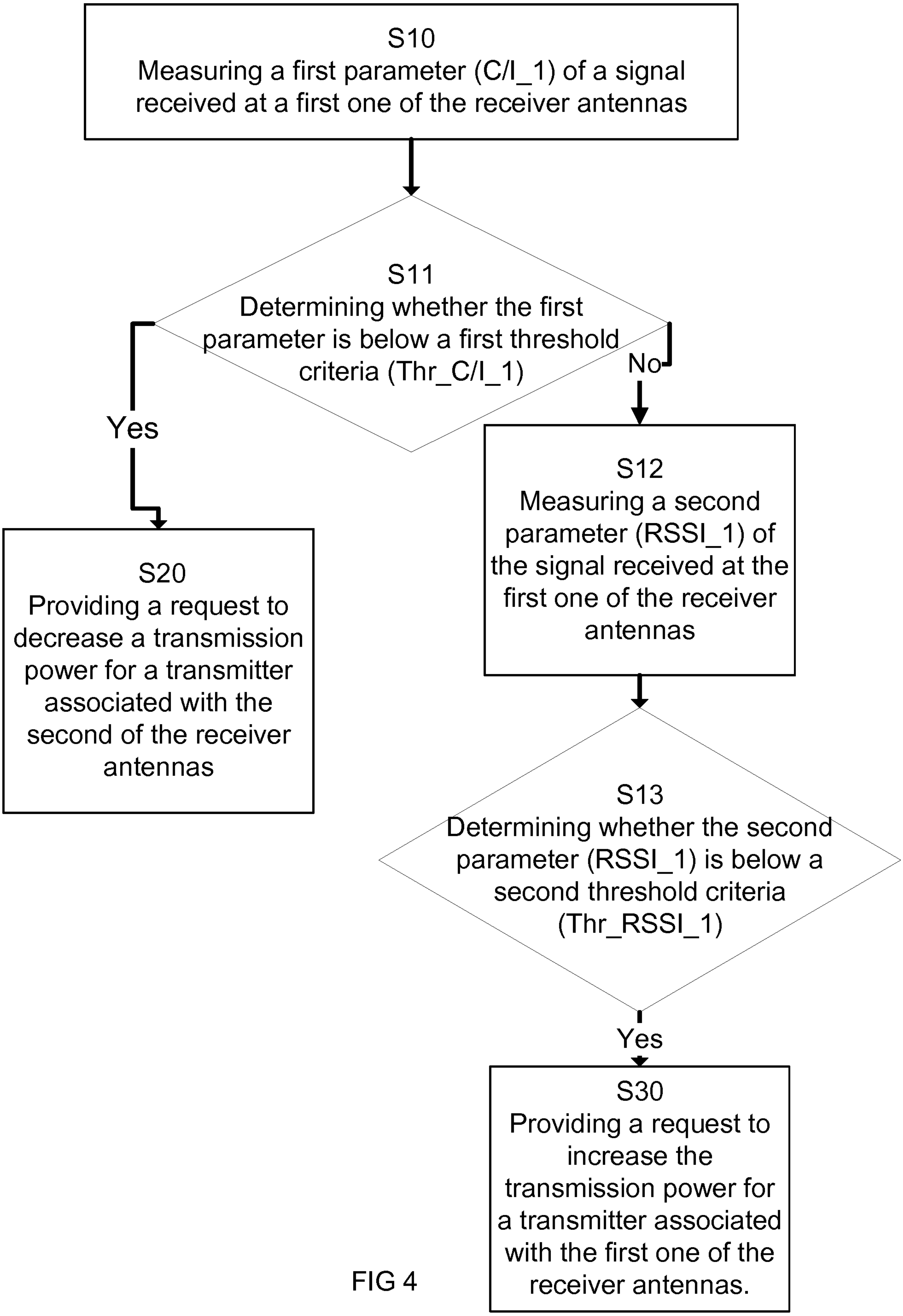

S10
Measuring a first parameter (C/I_1) of a signal received at a first one of the receiver antennas
S11
Determining whether the first parameter is below a first threshold criteria (Thr_C/I_1)
Yes
No
S20
Providing a request to decrease a transmission power for a transmitter associated with the second of the receiver antennas
S12
Measuring a second parameter (RSSI_1) of the signal received at the first one of the receiver antennas
S13
Determining whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1)
Yes
S30
Providing a request to increase the transmission power for a transmitter associated with the first one of the receiver antennas.

FIG 4

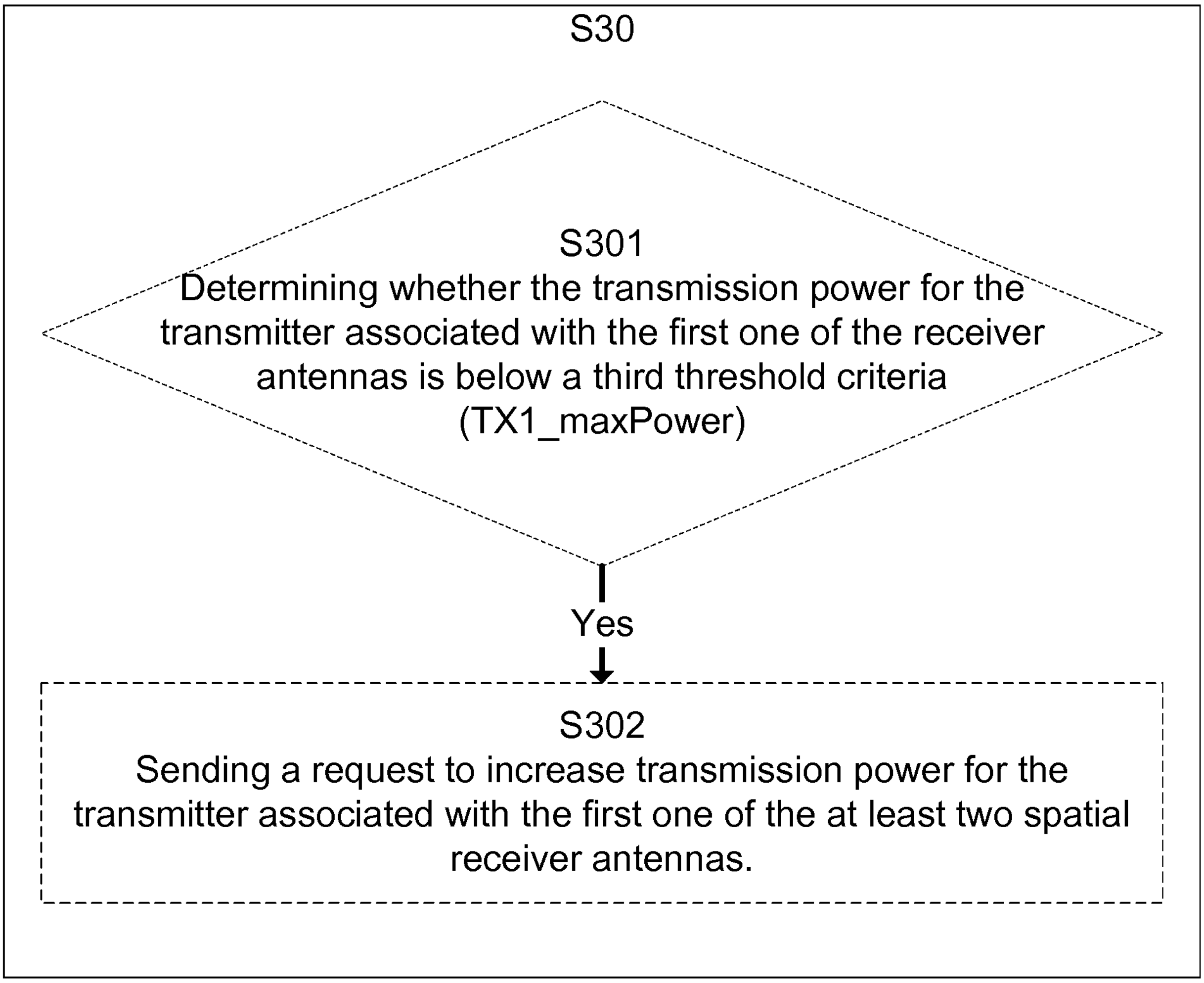

S30
S301
Determining whether the transmission power for the transmitter associated with the first one of the receiver antennas is below a third threshold criteria (TX1_maxPower)
Yes
S302
Sending a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.

FIG 5

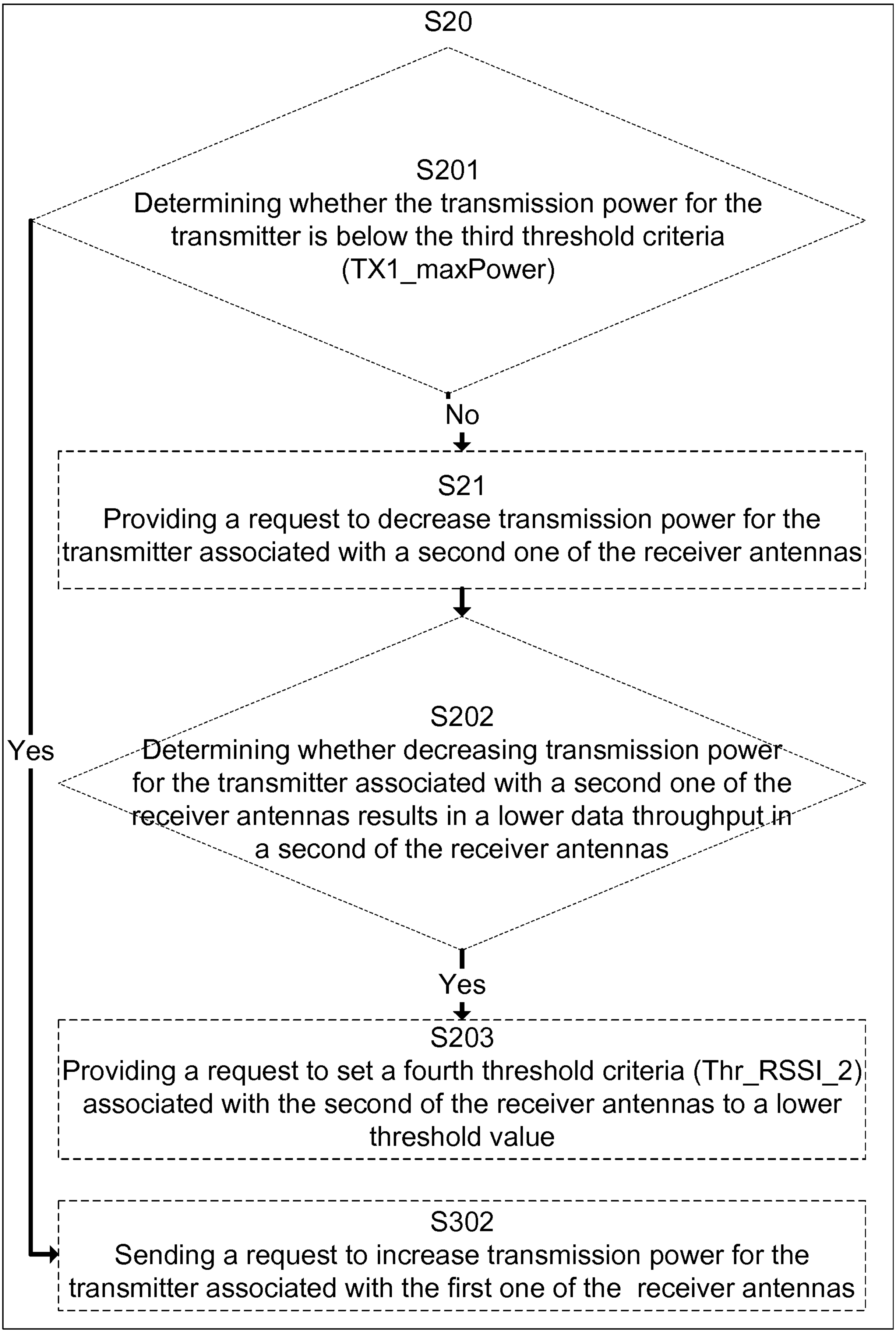

S20
S201
Determining whether the transmission power for the transmitter is below the third threshold criteria (TX1_maxPower)
No
S21
Providing a request to decrease transmission power for the transmitter associated with a second one of the receiver antennas
S202
Determining whether decreasing transmission power for the transmitter associated with a second one of the receiver antennas results in a lower data throughput in a second of the receiver antennas
Yes
Yes
S203
Providing a request to set a fourth threshold criteria (Thr_RSSI_2) associated with the second of the receiver antennas to a lower threshold value
S302
Sending a request to increase transmission power for the transmitter associated with the first one of the receiver antennas

FIG 6

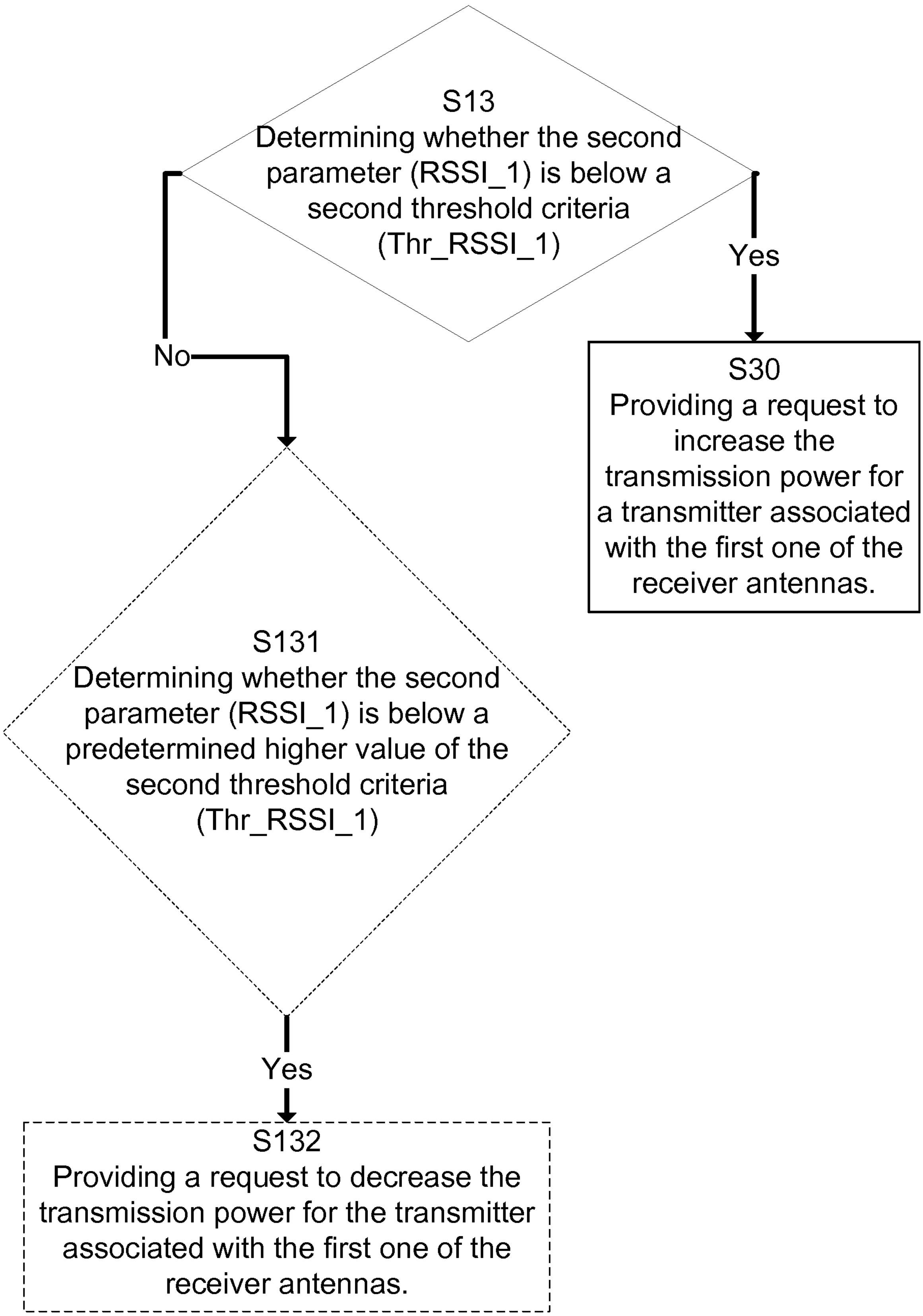

S13
Determining whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1)
Yes
No
S30
Providing a request to increase the transmission power for a transmitter associated with the first one of the receiver antennas.
S131
Determining whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1)
Yes
S132
Providing a request to decrease the transmission power for the transmitter associated with the first one of the receiver antennas.

FIG 7

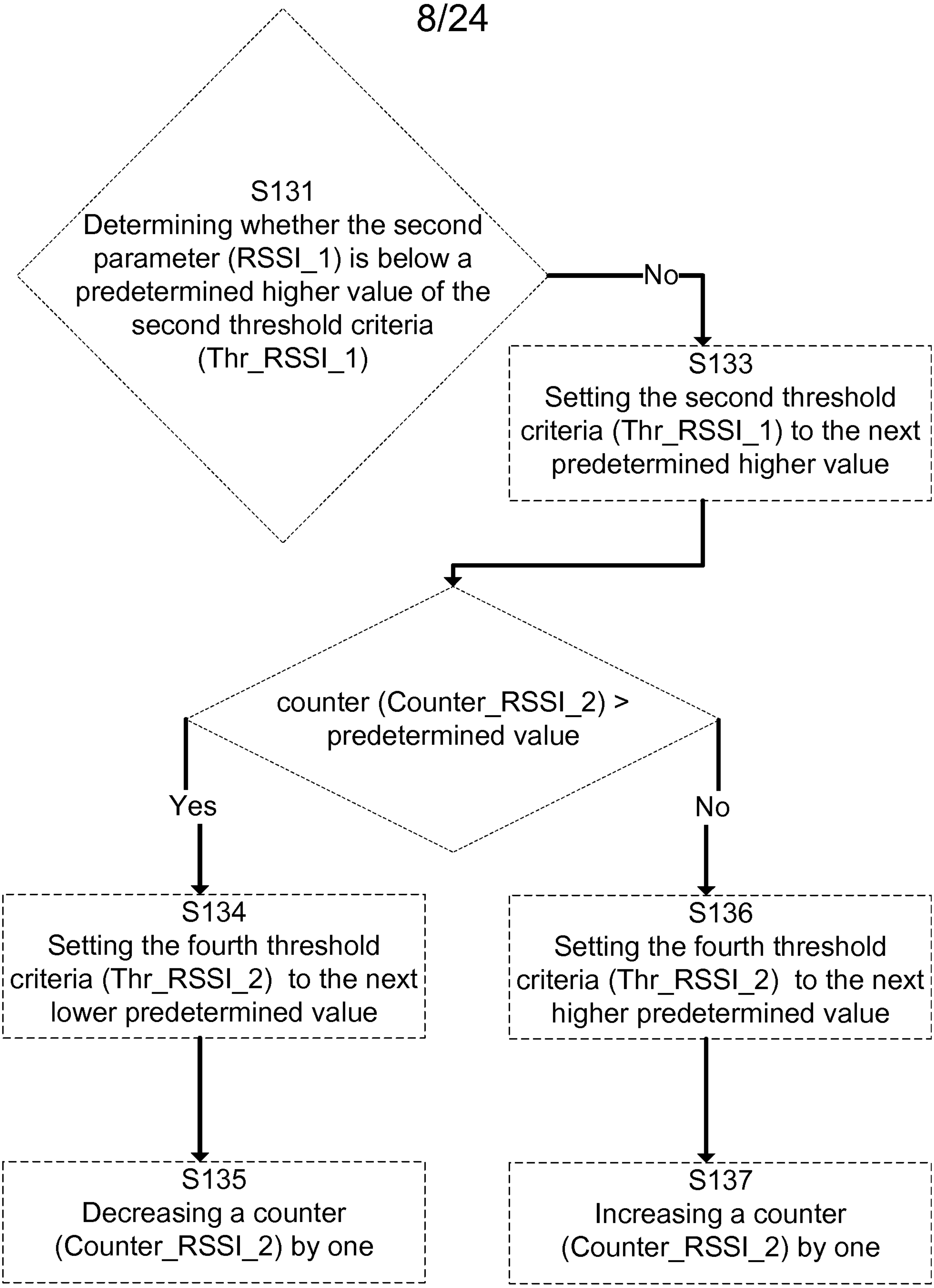

S131
Determining whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1)
No
S133
Setting the second threshold criteria (Thr_RSSI_1) to the next predetermined higher value
counter (Counter_RSSI_2) > predetermined value
Yes
No
S134
Setting the fourth threshold criteria (Thr_RSSI_2) to the next lower predetermined value
S136
Setting the fourth threshold criteria (Thr_RSSI_2) to the next higher predetermined value
S135
Decreasing a counter (Counter_RSSI_2) by one
S137
Increasing a counter (Counter_RSSI_2) by one

FIG 8

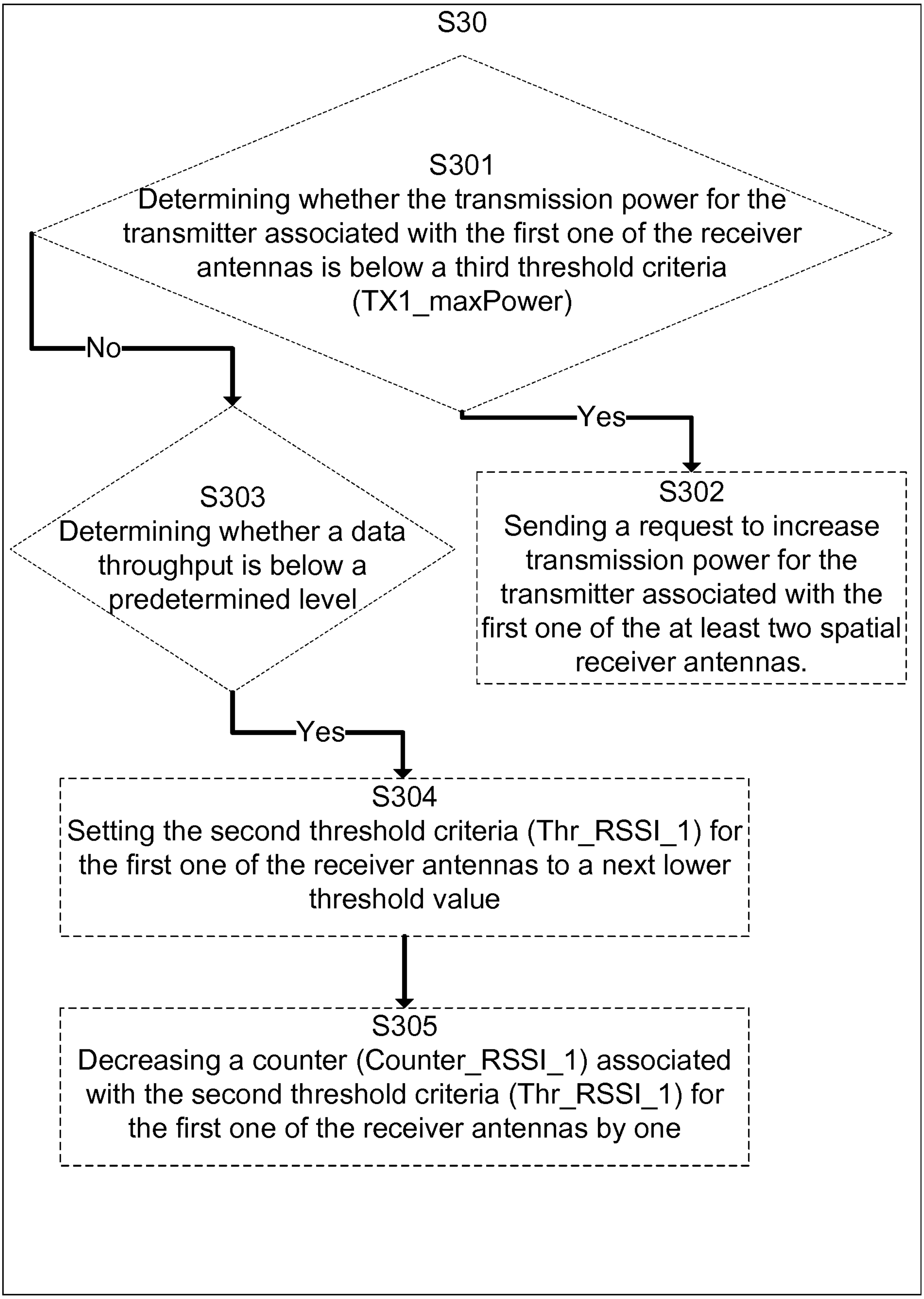

S30
S301
Determining whether the transmission power for the transmitter associated with the first one of the receiver antennas is below a third threshold criteria (TX1_maxPower)
No
Yes
S303
Determining whether a data throughput is below a predetermined level
S302
Sending a request to increase transmission power for the transmitter associated with the first one of the at least two spatial receiver antennas.
Yes
S304
Setting the second threshold criteria (Thr_RSSI_1) for the first one of the receiver antennas to a next lower threshold value
S305
Decreasing a counter (Counter_RSSI_1) associated with the second threshold criteria (Thr_RSSI_1) for the first one of the receiver antennas by one

FIG 9

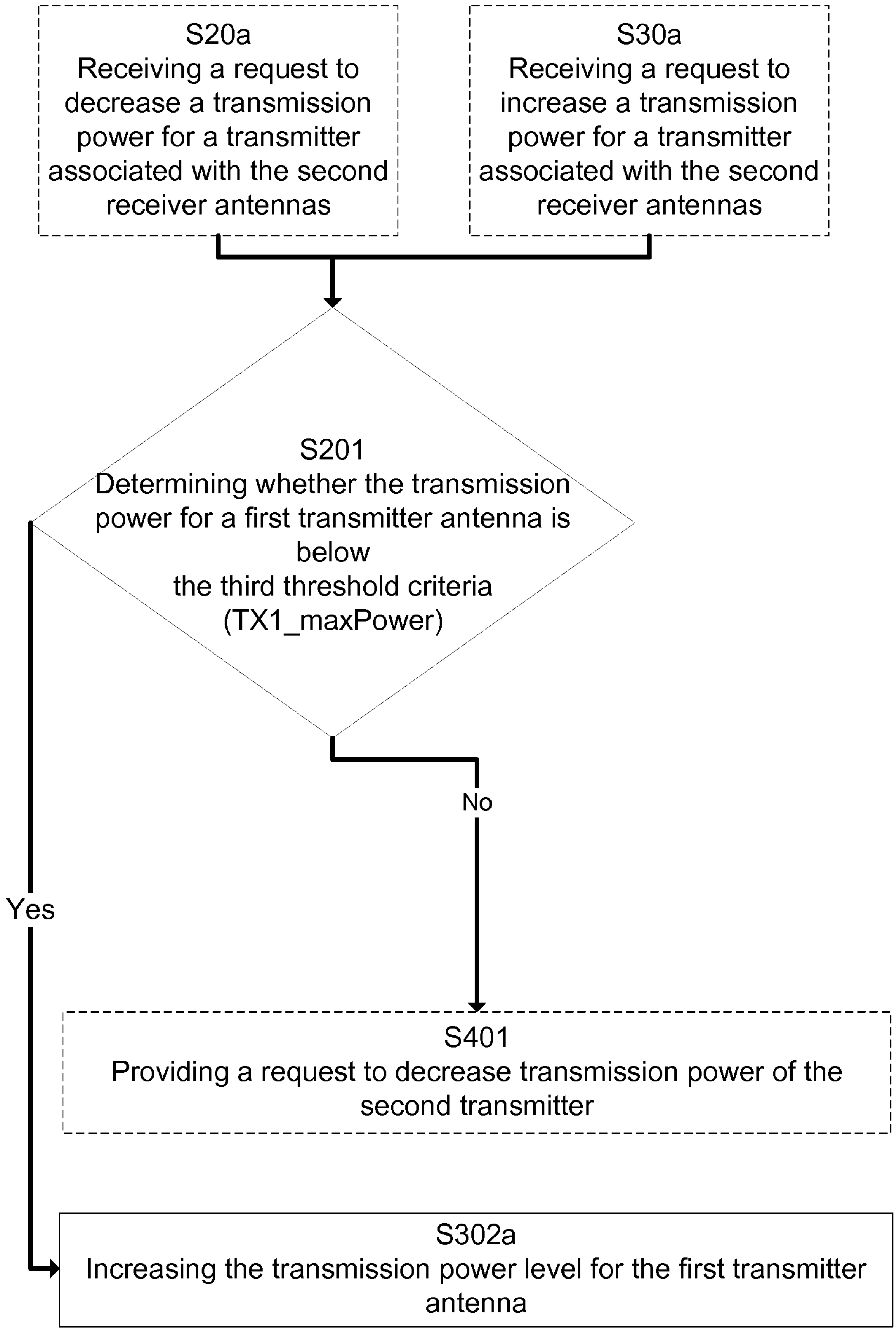

S20a
Receiving a request to decrease a transmission power for a transmitter associated with the second receiver antennas
S30a
Receiving a request to increase a transmission power for a transmitter associated with the second receiver antennas
S201
Determining whether the transmission power for a first transmitter antenna is below
the third threshold criteria (TX1_maxPower)
No
Yes
S401
Providing a request to decrease transmission power of the second transmitter
S302a
Increasing the transmission power level for the first transmitter antenna

FIG 10

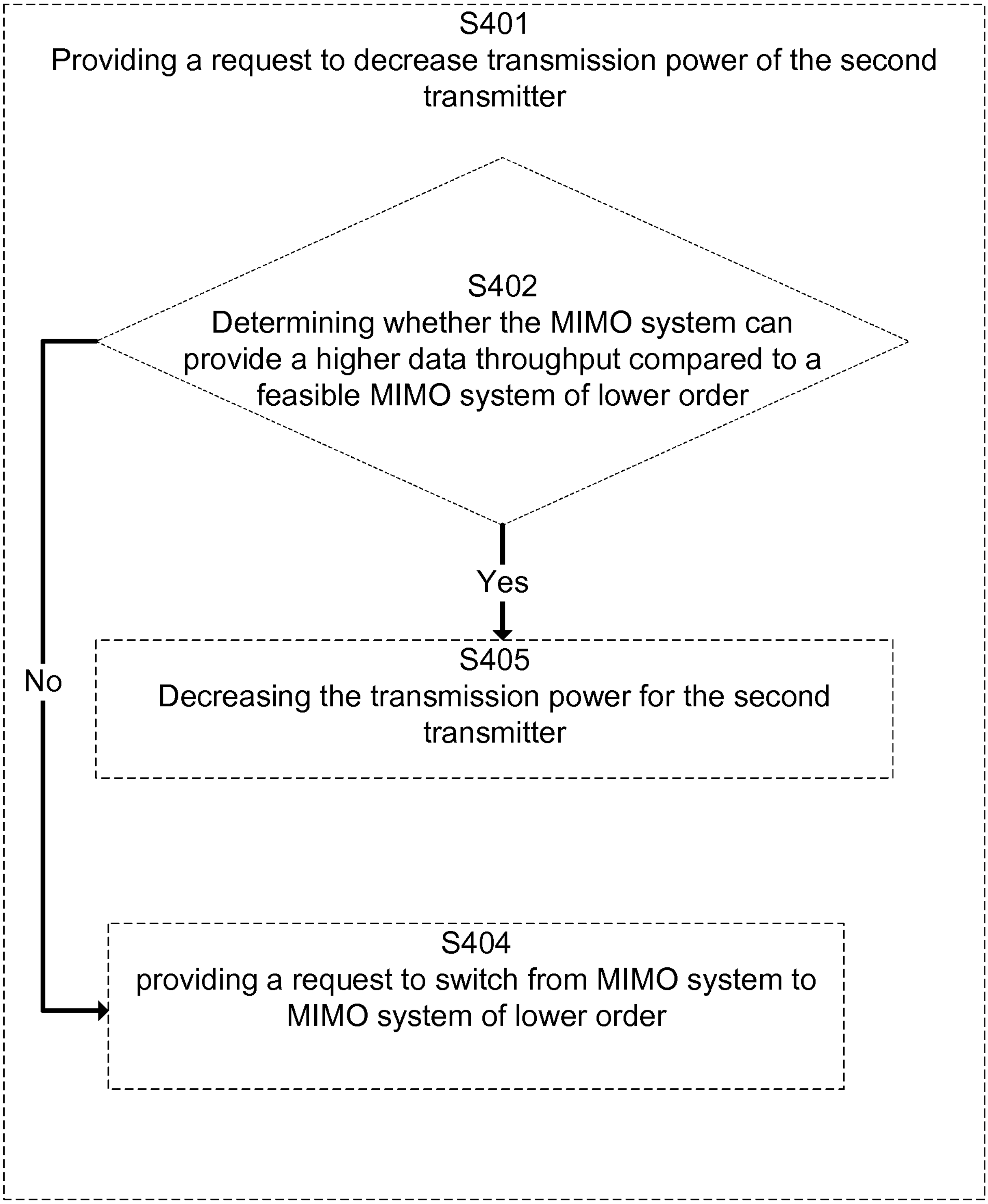

S401
Providing a request to decrease transmission power of the second transmitter
S402
Determining whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of lower order
Yes
No
S405
Decreasing the transmission power for the second transmitter
S404
providing a request to switch from MIMO system to MIMO system of lower order

FIG 11

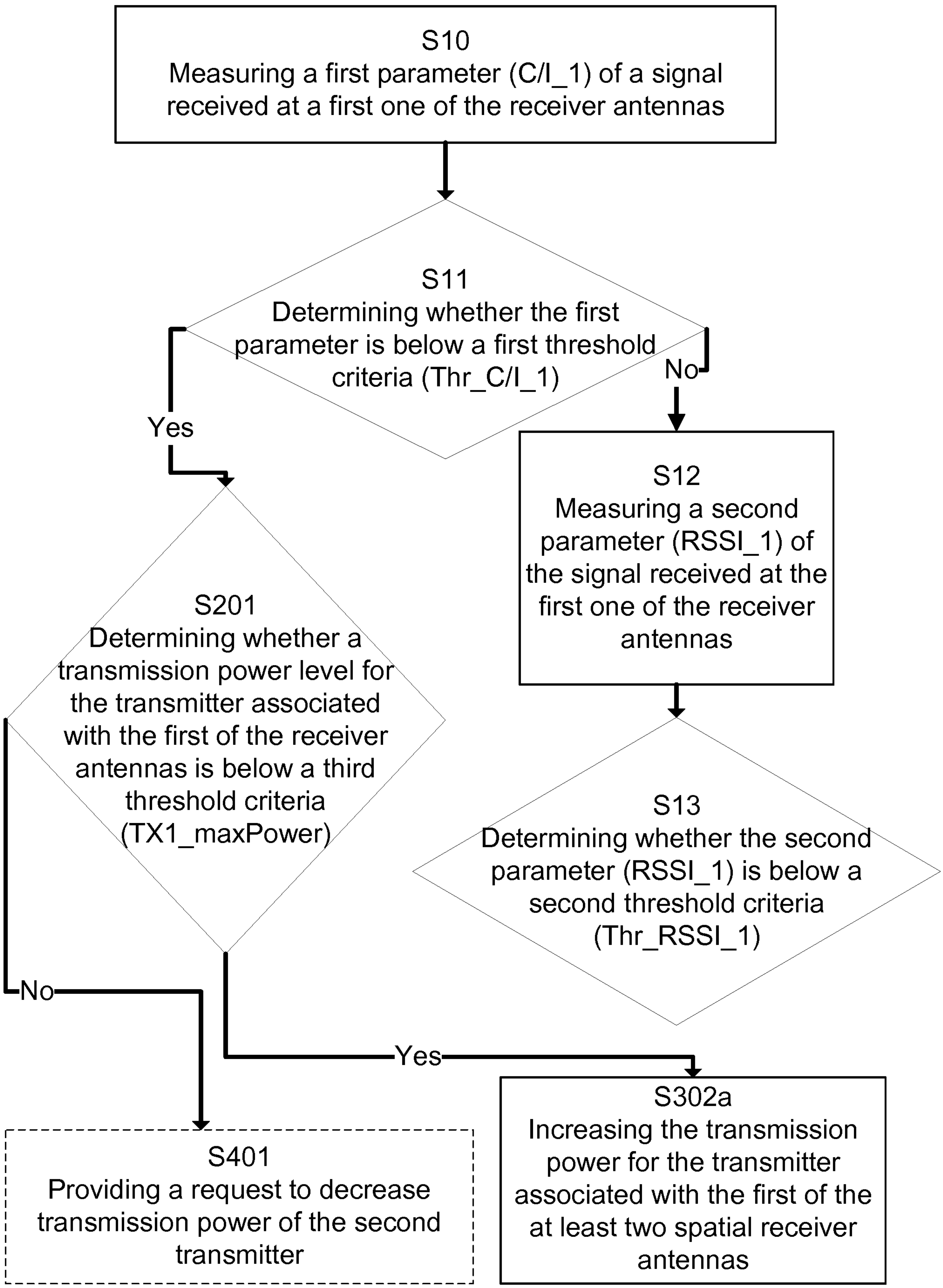

S10
Measuring a first parameter (C/I_1) of a signal received at a first one of the receiver antennas
S11
Determining whether the first parameter is below a first threshold criteria (Thr_C/I_1)
Yes
No
S12
Measuring a second parameter (RSSI_1) of the signal received at the first one of the receiver antennas
S201
Determining whether a transmission power level for the transmitter associated with the first of the receiver antennas is below a third threshold criteria (TX1_maxPower)
S13
Determining whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1)
No
Yes
S401
Providing a request to decrease transmission power of the second transmitter
S302a
Increasing the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas

FIG 12

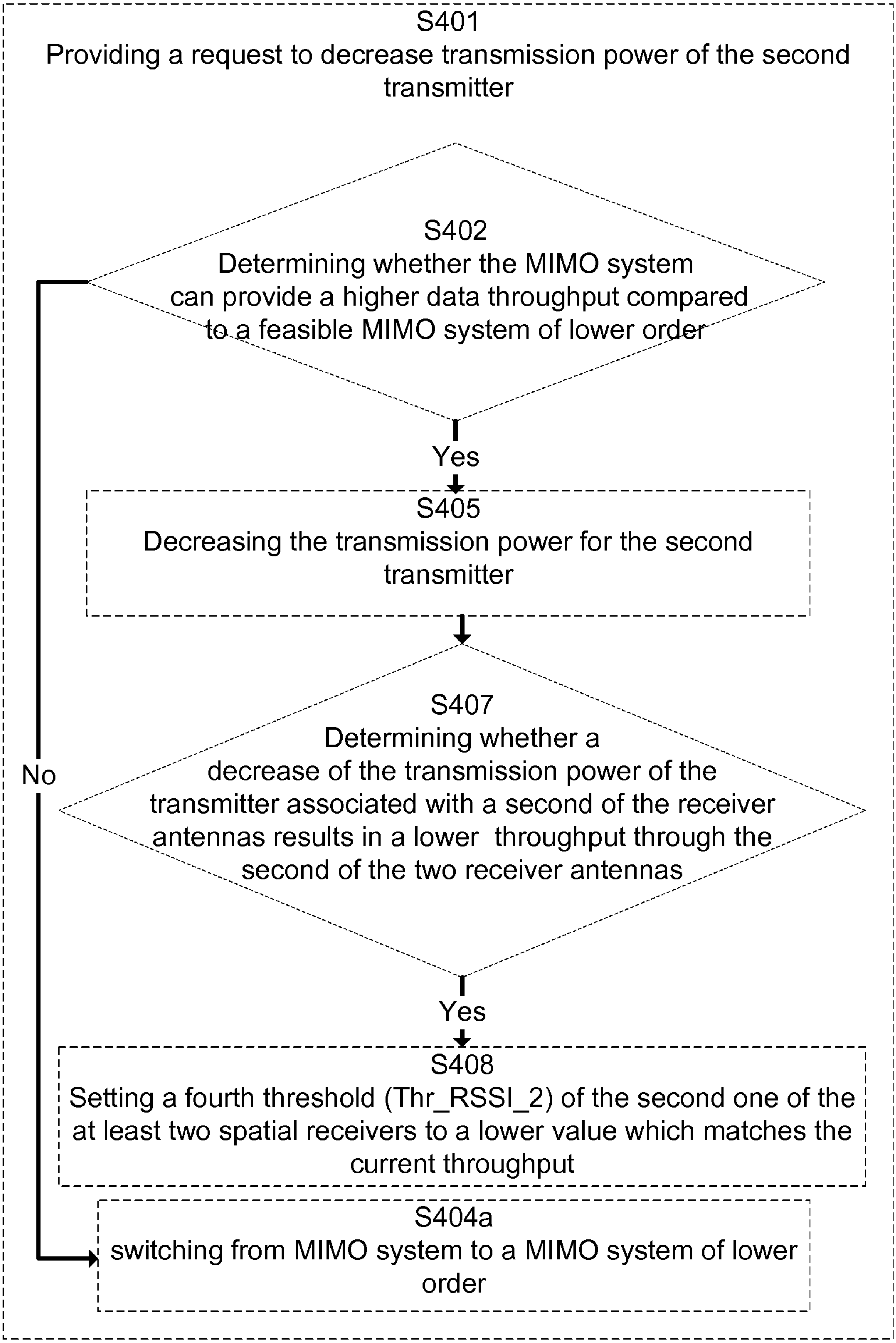

S401
Providing a request to decrease transmission power of the second transmitter
S402
Determining whether the MIMO system can provide a higher data throughput compared to a feasible MIMO system of lower order
Yes
No
S405
Decreasing the transmission power for the second transmitter
S407
Determining whether a decrease of the transmission power of the transmitter associated with a second of the receiver antennas results in a lower throughput through the second of the two receiver antennas
Yes
S408
Setting a fourth threshold (Thr_RSSI_2) of the second one of the at least two spatial receivers to a lower value which matches the current throughput
S404a
switching from MIMO system to a MIMO system of lower order

FIG 13

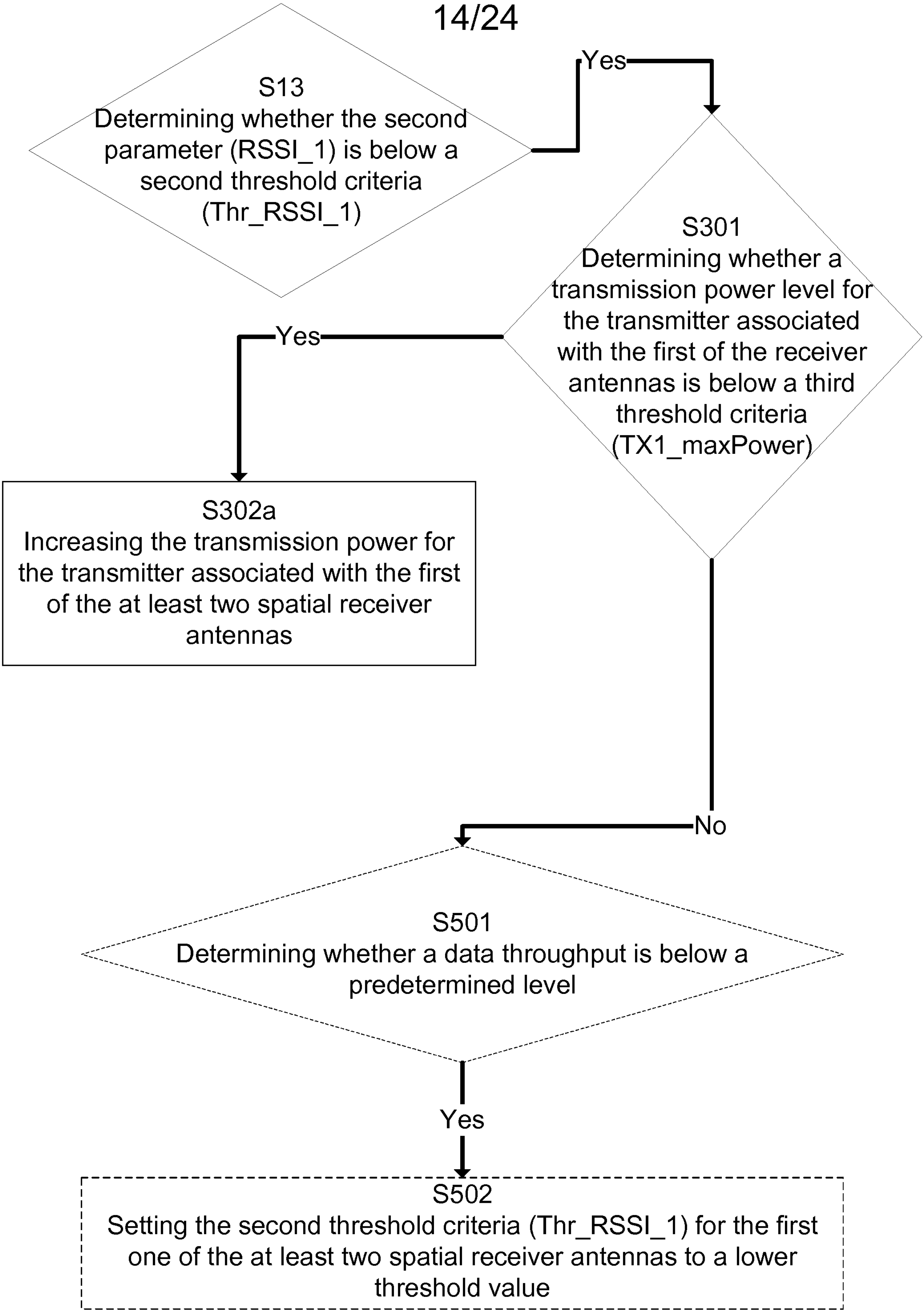

S13
Determining whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1)
Yes
S301
Determining whether a transmission power level for the transmitter associated with the first of the receiver antennas is below a third threshold criteria (TX1_maxPower)
Yes
S302a
Increasing the transmission power for the transmitter associated with the first of the at least two spatial receiver antennas
No
S501
Determining whether a data throughput is below a predetermined level
Yes
S502
Setting the second threshold criteria (Thr_RSSI_1) for the first one of the at least two spatial receiver antennas to a lower threshold value

FIG 14

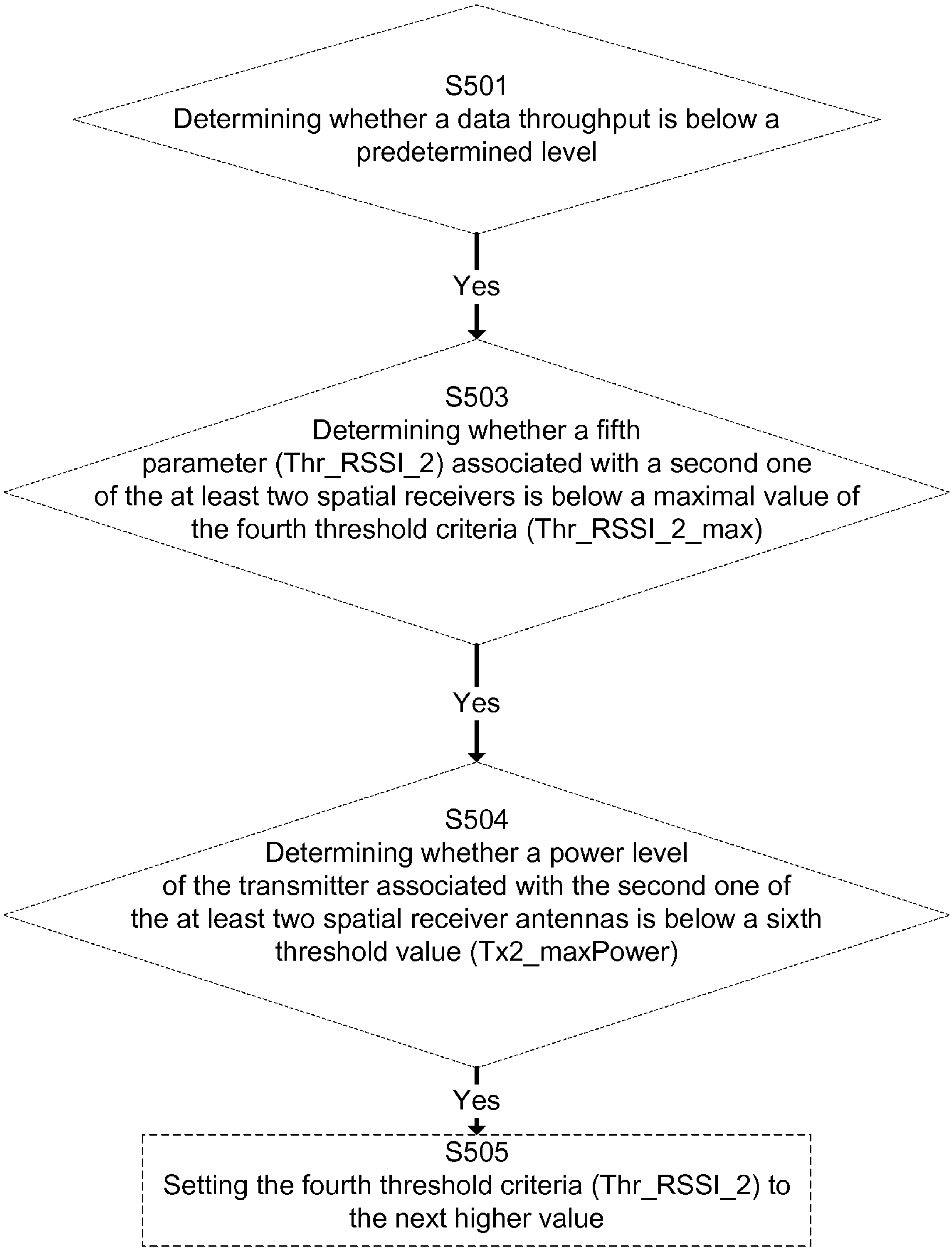

S501
Determining whether a data throughput is below a predetermined level
Yes
S503
Determining whether a fifth parameter (Thr_RSSI_2) associated with a second one of the at least two spatial receivers is below a maximal value of the fourth threshold criteria (Thr_RSSI_2_max)
Yes
S504
Determining whether a power level of the transmitter associated with the second one of the at least two spatial receiver antennas is below a sixth threshold value (Tx2_maxPower)
Yes
S505
Setting the fourth threshold criteria (Thr_RSSI_2) to the next higher value

FIG 15

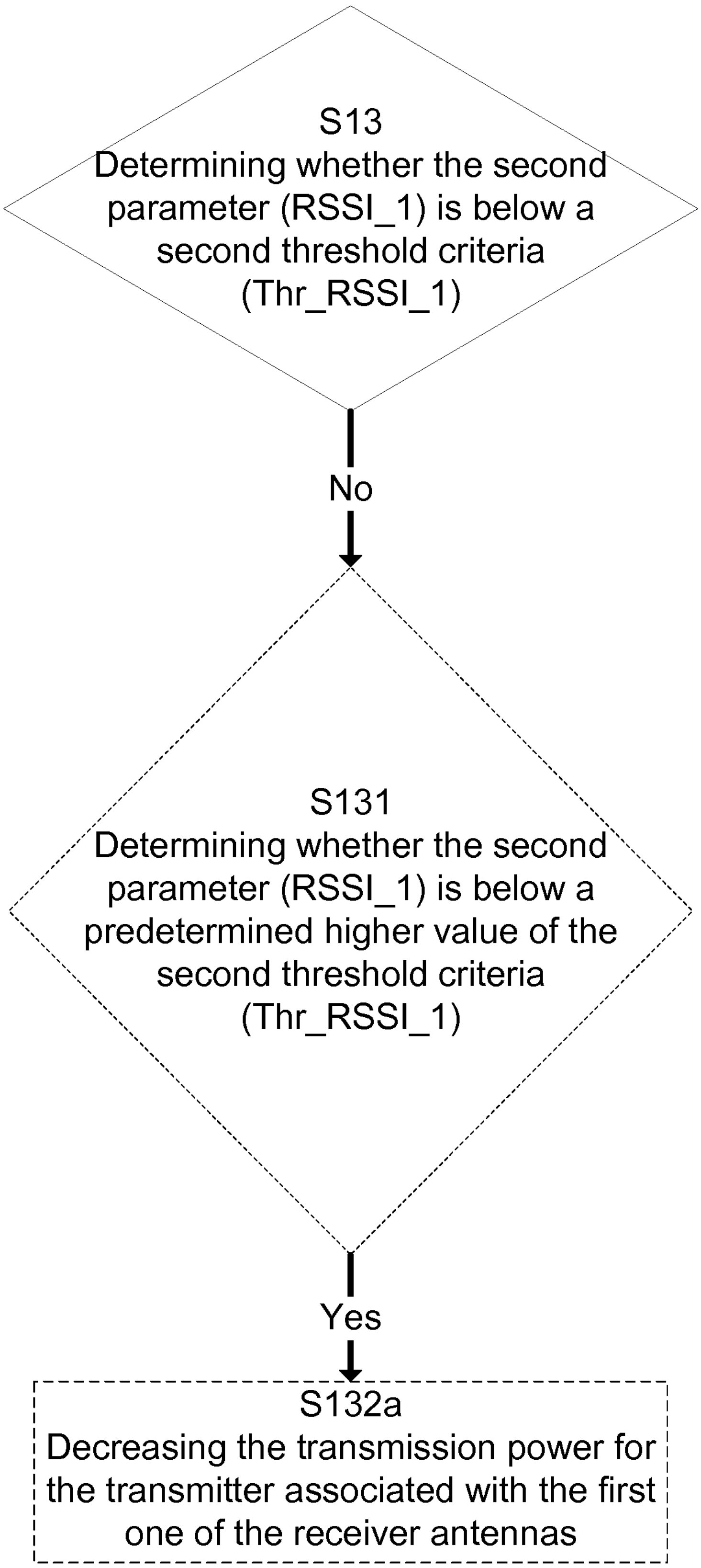

S13
Determining whether the second parameter (RSSI_1) is below a second threshold criteria (Thr_RSSI_1)
No
S131
Determining whether the second parameter (RSSI_1) is below a predetermined higher value of the second threshold criteria (Thr_RSSI_1)
Yes
S132a
Decreasing the transmission power for the transmitter associated with the first one of the receiver antennas

FIG 16

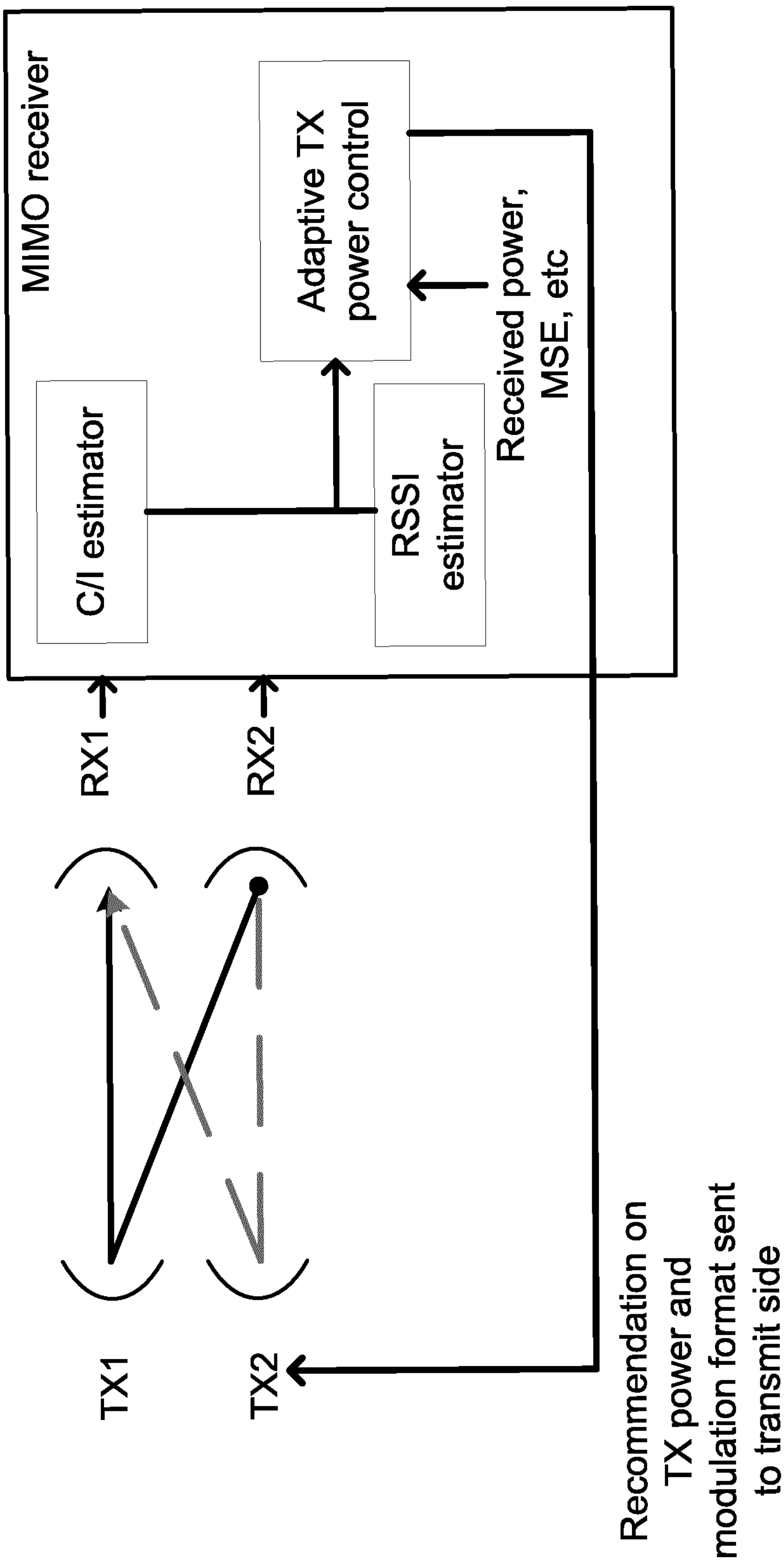

MIMO receiver
Adaptive TX power control
C/I estimator
RSSI estimator
Received power, MSE, etc
RX1
RX2
TX1
TX2
Recommendation on TX power and modulation format sent to transmit side

FIG 17

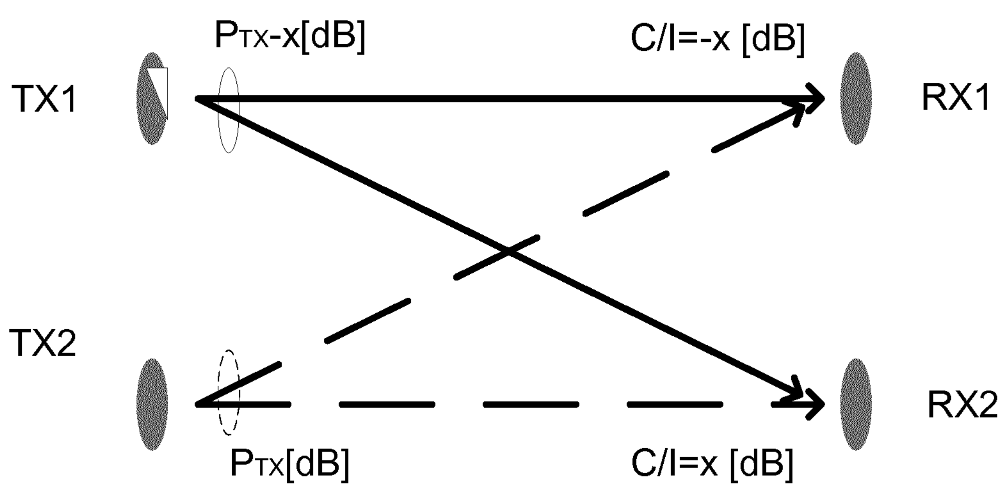



FIG 18A

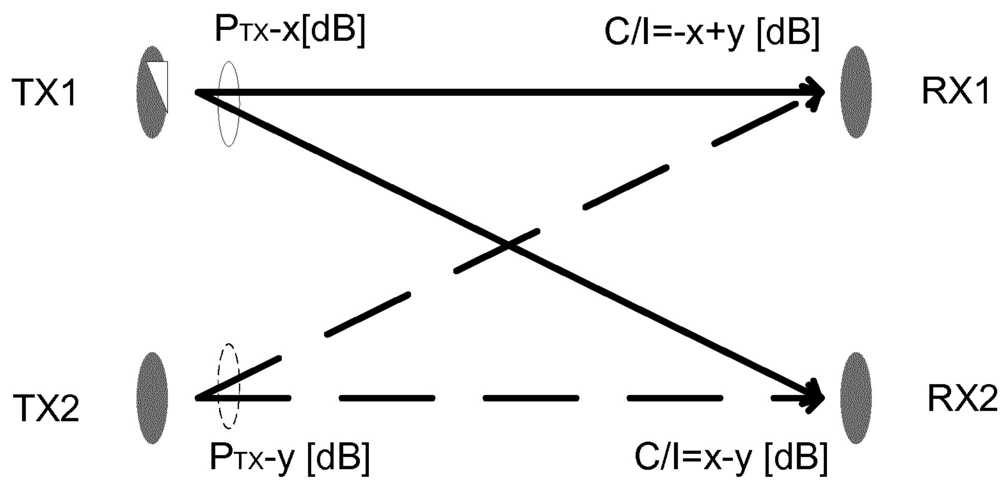



FIG 18B

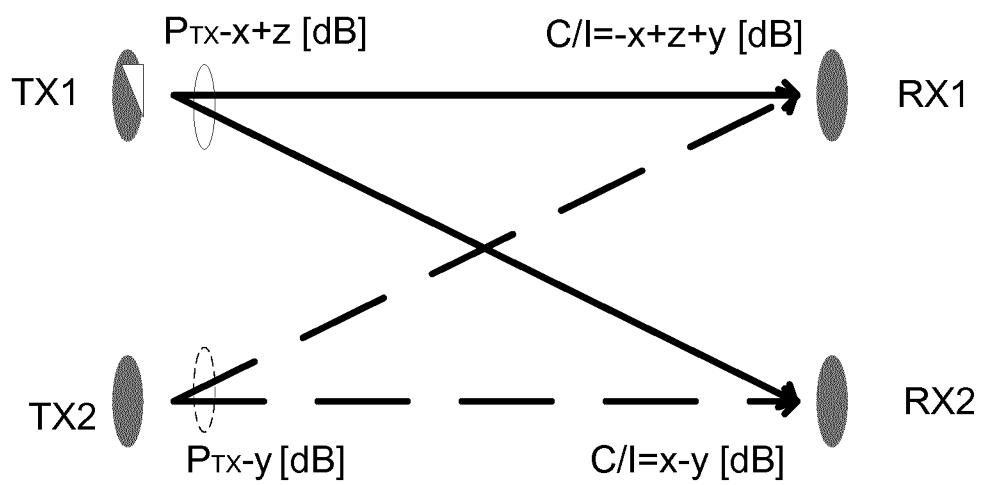



FIG 18C

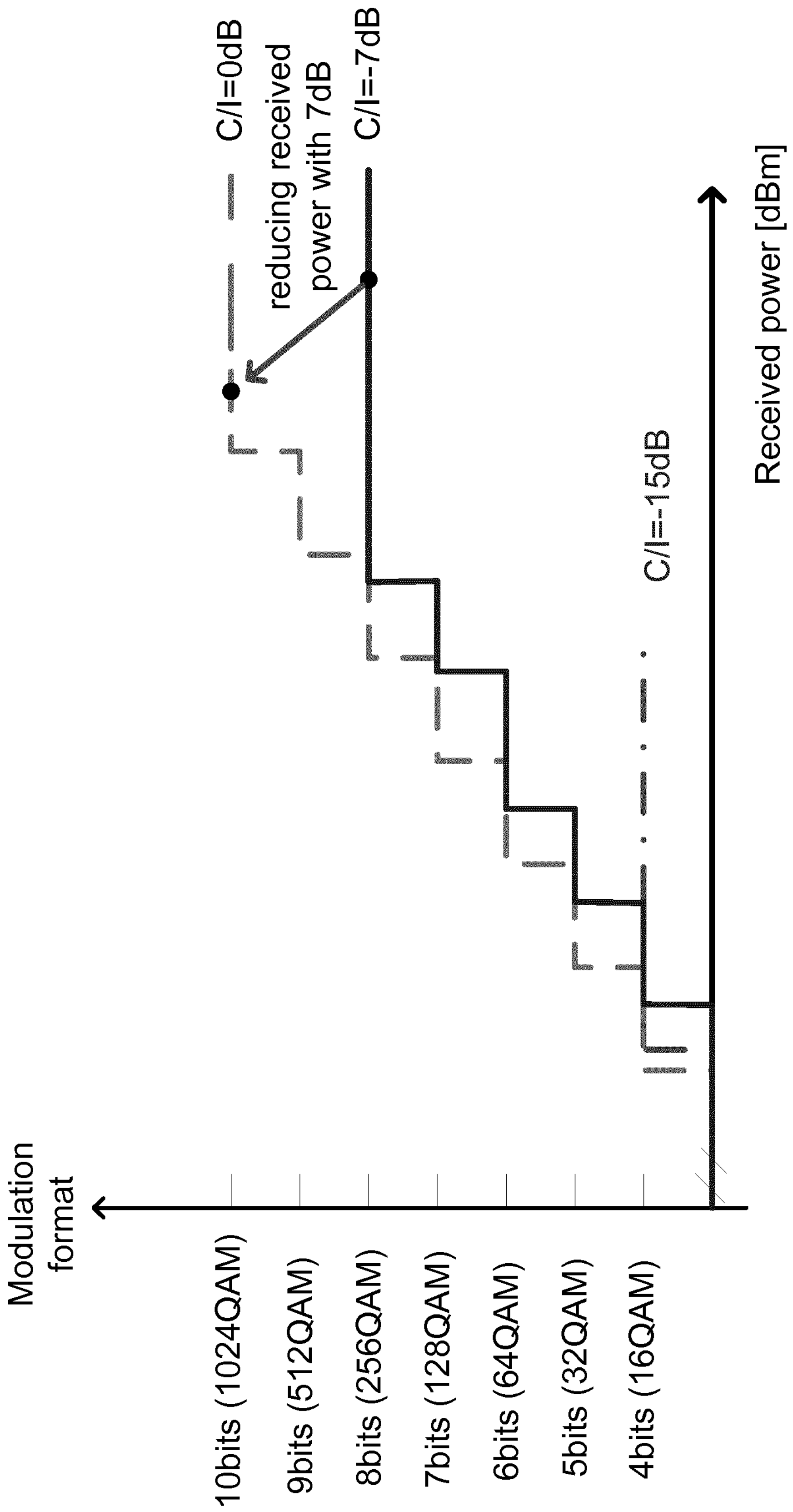

C/I=0dB
reducing received power with 7dB
C/I=-7dB
C/I=-15dB
Received power [dBm]
Modulation format
10bits (1024QAM)
9bits (512QAM)
8bits (256QAM)
7bits (128QAM)
6bits (64QAM)
5bits (32QAM)
4bits (16QAM)

FIG 19

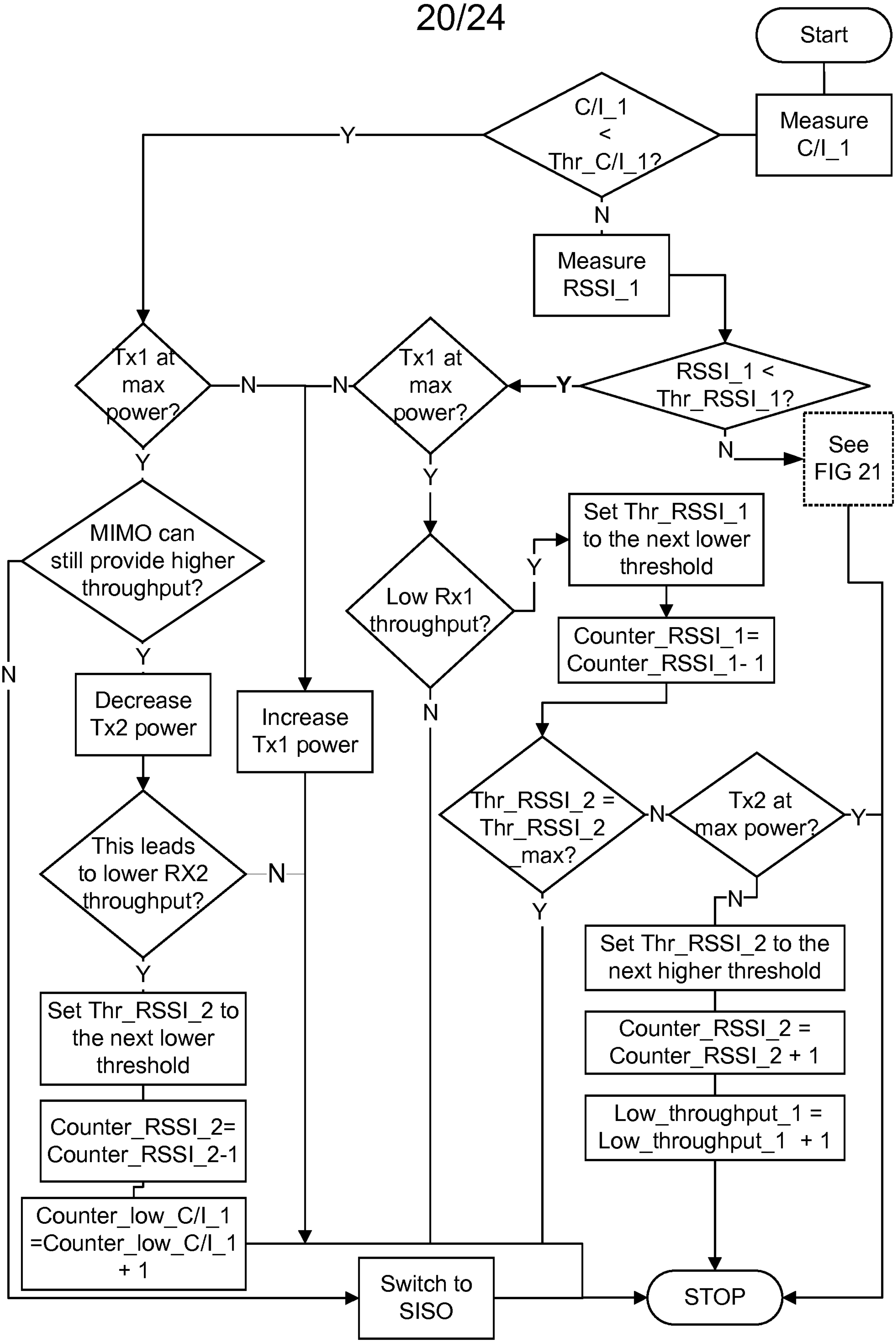

Start
Measure C/I_1
C/I_1 < Thr_C/I_1?
Y
N
Measure RSSI_1
RSSI_1 < Thr_RSSI_1?
Y
N
See FIG 21
Tx1 at max power?
N
Y
Tx1 at max power?
N
Y
MIMO can still provide higher throughput?
Y
N
Decrease Tx2 power
This leads to lower RX2 throughput?
N
Y
Set Thr_RSSI_2 to the next lower threshold
Counter_RSSI_2= Counter_RSSI_2-1
Counter_low_C/I_1 =Counter_low_C/I_1 + 1
Increase Tx1 power
Low Rx1 throughput?
Y
N
Set Thr_RSSI_1 to the next lower threshold
Counter_RSSI_1= Counter_RSSI_1- 1
Thr_RSSI_2 = Thr_RSSI_2 _max?
N
Y
Tx2 at max power?
Y
N
Set Thr_RSSI_2 to the next higher threshold
Counter_RSSI_2 = Counter_RSSI_2 + 1
Low_throughput_1 = Low_throughput_1 + 1
Switch to SISO
STOP

FIG 20

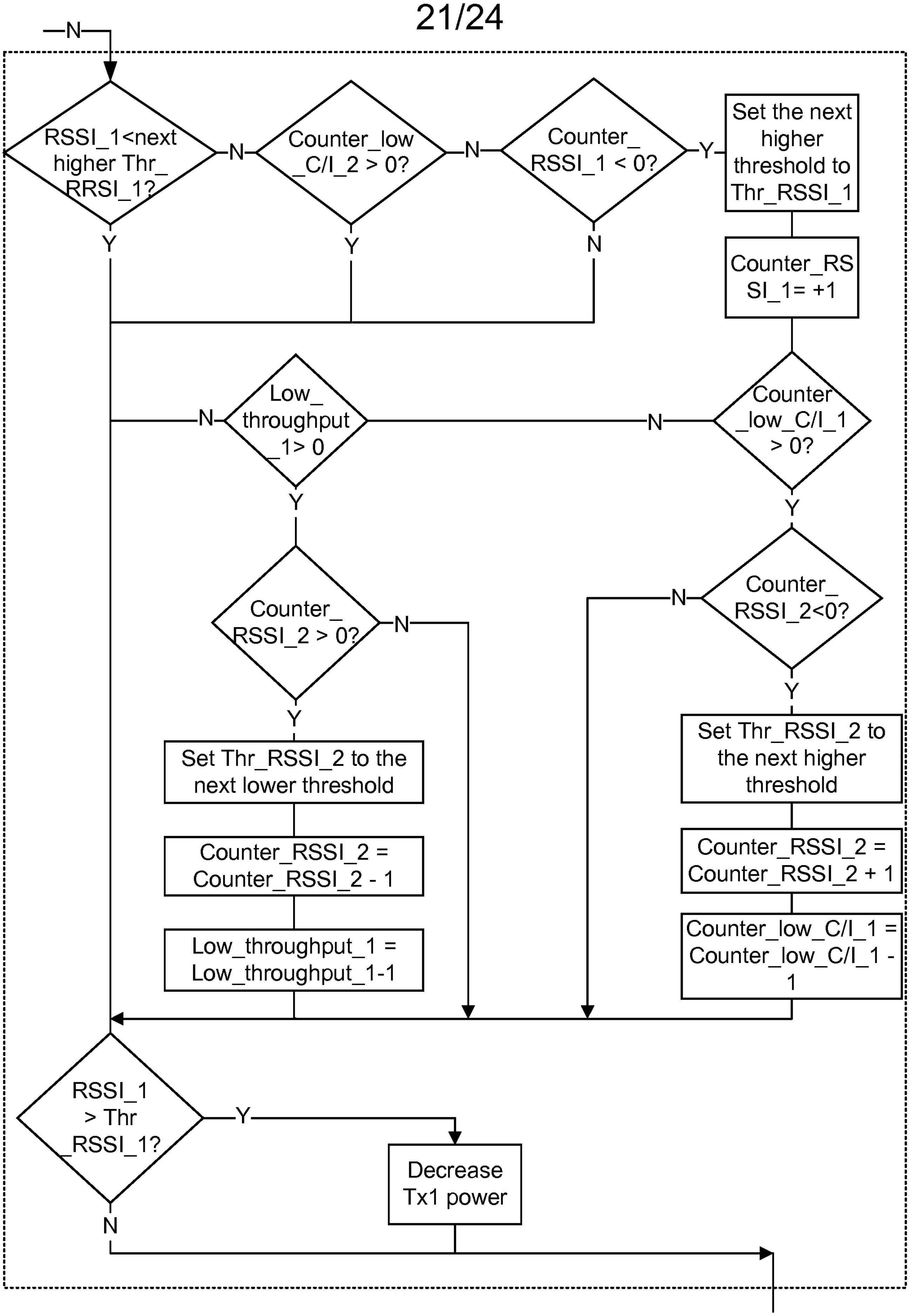

N
RSSI_1<next higher Thr_RRSI_1?
N
Counter_low_C/I_2 > 0?
N
Counter_RSSI_1 < 0?
Y
Set the next higher threshold to Thr_RSSI_1
Counter_RSSI_1= +1
Y
Y
N
Low_throughput_1> 0
N
N
Counter_low_C/I_1 > 0?
Y
Y
Counter_RSSI_2 > 0?
N
Counter_RSSI_2<0?
N
Y
Y
Set Thr_RSSI_2 to the next lower threshold
Counter_RSSI_2 = Counter_RSSI_2 - 1
Low_throughput_1 = Low_throughput_1-1
Set Thr_RSSI_2 to the next higher threshold
Counter_RSSI_2 = Counter_RSSI_2 + 1
Counter_low_C/I_1 = Counter_low_C/I_1 - 1
RSSI_1 > Thr_RSSI_1?
Y
Decrease Tx1 power
N

FIG 21

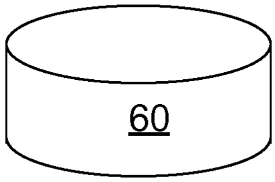



FIG 22A

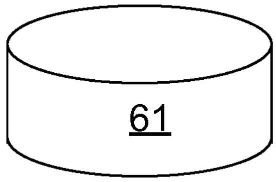



FIG 22B

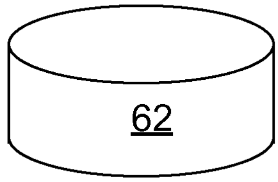



FIG 22C

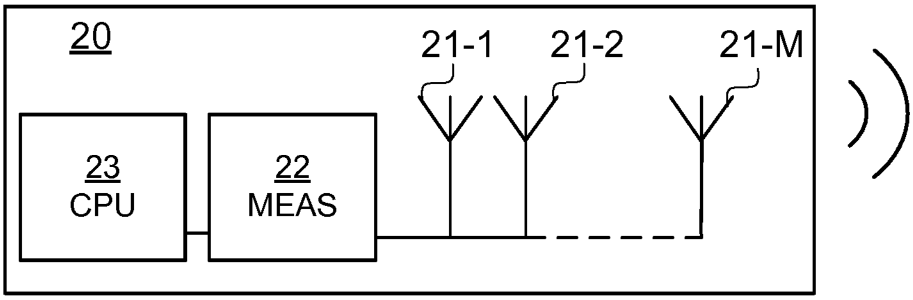



FIG 23

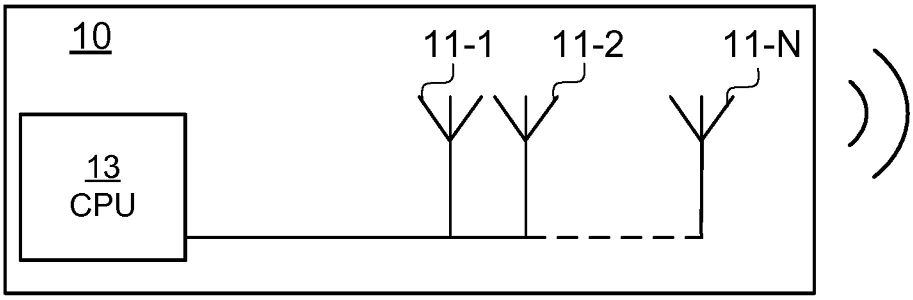



FIG 24

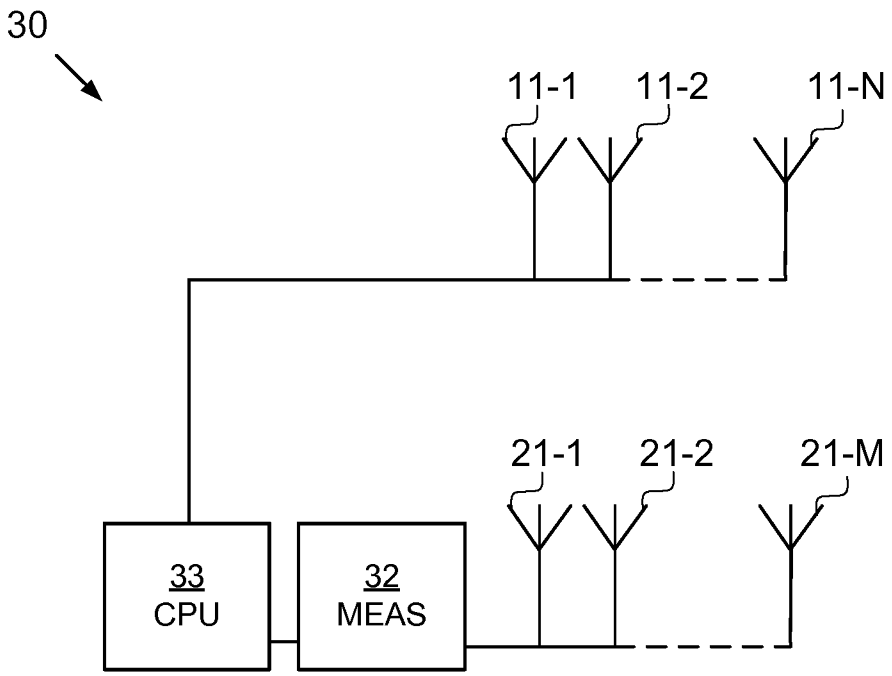



FIG 25

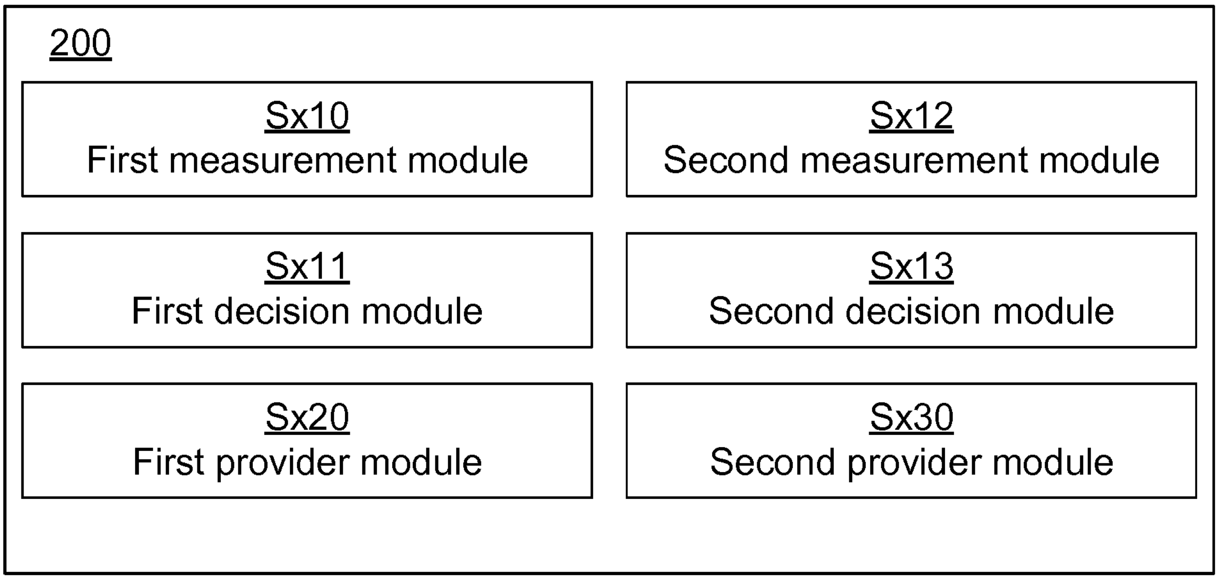



FIG 26

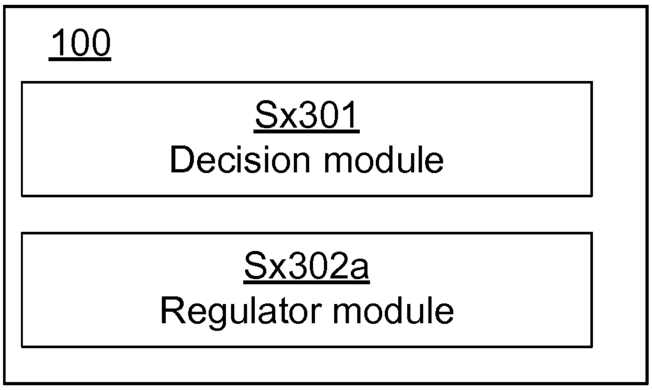



FIG 27

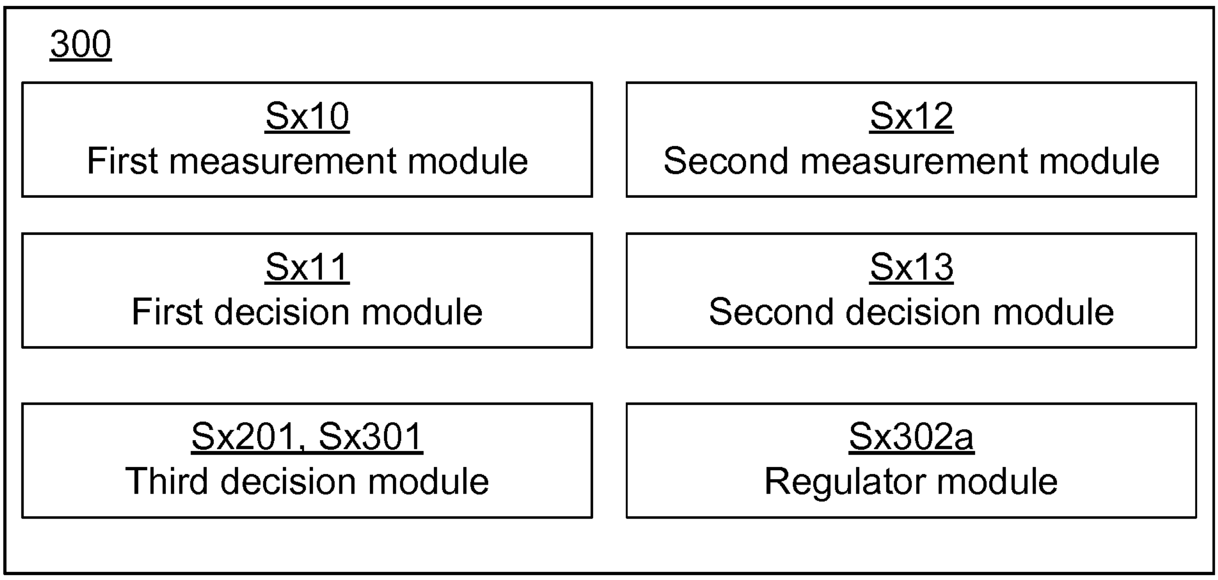



FIG 28

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/057794

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. 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)
H04W H04B

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | EP 3 041 297 A1 (HUAWEI TECH CO LTD [CN]) 6 July 2016 (2016-07-06) paragraph [0015] - paragraph [0052] figures 1-4 | 1-58 |
| A | US 2003/157954 A1 (MEDVEDEV IRINA [US] ET AL) 21 August 2003 (2003-08-21) paragraph [0012] - paragraph [0013] paragraph [0028] - paragraph [0059] paragraph [0070] - paragraph [0074] figures 1, 3-7 | 1-58 |

☐ Further documents are listed in the continuation of Box C.

☒ 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 |
|---|---|
| 1 December 2017 | 15/12/2017 |

| 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 | Spinnler, Florian |

2

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/057794

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
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| | | EP 3041297 A1 | 06-07-2016 |
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| | | WO 03071711 A2 | 28-08-2003 |