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(54) **MIMO Transmission in IEEE802.11 WLAN Systems**

(57) The present invention allows an IEEE802.11 receiver to operate on two alternative physical layers. The first of the two alternative physical layers is the conventional IEEE802.11 physical layer according to a respective specific standard, which is well known in the art and provides communication between a transmitter and a receiver via a SISO OFDM transmission. A second, alternative physical layer that, among other advantages, enables a higher reliability than the conventional IEEE802.11 physical layer, is provided by operating the

IEEE802.11 receiver to process a specific type of MIMO transmissions, which as such are foreign to the IEEE802.11 WLAN standards. A MIMO transmission according to the present invention has multiple concurrent transmissions of a single stream of analogue RF data signals, wherein corresponding analogue RF data signals of different ones of the concurrent transmissions of the stream differ only by having different amplitudes or different phases, or both, different amplitudes and phases.

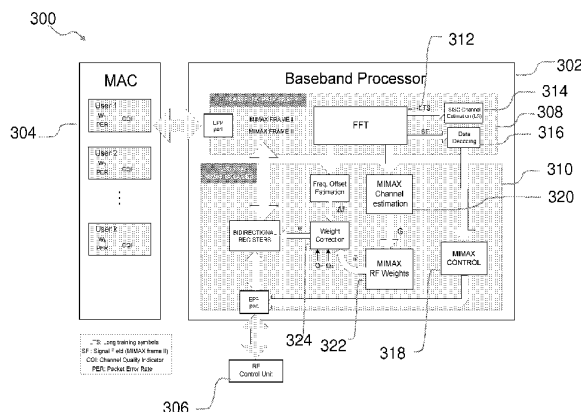


Fig. 3

Description

[0001] The IEEE 802.11 standard family specifies the implementation of a wireless local area network (WLAN), a wireless equivalent to the wired Ethernet standard. The 802.11 standards define the physical layer and data link layer, in particular the logical link control (LLC) and the media access control (MAC), according to the ISO/OSI reference model. Wireless local area networks (WLANs) can be implemented according to IEEE802.11 WLAN standards IEEE802.11a, b, or g. A transmitter, receiver or transceiver compliant with at least one of the mentioned IEEE 802.11 WLAN standards a, b, or g will in the following be referred to as a IEEE 802.11 transmitter, IEEE 802.11 receiver or IEEE 802.11 transceiver. However, to increase readability, an IEEE 802.11 transmitter, receiver, or transceiver will in the following also be referred to in short as a transmitter, receiver, or transceiver.

[0002] One of the main requirements for future evolutions of WLAN systems is increased cell capacity, and this will require enhanced multiple-input-multiple-output (MIMO) schemes with improved diversity and coding gains in comparison with those in existing systems. For enhancing the capacity of wireless radios, multi-antenna systems are used at the transmitter and the receiver, respectively. Some commercially available IEEE802.11a boards already have two antennas, but they only provide a basic switching function between antennas, i.e., antenna selection.

[0003] Known full MIMO transmission schemes provide improved transmission reliability and radio coverage, but require a strongly increased hardware effort for the baseband processing. For multiple spatial and temporal processing branches must be provided in the digital baseband part, the number of branches corresponding to the number of antennas. Consequently, chip area and cost are rather high for such systems.

[0004] It would be desirable to further improve the transmission reliability of an IEEE802.11 WLAN communication system with low additional hardware effort and backwards compatibility to the respective existing IEEE 802.11 standard employed.

[0005] It is therefore an object of the present invention to provide a method for operating an IEEE802.11 receiver, which allows a data communication with higher transmission reliability than the IEEE802.11 WLAN standards provide, without, however, losing the compatibility with a respective one of these well-established standards. The object of the present invention translates also to a method for operating an IEEE802.11 transmitter, and to IEEE802.11 receiver, transmitter and transceiver devices.

[0006] According to a first aspect of the present invention a method for operating an IEEE802.11 receiver is provided. The method comprises

- detecting whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is

possible, in RF communication with an IEEE802.11 transmitter, in other words, supported by the IEEE802.11 transmitter, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;

a) if yes, i.e., if a MIMO transmissions is enabled by both, IEEE802.11 transmitter and IEEE802.11 receiver:

- operating the IEEE802.11 receiver with a plurality of antennas in communication with the IEEE802.11 transmitter;
- performing a channel estimation process in communication with the IEEE802.11 transmitter,
- determining a set of weights to be applied to the analogue RF signals received in different ones of the concurrent transmissions of the MIMO transmission;
- receiving the MIMO transmission via the plurality of antennas;
- subsequently combining the plurality of analogue RF signals according to a combining algorithm using the determined set of weights, thus forming a combined analogue RF signal;
- subsequently converting the combined analogue RF signal into a combined digital baseband signal;
- subsequently further processing the combined digital baseband signal;

b) if no, i.e., if one of the IEEE802.11 transmitter and the IEEE802.11 receiver does not support a MIMO transmission:

- operating the IEEE802.11 receiver with a single antenna in communication with the IEEE802.11 transmitter;
- receiving and processing the stream of analogue radio frequency, RF, signals, in the form of a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via the single antenna.

[0007] The method of the first aspect of the present invention allows an IEEE802.11 receiver to operate on two alternative physical layers. The first of the two alternative physical layers is the conventional IEEE802.11 physical layer according to a respective specific standard, which is well known in the art and provides communication between a transmitter and a receiver via a SISO OFDM transmission. A second, alternative physical layer that, among other advantages, enables a higher reliability than the conventional IEEE802.11 physical layer, is provided by operating the IEEE802.11 receiver to process

a specific type of MIMO transmissions, which as such are foreign to the IEEE802.11 WLAN standards. A MIMO transmission according to the present invention has multiple concurrent transmissions of a single stream of analogue RF data signals, wherein corresponding analogue RF data signals of different ones of the concurrent transmissions of the stream differ only by having different amplitudes or different phases, or both, different amplitudes and phases.

[0008] MIMO wireless communication employing spatial multiplexing usually is based on transmitting independent and separately encoded RF data signals, thus multiple streams, one from each of the multiple transmitting antennas. The transmitted data signals are separately encoded in conventional MIMO systems. In contrast, a single stream is used for the MIMO transmission according to the present invention. The signals only differ in the applied weights in the analogue domain. That means, the signals transmitted by the different antennas differ only in their amplitudes and phases.

[0009] It turns out that single-stream MIMO transmissions are particularly suited to the front end reception and combining in the analogue RF domain, which is performed according to the method of the first aspect of the invention. By shifting the spatial processing to the analogue RF domain, the number of receiving and transmitting baseband digital processing paths can be reduced to a single one. Known MIMO-OFDM receivers, in contrast, perform all the spatial processing in the baseband domain and require a corresponding number of processing modules in the digital baseband part. The invention thus allows reducing the hardware overhead introduced by enabling MIMO transmissions to additional antennas and a modified RF front end. This translates into lower fabrication costs and a reduced power consumption of the receiver. Furthermore, it reduces the number of parameters to be adjusted on the transmitter and receiver side, thus simplifying the baseband design and making the receiver more robust to uncertainties, such as those due to the channel estimation procedure.

[0010] Part of the process of the invention is a channel estimation process, which an IEEE802.11 receiver performs, typically in the digital baseband part, in communication with the IEEE802.11 transmitter. After the channel estimation process for the MIMO transmissions, a set of weights, i.e., a set of weight factors is determined. The weights are applied to the analogue RF signals received in different ones of the concurrent transmissions of the MIMO transmission. This allows an adaptive beamforming at the receiver as well as at the transmitter.

[0011] A second aspect of the present invention is formed by a method for operating an IEEE802.11 transmitter. The method comprises:

- detecting whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with a target IEEE802.11 receiver;

wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;

a) if yes:

- operating the IEEE802.11 transmitter with a plurality of antennas in communication with the target IEEE802.11 receiver;

- performing a channel estimation process in communication with the target IEEE802.11 receiver of the MIMO transmission;

- determining a set of weights to be applied to the analogue RF signals to be transmitted in different ones of the concurrent transmissions of the MIMO transmission;

- transmitting the MIMO transmission via the plurality of antennas to the target IEEE802.11 receiver;

b) if no:

- operating the IEEE802.11 transmitter with a single antenna in communication with the target IEEE802.11 receiver;

- transmitting the stream of analogue RF signals as a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via at least one of the plurality of antennas.

[0012] The advantages of the method of the second aspect of the invention for operating an IEEE802.11 transmitter correspond to those described for the method of the first aspect of the invention.

[0013] It should be noted that the methods of the first and second aspect concern a communication between one transmitter and one receiver. However, the invention does not exclude that a transmitter may have different parallel communications with different receivers, just as a receiver may perform communications with different transmitters. Multiple parallel transmissions may be realized employing identical or different transmission schemes, MIMO according to the invention or standard SISO, for transmission links to different devices.

[0014] In the following, embodiments of the methods of the first and second aspects of the invention will be described. The additional features of different embodi-

ments can be combined to form further embodiments, unless such different embodiments are expressly described as forming alternatives to each other. For ease of description and reading, the method of the first aspect of the invention for operating an IEEE802.11 receiver will in the following be referred to as the receiver method, and the method of the second aspect of the invention for operating an IEEE802.11 transmitter will in the following be referred to as the transmitter method.

[0015] In an embodiment of the receiver method, performing the beamforming process, i.e., determining the set of weights comprises

- receiving a first frame from the transmitter in a first MIMO transmission, which employs a first subset of weights for the transmitter side, and updating only a second subset of weights for the receiver side, i.e., keeping the first subset of weights fixed;
- transmitting a second frame from the receiver to the transmitter in a second MIMO transmission using the updated second subset of weights; and
- repeating these foregoing steps until the first and second subsets of weights for the transmitter and receiver side achieve a predetermined convergence criterion.

[0016] The corresponding embodiment of the transmitter method comprises

- transmitting the first frame from the IEEE802.11 transmitter to the target IEEE802.11 receiver in the first MIMO transmission using the first subset of weights for the transmitter side;
- receiving the second frame from the target IEEE802.11 receiver in a second MIMO transmission and updating only the first subset of weights for the transmitter side;
- repeating these foregoing steps until the first and second subsets of weights for the transmitter and receiver side achieve a predetermined convergence criterion.

[0017] These embodiments have the advantage of a reduced processing amount required on the side of the transmitter for performing the channel estimation.

[0018] The channel estimation process and the process of weight calculation are different tasks. In a hardware implementation, they can form different sub-tasks of a common block or be implemented as separate circuit blocks.

[0019] The channel estimation procedure preferably uses a time-division duplex (TDD) operation mode. It is based on the assumption that the transmission channel observed between any pair of antennas is the same regardless of the direction of the link. In a preferred embodiment, the channel estimation on the receiver side is performed using a least-squares (LS) estimate.

[0020] Preferably, transmitting the first channel esti-

mation frame comprises transmitting a plurality of OFDM training symbols. Different OFDM training symbols may be transmitted employing different sets of weights. This allows the receiver to subsequently perform a selection of an optimal set of weights according to a predetermined selection criterion.

[0021] In a preferred embodiment of the transmitter and receiver methods of the invention, a common pair of subsets of weights, which are also referred to as Tx-Rx beamformers, is applied to all data carriers used. This embodiment requires a solution to the challenging problem of selecting an optimal pair of beamformers for a specific channel realization..

[0022] In one embodiment, the optimal set of weights is ascertained by employing a gradient search algorithm.

[0023] Once the channel has been estimated, the optimal weights, i.e., amplitudes and phases for each transmitted signal, are preferably selected to optimize a predetermined performance criterion. Selecting the optimal set of weights preferably comprises selecting that particular set of weights, for which a predetermined cost function is minimized. In particular, the system performance depends on a virtual SISO channel, which is the result of a combination of the selected weights and the true MIMO channel. A virtual or equivalent SISO channel is a hypothetical SISO transmission channel that has the transmission properties of a MIMO transmission channel under consideration, which MIMO channel has fixed set weights on the transmitter and receiver sides.

[0024] In one embodiment the following cost function is used:

$$\frac{1}{\alpha - 1} \log \left[\sum_{k=1}^{N_c} \frac{1}{N_c} \left(\frac{1}{1 + \gamma |h_k|^2} \right)^{\alpha - 1} \right],$$

wherein

- $h_k = \mathbf{w}_R^H \mathbf{H}_k \mathbf{w}_T$ represents the response of the virtual/equivalent SISO channel for the k-th active sub-carrier;
- N_c is the number of active subcarriers. In IEEE802.11a $N_c = 52$;
- \mathbf{H}_k is the (estimated) MIMO channel for the k-th sub-carrier. Each element in the matrix \mathbf{H}_k represents the channel between one transmit and one receive antenna;
- \mathbf{w}_T and \mathbf{w}_R are the transmit and receive beamformers. Each element in these vectors is a complex weight representing the amplitude and phase to be

applied by the RF-control unit;

- γ is the signal to noise ration defined as the relation between the transmitted power and the noise power at the receiver;
- α is a selectable fixed parameter which permits to select one of different performance criteria to be optimized by the selected set of weights..

[0025] In particular:

- $\alpha = 0$ translates into the optimization of the overall SNR. Equivalently, it reduces to the maximization of the energy of the equivalent SISO channel.
- $\alpha = 1$ provides the criterion consisting of the maximization of the system capacity. This can be proved by applying L'Hopital's rule to the general cost function.
- $\alpha = 2$ provides the criterion of minimizing the bit error rate under the assumption of linear receivers and optimal linear precoding.
- Other α values provide a tradeoff between the energy and the spectral flatness of the equivalent SISO channel. For larger α , part of the channel energy is sacrificed in order to obtain more frequency-flat equivalent channels.

[0026] In a further embodiment, the detection of the capability of handling MIMO transmissions is based on setting (on the respective transmitter side) and detecting (on the respective receiver side) a bit at a predefined bit position of a predefined field of a frame transmitted by the IEEE802.11 transmitter, which assumes a predefined value indicative of the capability of a MIMO transmission. Preferably, additional information about the system is included in the frame. In particular, the number of receive/transmit antennas and a number of training symbols to follow may be comprised by the frame. The receiver indicates its capability preferably by transmitting a corresponding frame to the IEEE802.11 transmitter. The mentioned information can be added to frames, which are otherwise in full accordance with the IEEE802.11 standard, thus supporting a backwards compatibility of the methods of the invention. For instance, the bit indicative of MIMO transmission capability may be the known reserved bit or the known parity bit of the conventional IEEE802.11 Signal Field of a frame transmitted during channel estimation.

[0027] Further aspects of the invention are formed by an IEEE802.11 receiver, which is configured to perform the method of the first aspect of the invention or one of its embodiments disclosed herein.

[0028] One embodiment of such an IEEE802.11 receiver comprises:

- a MIMO detecting unit, which is configured to detect whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with an IEEE802.11 transmitter, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;
- a channel estimation unit, which is connectable with a plurality of antennas and which is configured to perform, if a MIMO transmission is possible with the IEEE802.11 transmitter, a channel estimation process in communication with the IEEE802.11 transmitter,
- a beamforming unit, which is configured to determine a set of weights to be applied to the analogue RF signals received in different ones of the concurrent transmissions of the MIMO transmission;
- an RF frontend unit, which is connectable with the channel estimation unit, the beamforming unit, and with a plurality of antennas and which is configured to receive the MIMO transmission via the plurality of antennas;
- subsequently combine the plurality of analogue baseband signals according to a combining algorithm using the determined set of weights, thus forming a combined analogue RF signal;
- subsequently convert the combined analogue RF signal into a combined analogue digital baseband signal;
- a baseband unit, which is connected with the RF frontend and which is configured to further process the combined digital baseband signal;

wherein the RF frontend unit and the baseband unit are further configured to, if a MIMO transmission is not possible with the IEEE802.11 transmitter, receive and process the stream of analogue radio frequency, RF, signals, in the form of a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via at least one of the plurality of antennas.

[0029] A fourth aspect of the present invention is formed by an IEEE802.11 transmitter, which is configured to perform a method according to the second aspect of the inventions or one of its embodiments disclosed herein. One embodiment of the IEEE802.11 transmitter comprises:

- a MIMO detecting unit, which is configured to detect whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with a target IEEE802.11 receiver, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream

of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;

- a channel estimation unit, which is connectable with a plurality of antennas and which is configured to perform, if a MIMO transmission is possible with the target IEEE802.11 receiver, a channel estimation process in communication with the target IEEE802.11 receiver;

- a beamforming unit, which is configured to determine a set of weights to be applied to the analogue RF signals to be transmitted in different ones of the concurrent transmissions of the MIMO transmission;

- an RF frontend unit, which is connectable with the channel estimation unit and with a plurality of antennas and which is configured to, if a MIMO transmission is possible with the target IEEE802.11 receiver, transmit the MIMO transmission via the plurality of antennas and, if a MIMO transmission is not possible with the target IEEE802.11 receiver, transmit the stream of analogue RF signals as a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via at least one of the plurality of antennas.

[0030] A fifth aspect is formed by an IEEE802.11 transceiver, which comprises an IEEE802.11 receiver according to the third aspect of the invention and an IEEE802.11 transmitter according to the fourth aspect of the invention.

[0031] The methods and devices disclosed herein may be used in the context of any of the IEEE802.11 WLAN standards mentioned in the beginning of this specification.

[0032] Further embodiments are defined by the dependent claims at the end of the present specification.

[0033] In the following, further embodiments will be described with reference to the enclosed drawings. In the drawings:

Fig. 1 shows a schematic representation of a protocol stack implemented in an IEEE802.11a transmitter, receiver or transceiver;

Fig. 2 shows a schematic representation of protocol stacks on the physical layer and the data link layer for a communication between an IEEE802.11a transceiver capable of MIMO transmissions and IEEE802.11a device, which is not capable of MIMO transmissions;

Fig. 3 is a simplified block diagram of an IEEE802.11a transceiver capable of MIMO transmissions according to one embodiment of the inven-

tion;

Fig. 4 is a schematic representation of a frame structure that can be used in the context of MIMO transmissions;

Fig. 5 shows a schematic representation of a section of the frame of Fig. 4 with bit assignments in the MIMAX Signal Field;

Fig. 6 is a schematic flow diagram of a channel estimation process in the communication between two IEEE802.11a transceivers capable of MIMO transmissions;

Fig. 7 is a simplified flow diagram of a channel estimation process performed at the receiving end; and

Fig. 8 is a simplified block diagram of an IEEE802.11 transceiver.

[0034] In the following, the description of further embodiments will focus on the context of the IEEE802.11a standard. However, it should be understood that this is purely exemplary, and should not be understood as implying that the invention is not applicable in the context of other IEEE802.11 standards.

[0035] Reference is made in parallel to Figs. 1 and 2. Fig. 1 shows a schematic representation of a protocol stack implemented in an IEEE802.11a device 100, i.e., a transmitter, receiver, or transceiver. Fig 2 shows the corresponding protocol stacks of two IEEE802.11a devices 100 and 200, wherein the device 200 is a conventional device according to the prior art.

[0036] In the following, an IEEE802.11a device according to the present invention, whether a receiver, transmitter or transceiver will also be referred to as a MIMAX device.

[0037] Fig. 1 only shows a section of a protocol stack that covers the physical layer, the data link layer and the network and transport layer, also known as layers 1 to 4 according the well known OSI reference model representing a layered communication architecture. Fig. 1 serves particularly to indicate those sections of the protocol stack of the MIMAX device 100, which comprise modifications in comparison with a device that supports the conventional IEEE802.11a standard only, such as MIMAX device 200 in Fig. 2.

[0038] The physical layer has two sub-layers 102 and 104. On a physical-medium-dependent (PMD) sub-layer, which is shown by reference label 102, the communication between two MIMAX devices is modified in comparison with conventional IEEE802.11a devices by the introduction of MIMO capabilities and a signal combining in an analogue front end on the transmitting and receiving sides.

[0039] Note that the introduction of MIMO capabilities in done in the form of an option. The conventional phys-

ical layer that uses an OFDM based SISO air interface on the physical layer in the 5 GHz band forms another option implemented in the MIMAX PMD 102. The provision of the two options on the physical layer 102 requires adaptations in the Physical Layer Convergence Protocol PLCP, which forms an upper sub-layer 104 of the physical layer. For a MIMAX device, therefore, a modified MIMAX PLCP layer 104 is provided. The PLCP enables the presence of different physical-layer procedures, as used by a MIMAX device.

[0040] On top of the physical layer a data link layer comprising two sub-layers 106 and 108 is provided. The lower sub-layer 106 is a MIMAX MAC layer, which also comprises modifications in comparison with a conventional IEEE802.11a device, and which will be described further below in more detail. In contrast, the upper sub-layer 108 of the data link layer, which is formed by the link-level control layer, is compliant with the conventional IEEE802.11a standard and not modified in a MIMAX device 100.

[0041] On top of the data link layer, the network and transport layers 110 are summarized. In the present embodiment they are formed by a standard TCP/IP stack for both the MIMAX device 100 and the conventional IEEE802.11a device 200.

[0042] Fig 2 arranges corresponding protocol layers of the two devices 100 and 200 side by side. Communication between the two devices 100 and 200 is enabled by a backwards compatibility provided in the layers 102 to 106, which will be explained in more detail below.

[0043] Fig. 3 is a simplified block diagram of an IEEE802.11a transceiver 300 capable of MIMO transmissions according to one embodiment of the invention. The transceiver 300 thus is an example of a MIMAX device. Only a baseband processor 302 and a MAC unit 304 are shown with some detail. An RF control unit 306 is only represented as a block.

[0044] The baseband processor 302 is connected with the RF control unit 306. The baseband processor is divided into two sections 308 and 310. The first section 308 implements known functionalities of an IEEE802.11a device, such as Fast Fourier Transform (FFT) in an FFT block 312, SISO channel estimation using long training symbols (LTS) in a SISO-channel estimation block 314, and data decoding in a data-decoding block 316 on the receiver side of the baseband processor.

[0045] In addition, and as a difference to a conventional IEEE802.11a device, the data-decoding block 316 serves for detecting MIMO capabilities in an incoming frame. This is achieved by evaluating predefined bit in a Signal Field of a MIMAX frame, which indicates whether the other end of the communication is a MIMAX device as well, cf. also Fig. 4 and the pertaining description.

[0046] The second section 310 of the baseband processor is added in comparison with conventional IEEE802.11a devices. It comprises a MIMAX control unit 318, which activates or deactivates the MIMAX operation, i.e. the processing of a MIMO transmission accord-

ing to the present invention, if the data decoding unit 316 indicates that the corresponding bit in the Signal Field is activated.

[0047] A MIMAX channel estimation block 320 performs a channel estimation for the MIMO-transmission communication, which will be explained in more detail further below with reference to Fig. 6. Units 322 and 324 are connected with the MIMAX channel-estimation unit 320 and serve for determining and correcting weight factors to be used for combining the incoming different concurrent analogue RF signals of the concurrent transmissions of a MIMO transmission. The weight correction is done in dependence on a frequency offset estimation provided by a corresponding block 326.

[0048] For the data link layer, the standard IEEE 802.2 LLC is used on top of the 802.11a MAC. In the following, the functionalities of the MAC unit 304, which differ from the standard-compatible functionalities and adapt the MAC layer to the MIMAX transmission system will be explained. The new functionalities of the MIMAX base band processor impose some changes on the MAC processor, e.g. knowledge of the configuration of the transceiver including the number of antennas for RX and TX or a database of active and available users (MAC addresses, number of antennas at the user, last optimum weights, etc.). These tasks and the storage are related to the MAC because no memory is available at the PLCP base band processor.

[0049] The MAC processor controls the data and control-signal flow to the base band processor depending on the communication scheme. Not only data transmission is initialised by the MAC processor transmitting data and the (last) optimum weights to the base band, but also transferring weights for channel estimation to the PLCP.

[0050] In the following, reference is made to Figs. 4 and 5 in parallel. Fig. 4 is a schematic representation of a frame structure that can be used in the context of MIMO transmissions. Fig. 5 shows a schematic representation of a section of the frame of Fig. 4 with bit assignments in the MIMAX Signal Field 402.

[0051] The frame 400 shown in Fig. 4 is a physical-layer frame. It is modified in comparison with a conventional IEEE802.11a frame for the purpose of allowing communication via a MIMO transmission. In particular, the modified structure allows for MIMO channel estimation in a backwards-compatible manner. To that end, a MIMAX Signal Field 402 is used for indicating the capability of handling MIMO transmissions. For a conventional IEEE802.11a frame, a reserved bit in the Signal Field 402 will be set to zero, whereas for a MIMAX frame, the reserved bit of the Signal Field 402 will be set to one.

[0052] Furthermore, specific OFDM training symbols, herein also referred to as MIMO or MIMAX training symbols, are contained in the frame 400, and indicated by the reference labels TW1, ..., TWn. The MIMAX training symbols TW1 to TWn are transmitted and then processed on the receiver side using different RF beamformer weights in the analogue RF domain. This process is per-

formed separately and after a SISO channel estimation, for which long training symbols Ts and T2 are used. The long training symbols preceded by a guard interval G12 for separation from short training symbols t1, t2,..., t0, which serve for signal detection, automatic gain control (AGC), time and coarse frequency synchronization.

[0053] The frame advantageously includes additional information about the system parameters. In particular, the number of receive/transmit antennas and the number of training symbols are contained in the MIMAX Signal Field 402 (Fig. 5). In particular the number of receive antennas (N_RX, bits 9 and 10), and transmit antennas (N_TX, bits 6 and 7) is exchanged in this field. Also, the number N_T of training symbols is determined by the number of transmit and receive antennas bits 12 to 16, wherein the least significant bit (LSB) of the number is given first at bit position 12, and the most significant bit (MSB) is given last at bit position 16 of the MIMAX Signal Field 402. Bit 17 is a parity bit P. Bits H1-H4 at bit positions 0 to 3 are reserved for further use.

[0054] As a further difference over a conventional IEEE802.11a, a number of MIMAX stuffing symbols, shown by way of example by the MIMAX stuffing symbol "Stuff 1" is included between the MIMAX Signal Field and the MIMAX training symbols in the frame 400 (Fig. 4). The stuffing symbols serve to provide enough time to the analogue front end in order to change amplitudes and phases employed during the reception of each OFDM training symbol.

[0055] To allow backwards-compatibility, the remainder of the frame 400 is exactly the same as a conventional IEEE802.11a frame.

[0056] Fig. 6 shows schematic flow diagram of a channel estimation process in the communication between two IEEE802.11a transceivers capable of MIMO transmissions. The displayed channel estimation process for two MIMAX devices MD1 and MD2 is based on a time-division-duplex (TDD) operation mode. It assumes channel reciprocity, so that the channel observed between any pair of antennas is assumed to be the same regardless of the direction of the link.

[0057] The procedure comprises two phases. In a first phase, the first MIMAX device MD1 transmits a channel estimation frame. For the present description, it is assumed by way of example that both MIMAX devices have four antennas and transmit four MIMAX frames per antenna so that 16 OFDM training symbols are transmitted from the MIMAX device MD1 to the MIMAX device MD2.

[0058] In a step 602, on the basis of the received 16 OFDM training symbols, the second MIMAX device MD2 estimates the MIMO channel and obtains RF weights in steps 604 and 606. In a subsequent step 608, the second MIMAX device MD2 transmits a frame with only 4 OFDM training symbols, that is, by using only one of its 4 antennas, to the MIMAX device MD1. Accordingly, the MIMAX device MD1 only estimates the received SIMO channel, which is received via the four different receive antennas of the first MIMAX MD1. From this, the RF weights are

obtained in a step 612. A distinguishing feature of the channel estimation procedure shown in Fig. 6 is that, due to the use of Tx-Rx beamforming at the second MIMAX device MD2, it is only required to estimate a SIMO channel at the first MIMAX device MD1 after the second MIMAX device MD2 has estimated the full MIMO channel.

[0059] The channel estimation block 320 at the receiving second MIMAX device MD2 estimates the MIMO OFDM channel from the received training symbols. To this end, the block implements a least-squares (LS) estimate. By default, the estimation algorithms use binary-phase-shift keying (BPSK) training symbols and orthogonal sets of beamformers.

[0060] Fig. 7 is a simplified flow diagram of a channel estimation process performed at the receiving end. The procedure shown in Fig. 7 is performed by blocks 320 and 322 of the MIMAX device 300 of Fig. 3. The proposed MIMO transmission of the present invention, unlike conventional MIMO systems, applies a common pair of Tx-Rx beamformers to all the IEEE802.11a data carriers. This translates into the problem of selecting the optimal pair of beamformers for a specific channel realization. The beamformer selection block 322, which is responsible for determining the RF weights uses an efficient gradient search algorithm shown in Fig. 7. The algorithm is based on the minimization of the following cost function:

$$\frac{1}{\alpha - 1} \log \left[\sum_{k=1}^{N_c} \frac{1}{N_c} \left(\frac{1}{1 + \gamma |h_k|^2} \right)^{\alpha - 1} \right]$$

[0061] The symbols used in the cost function have been defined in a previous section of this specification. The choice of the parameter α permits to select different performance criteria in the adjustment of the beamforming parameters at the receiver and the transmitter. Once a criterion has been selected, α is a fixed parameter. In particular, $\alpha = 0$ translates into an optimization of the overall signal-to-noise ratio (SNR). Equivalently, it reduces to the maximization of the energy of the equivalent SISO channel. $\alpha = 1$ provides the criterion consisting of the maximization of the system capacity. This can be proved by applying L'Hopital's rule to the general cost function. $\alpha = 2$ provides the criterion of minimizing the bit error rate under the assumption of linear receivers and optimal linear precoding. Other α values provide a trade-off between the energy and the spectral flatness of the equivalent SISO channel. For larger α , part of the channel energy is sacrificed in order to obtain more frequency-flat equivalent channels.

[0062] In the following, a short overview of the process is given. After channel estimation, selection of an optimization criterion and an initialization of the beamformers for the transmitter and the receiver, in steps 702 and 704,

only the receive beamformer is modified in a first series of steps 706 to 710, while the transmit beamformer is kept fixed. In a second series of steps 712 to 716, the transmit beamformer is modified, considering fixed the receive beamformer.

[0063] More specifically, the process starts ascertaining a channel estimation matrix H and selecting the desired value of the parameter α at step 702. In step 704, the Tx-Rx beamformers are initialized.

[0064] Subsequently, in a sequence of steps 706 to 710, the transmitter weights are set as fixed (step 706), and

[0065] the receiver weights are updated (step 708) and subsequently normalized (step 710). Then, the receiver weights are set as fixed (step 712), the transmitter weights are updated (step 714) and normalized (step 714). Then, the convergence of the current beamformer determination is checked by checking for a minimization of the cost function with the current beamforming parameters at step 718.

[0066] If no convergence has been achieved, the procedure branches back to step 706 and follows the sequence of the steps 706 to 716 to check if the convergence is achieved with a next set of beamforming parameters. If convergence is indeed achieved, the procedure ends with step 720.

[0067] Fig. 8 is a simplified block diagram of a MIMAX receiver 800 that illustrates the combining in the analogue part 802 of the receiver.

[0068] The MIMAX receiver has a plurality of antennas 804.1 to 804.n for receiving incoming signals RF signals, each antenna forming a separate reception branch. Subsequent band-pass filters and low-noise amplifiers in each branch, as known in the art, are not shown here for reasons of graphical simplification. An analogue beamforming unit 806 comprises controllable vector modulators 806.1 to 806.n, which modify amplitude and phase of the respective antenna signals by multiplying the incoming RF signals with respective complex weight factors $w[1]$ to $w[n]$ received from a digital baseband unit 816. The weighted analogue signals are then fed to and combined by an adder 808. Thus, spatial processing of the received signals is immediately performed after reception and before demodulation. A demodulation unit 810 has two demodulators 810.1 and 810.2 for I and Q signal components of the combined signal. The demodulators are driven by a local oscillator LO. The demodulated I and Q signals are forwarded to respective low-pass filters 812.1 and 812.2 and subsequently converted to digital signals by Analogue-to-Digital converters 814.1 and 814.2, respectively. The digital signals are then fed to a digital baseband unit 816 for further processing. The digital baseband unit comprises an RF control unit (cf. Fig. 3), which determines the complex weight factors $w[1]$ to $w[n]$ and provides them to the vector modulators of the beamforming unit 806.

[0069] The signal flow described above for a receiver is inverted for a MIMAX transmitter, which is not shown

here. From the foregoing description of the MIMAX receiver, a person of ordinary skill in the art immediately visualizes a corresponding MIMAX transmitter structure, in which digital baseband signals are converted to analogue I and Q components, up-converted to the RF domain, combined, and then fed to multiple parallel vector modulators, each connected with a respective transmit antenna of a respective transmit branch for enabling multiple spatially diverse transmissions of the single data stream.

[0070] The MIMAX transmission and reception concept described combines the available spatial diversity of smart antenna systems with the low system complexity of SISO systems. The spatial processing of a conventional MIMO approach is shifted to each receive path in the RF front-end. Albeit additional circuitry is needed for this spatial processing, parallel receive paths merge into a single analogue base band after the spatial signal processing. Furthermore, no spatial processing is required in the digital base band. This reduces system complexity and power consumption because the most power consuming subsystems are shared among the receive paths.

[0071] This fundamental concept of coherent processing is generally applicable to all air interfaces. It allows a parallel and independent processing on all traffic resources.

Claims

1. A method for operating an IEEE802.11 receiver, comprising

- detecting whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with an IEEE802.11 transmitter, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;
- if yes:
 - operating the IEEE802.11 receiver with a plurality of antennas in communication with the IEEE802.11 transmitter;
 - performing a channel estimation process in communication with the IEEE802.11 transmitter;
 - determining a set of weights to be applied to the analogue RF signals received in different ones of the concurrent transmissions of the MIMO transmission;
 - receiving the MIMO transmission via the plu-

ality of antennas;

- subsequently combining the plurality of analogue RF signals according to a combining algorithm using the determined set of weights, thus forming a combined analogue RF signal;

- subsequently converting the combined analogue RF signal into a combined digital baseband signal;

- subsequently further processing the combined digital baseband signal;

- if no:

- operating the IEEE802.11 receiver with a single antenna in communication with the IEEE802.11 transmitter;

- receiving and processing the stream of analogue radio frequency, RF, signals, in the form of a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via the single antenna.

2. The method of claim 1, wherein determining the set of weights comprises

- receiving a first frame from the IEEE 802.11 transmitter in a first MIMO transmission, which employs a first subset of weights for the IEEE 802.11 transmitter, and updating only a second subset of weights for the IEEE 802.11 receiver;

- transmitting a second frame from the IEEE 802.11 receiver to the IEEE 802.11 transmitter in a second MIMO transmission, using the updated second subset of weights; and

- repeating these foregoing steps until the first and second subsets of weights for the IEEE 802.11 transmitter and receiver achieve a predetermined convergence criterion.

3. The method of one of the preceding claims, wherein receiving the first channel estimation frame comprises

- receiving a plurality of OFDM training symbols, different ones of the OFDM symbols being transmitted by employing different sets of weights;

- selecting an optimal set of weights according to a predetermined selection criterion.

4. The method of claim 4, wherein selecting the optimal set of weights comprises selecting that set of weights, for which the following cost function is minimized:

$$\frac{1}{\alpha - 1} \log \left[\sum_{k=1}^{N_c} \frac{1}{N_c} \left(\frac{1}{1 + \gamma |h_k|^2} \right)^{\alpha - 1} \right],$$

wherein

$h_k = \mathbf{w}_R^H \mathbf{H}_k \mathbf{w}_T$ represents a response of a virtual equivalent SISO channel for the k-th active subcarrier,

- N_c is the number of active subcarriers;
- \mathbf{H}_k is a matrix representing the MIMO channel estimation for the k-th subcarrier, wherein each element of the matrix \mathbf{H}_k represents the channel between one transmit and one receive antenna;
- \mathbf{w}_T and \mathbf{w}_R are transmit and receive beamformer vectors (beamformers), wherein each element in these vectors is a complex weight factor representing an amplitude and phase to be applied by the RF-control unit;
- γ is a signal-to-noise ratio defined as the relation between a transmitted power and a noise power at the receiver; and
- α is a selectable fixed parameter which permits to select one of different performance criteria to be optimized by the selected set of weights.

5. The method of one of the preceding claims, wherein

- transforming the radio signals of the MIMO transmission into a plurality of analogue baseband signals and combining the plurality of analogue baseband signals is performed by operating a corresponding plurality of analogue receiver front ends of the receiver; and wherein

- transforming the combined analogue baseband signal into a combined digital baseband signal and further processing the combined digital baseband signal is performed by operating a single digital baseband part of the receiver.

6. The method of one of the preceding claims, wherein detecting whether the MIMO transmission is possible in RF communication with the IEEE802.11 transmitter comprises detecting whether a bit at a predefined bit position of a predefined field of a frame received from the IEEE802.11 transmitter assumes a predefined value indicative of the capability for a MIMO transmission.

7. The method of one of the preceding claims, further comprising

- detecting from a received frame of the MIMO transmission how many concurrent transmissions are provided in the MIMO transmission;

- operating a corresponding number of antennas and receiver front ends for receiving the MIMO transmission.

8. A method for operating an IEEE802.11 transmitter, comprising

- detecting whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with a target IEEE802.11 receiver, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or phases;
- if yes:
- operating the IEEE802.11 transmitter with a plurality of antennas in communication with the target IEEE802.11 receiver;;
- performing a channel estimation process in communication with the target IEEE802.11 receiver of the MIMO transmission;
- determining a set of weights to be applied to the analogue RF signals to be transmitted in different ones of the concurrent transmissions of the MIMO transmission;
- transmitting the MIMO transmission via the plurality of antennas to the target IEEE802.11 receiver;
- if no:
- operating the IEEE802.11 transmitter with a single antenna in communication with the target IEEE802.11 receiver;
- transmitting the stream of analog RF signals as a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via at least one of the plurality of antennas.
9. The method of claim 8, wherein determining the set of weights comprises
- transmitting a first frame from the IEEE802.11 transmitter to the target IEEE802.11 receiver in a first MIMO transmission using a first subset of weights for the IEEE 802.11 transmitter;
- receiving a second frame from the target IEEE802.11 receiver in a second MIMO transmission and updating only the first subset of weights for the IEEE802.11 transmitter;
- repeating these foregoing steps until the first and second subsets of weights for the IEEE802.11 transmitter and receiver achieve a predetermined convergence criterion.
10. The method of claim 9, wherein transmitting the first channel estimation frame comprises transmitting a plurality of OFDM training symbols, different ones of the OFDM symbols being transmitted by employing different sets of weights;
11. The method of claim 8 or 9, wherein detecting whether a MIMO transmission is possible in RF communication with the target IEEE802.11 receiver, comprises including a bit assuming a predefined value indicative of a capability of the transmitter for a MIMO transmission at a predefined bit position of a predefined field of a frame to be transmitted.
12. An IEEE802.11 receiver, comprising
- a MIMO detecting unit, which is configured to detect whether a multiple-input-multiple-output transmission, hereinafter MIMO transmission, is possible in RF communication with an IEEE802.11 transmitter, wherein the MIMO transmission takes the form of multiple concurrent transmissions of a single stream of analogue radio frequency, RF, signals, corresponding analogue RF signals of different concurrent transmissions of the stream differing only by having different amplitudes or different phases or different amplitudes and phases;
- a channel estimation unit, which is connectable with a plurality of antennas and which is configured to perform, if a MIMO transmission is possible with the IEEE802.11 transmitter, a channel estimation process in communication with the IEEE802.11 transmitter;
- a beamforming unit, which is configured to determine a set of weights to be applied to the analogue RF signals received in different ones of the concurrent transmissions of the MIMO transmission;
- an RF frontend unit, which is connectable with the channel estimation unit, the beamforming unit and with a plurality of antennas and which is configured to
- receive the MIMO transmission via the plurality of antennas;
- subsequently combine the plurality of analogue baseband signals according to a combining algorithm using the determined set of weights, thus forming a combined analogue RF signal;
- subsequently convert the combined analogue RF signal into a combined analogue digital baseband signal;
- a baseband unit, which is connected with the RF frontend and which is configured to further process the combined digital baseband signal; wherein the RF frontend unit and the baseband unit are further configured to, if a MIMO transmission is not possible with the IEEE802.11 transmitter, receive and process the stream of analogue radio frequency, RF, signals, in the form of a single-input-single-output transmission according to the IEEE802.11 standard, hereinafter SISO transmission, via at least one

of the plurality of antennas.

13. An IEEE802.11 transmitter, comprising

- a MIMO detecting unit, which is configured to
detect whether a multiple-input-multiple-output
transmission, hereinafter MIMO transmission, is
possible in RF communication with a target
IEEE802.11 receiver,
wherein the MIMO transmission takes the form
of multiple concurrent transmissions of a single
stream of analogue radio frequency, RF, sig-
nals, corresponding analogue RF signals of dif-
ferent concurrent transmissions of the stream
differing only by having different amplitudes or
different phases or different amplitudes and
phases;
- a channel estimation unit, which is connectable
with a plurality of antennas and which is config-
ured to perform, if a MIMO transmission is pos-
sible with the target IEEE802.11 receiver, a
channel estimation process in communication
with the target IEEE802.11 receiver;
- a beamforming unit, which is configured to de-
termine a set of weights to be applied to the an-
alogue RF signals to be transmitted in different
ones of the concurrent transmissions of the MI-
MO transmission;
- an RF frontend unit, which is connectable with
the channel estimation unit and with a plurality
of antennas and which is configured to, if a MI-
MO transmission is possible with the target
IEEE802.11 receiver, transmit the MIMO trans-
mission via the plurality of antennas and, if a
MIMO transmission is not possible with the tar-
get IEEE802.11 receiver, transmit the stream of
analogue RF signals as a single-input-single-
output transmission according to the
IEEE802.11 standard, hereinafter SISO trans-
mission, via at least one of the plurality of an-
tennas;

14. An IEEE802.11 transceiver, which comprises an
IEEE802.11 receiver according to claim 12 and an
IEEE802.11 transmitter according to claim 13.

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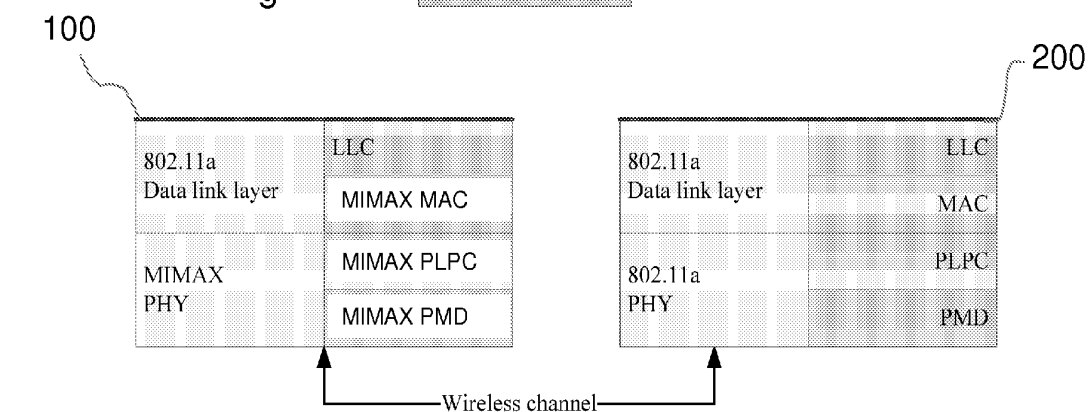
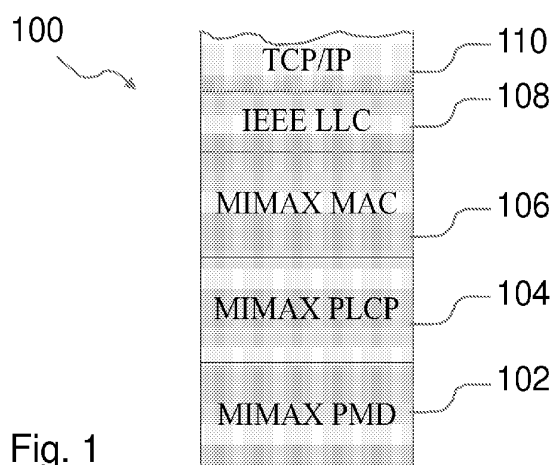


Fig. 2

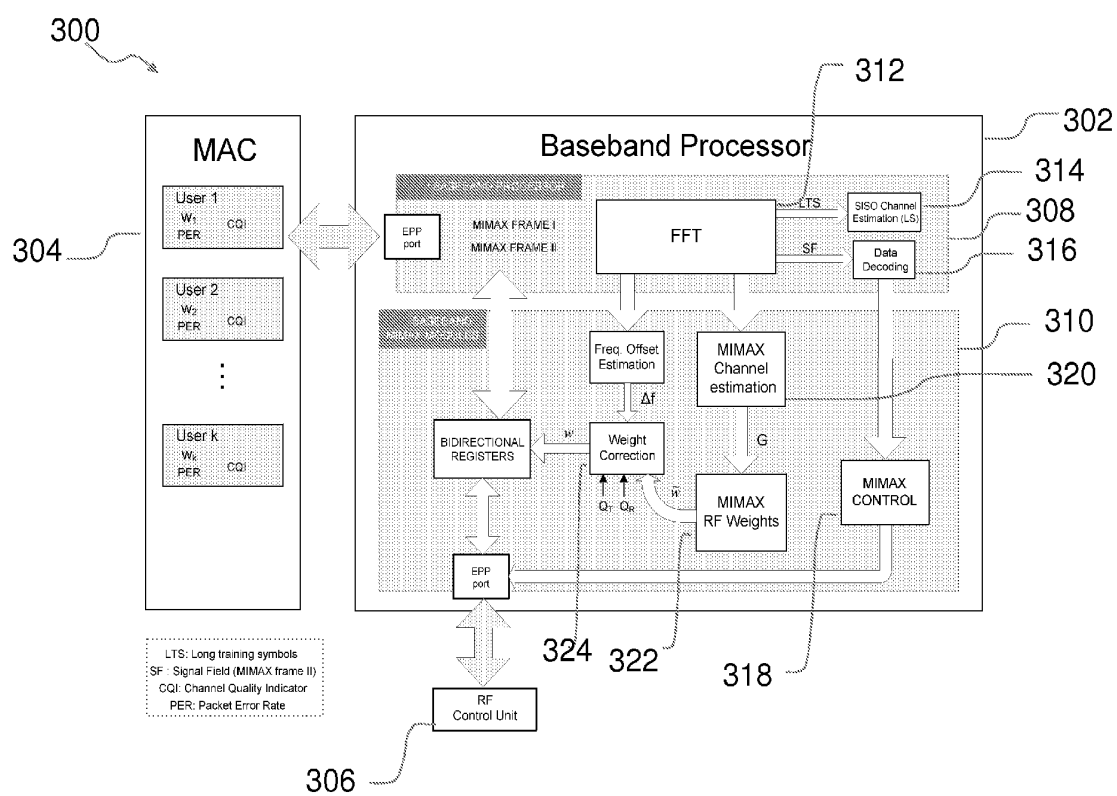


Fig. 3

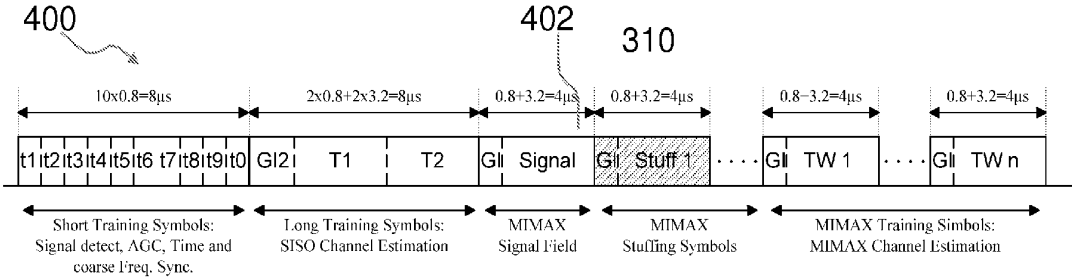


Fig. 4

MIMAX_CONF					R	N_TX		R	N_RX		R	N_T					P	SIGNAL TAIL					
H1	H2	H3	H4	"1"								LSB				MSB		"0"	"0"	"0"	"0"	"0"	"0"
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Fig. 5

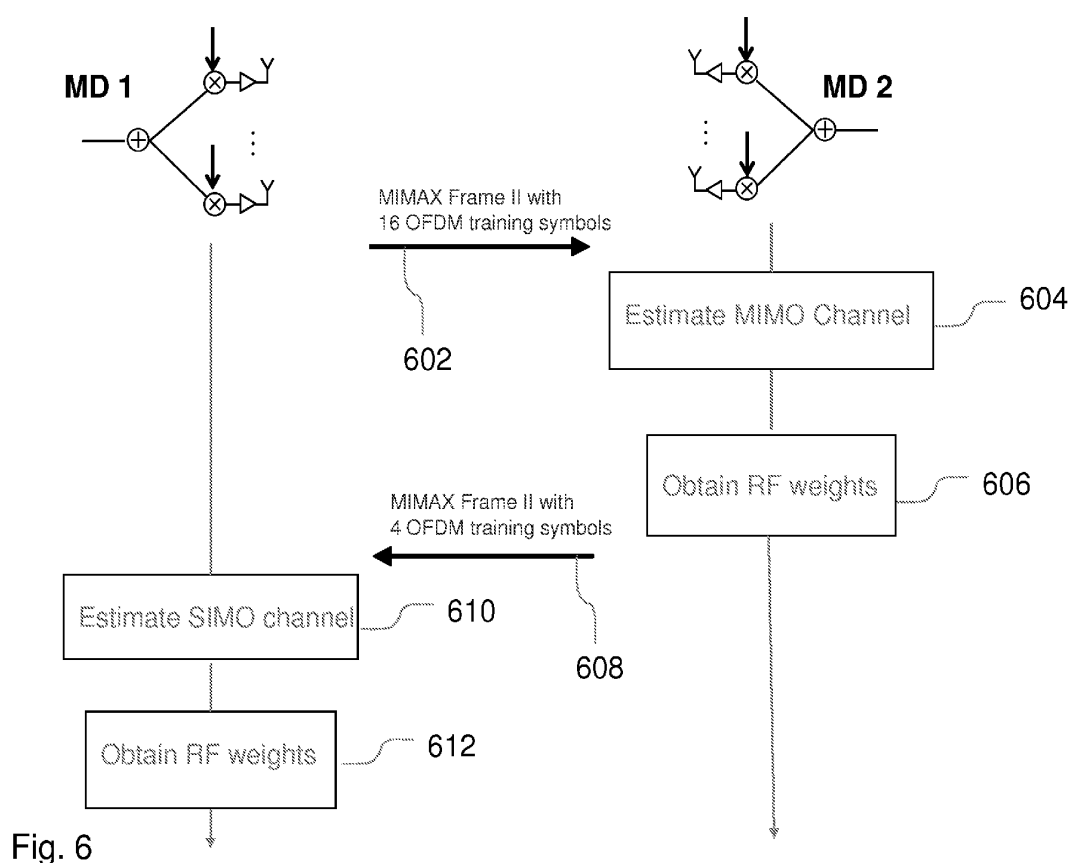


Fig. 6

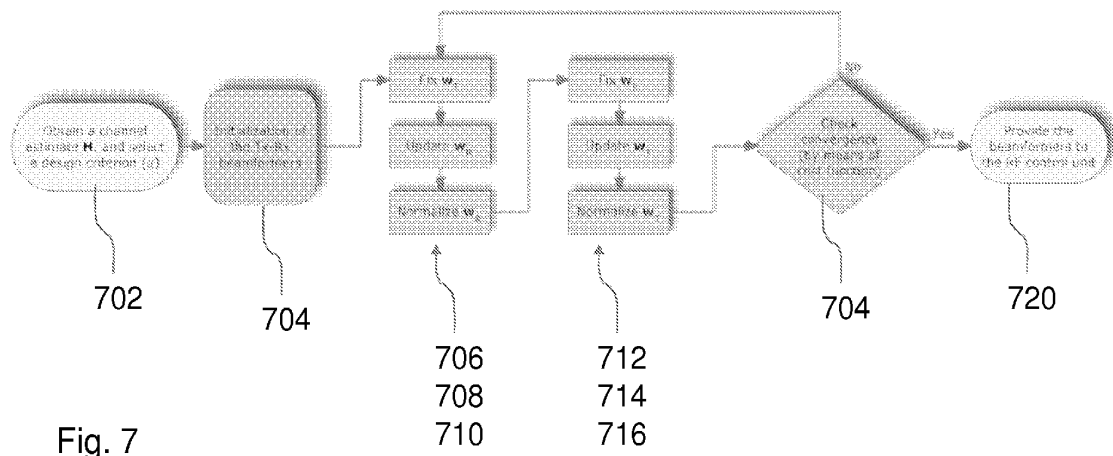


Fig. 7

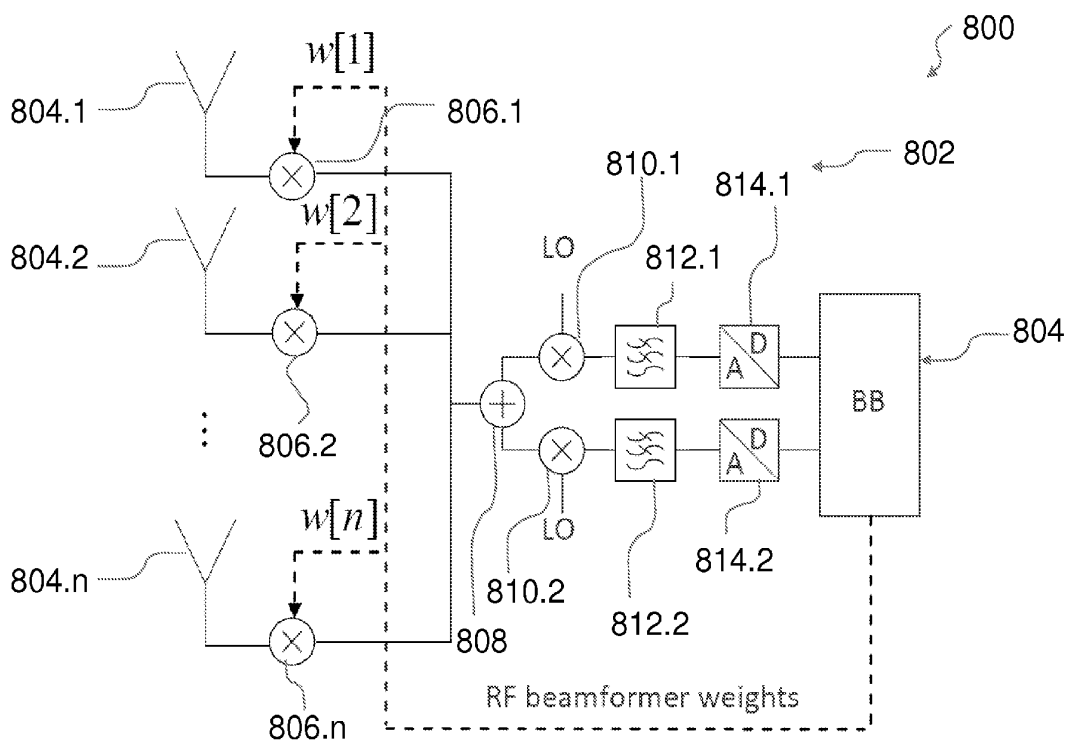


Fig. 8



EUROPEAN SEARCH REPORT

 Application Number
EP 09 15 6126

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Place of search The Hague		Date of completion of the search 28 October 2009	Examiner Reilly, Declan
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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