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(54) **Title:** METHOD AND APPARATUS FOR PREAMBLE TRAINING WITH SHORTENED LONG TRAINING FIELD IN A MULTIPLE ANTENNA COMMUNICATION SYSTEM
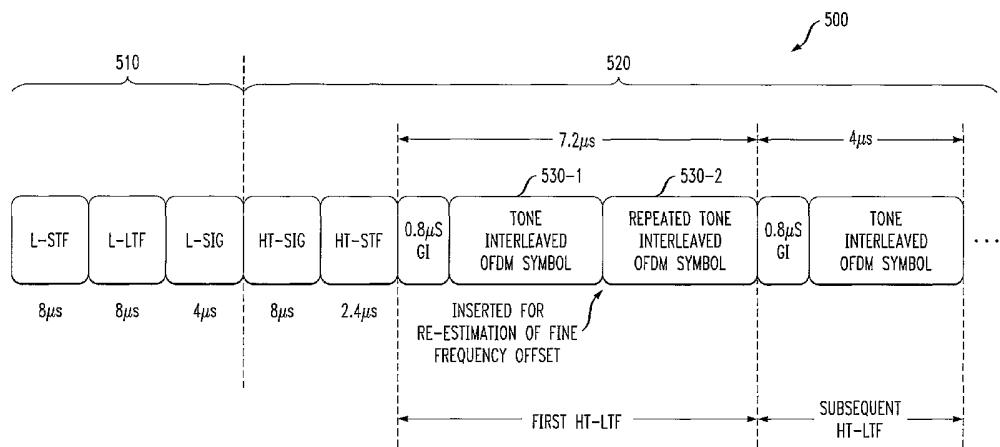
(57) **Abstract:** Methods and apparatus are provided for communicating data in a multiple antenna communication system having N transmit antennas. According to one aspect of the invention, a disclosed header format includes a legacy preamble having at least one legacy long training field and an extended portion having at least N additional long training fields on each of the N transmit antennas, wherein one or more of said at least N additional long training fields are comprised of only one OFDM symbol. The extended portion optionally comprises one or more repeated OFDM symbols for frequency offset estimation. In one implementation, the extended portion comprises a first high throughput long training field comprised of two repeated OFDM symbols and N-I high throughput long training fields comprised of only one OFDM symbol. In another variation, the extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

METHOD AND APPARATUS FOR PREAMBLE TRAINING WITH SHORTENED LONG TRAINING FIELD IN A MULTIPLE ANTENNA COMMUNICATION SYSTEM

5   ## Cross-Reference to Related Applications

The present application claims priority to United States Provisional Patent Application Serial Number 60/651,346, filed February 9, 2005, incorporated by reference herein.

10   ## Field of the Invention

The present invention relates generally to multiple antenna wireless communication systems, and more particularly, to preamble training techniques for a multiple antenna communication system.

15   ## Background of the Invention

Multiple transmit and receive antennas have been proposed to provide both increased robustness and capacity in next generation Wireless Local Area Network (WLAN) systems. The increased robustness can be achieved through techniques that exploit the spatial diversity and additional gain introduced in a system

20   with multiple antennas. The increased capacity can be achieved in multipath fading environments with bandwidth efficient Multiple Input Multiple Output (MIMO) techniques. A multiple antenna communication system increases the data rate in a given channel bandwidth by transmitting separate data streams on multiple transmit antennas. Each receiver receives a combination of these data streams on multiple

25   receive antennas.

In order to properly receive the different data streams, receivers in a multiple antenna communication system must acquire the channel matrix through training. This is generally achieved by using a specific training symbol, or preamble, to perform synchronization and channel estimation. It is desirable for multiple

30   antenna communication systems to co-exist with legacy single antenna communications systems (typically referred to as Single Input Single Output (SISO) systems). Thus, a legacy (single antenna) communications system must be able to

interpret the preambles that are transmitted by multiple antenna communication systems. Most legacy Wireless Local Area Network (WLAN) systems based upon OFDM modulation comply with either the IEEE 802.11a or IEEE 802.11g standards (hereinafter "IEEE 802.11a/g"). Generally, the preamble signal seen by the legacy

5 device should allow for accurate synchronization and channel estimation for the part of the packet that the legacy device needs to understand. Previous MIMO preamble formats have reused the legacy training preamble to reduce the overhead and improve efficiency. Generally, the proposed MIMO preamble formats include the legacy training preamble and additional long training symbols, such that the extended MIMO

10 preamble format includes at least one long training symbol for each transmit antenna or spatial stream.

A number of frame formats have been proposed for evolving multiple antenna communication systems, such as MIMO-OFDM systems. Existing frame formats provide inaccurate estimations for the MIMO systems, such as inaccurate

15 power measurement or outdated frequency offset and timing offset information, or fail to provide full backwards compatibility to the legacy devices of some vendors. In one proposed MIMO frame format, each transmit antenna sequentially transmits one or more long training symbols, such that only one transmit antenna is active at a time. As the transmit antennas are switched on and off, however, the temperature of the

20 corresponding power amplifier will increase and decrease, respectively. Generally, such heating and cooling of the power amplifier will lead to "breathing" effects that cause the transmitted signal to have a phase or magnitude offset, relative to the desired signal.

It is therefore desirable to have a continuous transmission from all

25 transmit antennas to avoid temperature related signal "breathing." Thus, in further proposed MIMO frame formats, orthogonality is maintained using cyclic delay diversity (CDD) or tone-interleaving across different transmit antennas. The CDD short training symbol, however, cannot measure the received signal power with sufficient accuracy. Thus, additional backoff is required in the RF chain and

30 additional dynamic range is required in the digitization process. Likewise, the tone interleaved design is not fully backwards compatible with a number of existing

802.11a/g devices that use short training for timing synchronization or use time domain channel estimation.

A need therefore exists for a method and system for performing channel estimation and training in a MIMO-OFDM system that is compatible with
5   current IEEE 802.11a/g standard (SISO) systems, allowing MIMO-OFDM based WLAN systems to efficiently co-exist with SISO systems. A further need exists for MIMO preamble formats and training techniques that provide reduced preamble overhead.

10   **Summary of the Invention**

Generally, methods and apparatus are provided for communicating data in a multiple antenna communication system having N transmit antennas. According to one aspect of the invention, a disclosed header format includes a preamble having at least one legacy long training field and an extended portion
15   having at least N additional long training fields on each of the N transmit antennas, wherein one or more of said at least N additional long training fields are comprised of only one OFDM symbol. The extended portion optionally comprises one or more repeated OFDM symbols for frequency offset estimation. In one implementation, the extended portion comprises a first high throughput long training field comprised of
20   two repeated OFDM symbols and N-1 high throughput long training fields comprised of only one OFDM symbol. In another variation, the extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference
25   to the following detailed description and drawings.

Brief Description of the Drawings

FIG. 1 is a schematic block diagram of an exemplary MIMO transmitter;
30   FIG. 2 is a schematic block diagram of an exemplary MIMO receiver;

FIG. 3 illustrates a preamble design that is backwards compatible with 802.11a/g legacy devices;

FIG. 4 illustrates the preamble format of FIG. 3 in further detail;

FIG. 5 illustrates a preamble format incorporating features of the present invention; and

FIG. 6 illustrates an alternate preamble format incorporating features of the current invention.

Detailed Description

The present invention provides preamble formats and techniques for preamble training for MIMO system. The training phase of a MIMO transmission will contain two phases. The first training phase is a legacy training phase particularly suited, for example, to WLAN OFDM legacy systems and the second phase is particularly suited to a multiple antenna system, such as a MIMO system. To overcome the problems in the prior systems, the Automatic Gain Control (AGC) of a receiver will perform one training sequence during the first training phase and the AGC of the receiver will retrain during the second training phase. This will allow the receiver to retrain its power measurements during the MIMO phase in order to ensure accuracy, while also allowing the receiver to be backwards compatible to WLAN systems that are not MIMO based.

FIG. 1 is a schematic block diagram of a MIMO transmitter 100. As shown in FIG. 1, the exemplary two antenna transmitter 100 encodes the information bits received from the medium access control (MAC) layer and maps the encoded bits to different frequency tones (subcarriers) at stage 105. For each transmit branch, the signal is then transformed to a time domain wave form by an IFFT (inverse fast Fourier transform) 115. A guard interval (GI) of 800 nanoseconds (ns) is added in the exemplary implementation before every OFDM symbol by stage 120 and a preamble of 32 μs is added by stage 125 to complete the packet. The digital signal is then pre-processed at stage 128 and converted to an analog signal by converter 130 before the RF stage 135 transmits the signal on a corresponding antenna 140.

FIG. 2 is a schematic block diagram of a MIMO receiver 200. As
shown in FIG. 2, the exemplary two antenna receiver 200 processes the signal
received on two receive antennas 255-1 and 255-2 at corresponding RF stages 260-1,
260-2. The analog signals are then converted to digital signals by corresponding

5   converters 265. The receiver 200 processes the preamble to detect the packet, and
then extracts the frequency and timing synchronization information at synchronization
stage 270 for both branches. The guard interval is removed at stage 275. The signal
is then transformed back to the frequency domain by an FFT at stage 280. The
channel estimates are obtained at stage 285 using the long training symbol. The

10   channel estimates are applied to the demapper/decoder 290, and the information bits
are recovered.

FIG. 3 illustrates a preamble design 300 that is backwards compatible
with 802.11a/g legacy devices. The preamble design 300 provides a dedicated legacy
portion 310 with a signal field for backward compatibility and a dedicated MIMO

15   training portion 320 for performance of the MIMO system.

For a detailed discussion of an implementation of the preamble design
of FIG. 3 and techniques for employing cyclic delay diversity (CDD) or tone-
interleaving across different transmit antennas, see, for example, United States Patent
Application 11/043,025, filed January 24, 2005, entitled "Method And Apparatus For

20   Preamble Training In A Multiple Antenna Communication System," incorporated by
reference herein.

In the exemplary preamble design 300, the transmitter 100 first
transmits the legacy 802.11a/g preamble 310, for example, using CDD. The legacy
preamble 310 permits the performance of packet detection and coarse frequency

25   offset estimation. The results of these two functions are also going to be used in the
MIMO transmission. In addition to these two functions, the legacy preamble 310 is
used to perform legacy AGC, timing and frequency synchronization and channel
estimation, in a known manner. The receiver 200 then decodes the subsequent legacy
and HT signal fields. The HT signal field is also transmitted using CDD. As shown

30   in FIG. 3, following the legacy and HT signal fields is a MIMO short training field
330 and then the MIMO long training fields. The MIMO short training field 330 is

used only to adjust the AGC setting, and the length can be much shorter than the legacy short training field. As illustrated herein, the MIMO short training field includes a 0.8μs guard interval and a 1.6μs training symbol for the accurate power measurement.

5   It is noted that the preamble format 300 of FIG. 3 may not use the first Long Preamble in the legacy header for MIMO channel estimation. The dedicated short training symbol 330 allows precise power measurement for MIMO, at the expense of higher preamble overhead (9.6μs extra). Hence, the preamble format 300 provides low dynamic range requirements (ten bit ADC). The MIMO long training

10   fields of FIG. 3 can be transmitted on the same frequency grid as the data. Thus, Frequency Domain Channel Estimation (FDE) may be performed.

The short training field 330 of FIG. 3 can be constructed in a tone-interleaved fashion. While an OFDM symbol with 12 tones (i.e., 0.8us long) would be sufficient to provide accurate power across four antennas, a 24-tone OFDM

15   symbol (i.e. 1.6us long) provides even more accuracy, at the expense of slightly larger overhead. The populated tones are interleaved across the transmit antennas.

Since the short training symbol 330 is only 1.6μs long, only 24 tones are used (of 64 total available tones). The indices of those tones are all multiples of four, so that the resulting time domain signal has a period of 1.6μs. In the exemplary

20   two antenna case, only half of the tones are transmitted on each transmitter antenna, i.e., every other used tone is transmitted on the first antenna and the rest of tones are transmitted on the second antenna. Moreover, this short training symbol 330 can be further shortened to 0.8μs, which only uses 12 tones, to reduce the overhead.

FIG. 4 illustrates the preamble format 300 of FIG. 3 in further detail.

25   The preamble design 300 provides the dedicated legacy portion 310 with a signal field for backward compatibility and a dedicated MIMO training portion 320 for performance of the MIMO system. As shown in FIG. 4, the dedicated MIMO training portion 320 includes two OFDM symbols for each MIMO long training field (HT-LTF). Thus, a single MIMO long training field in the exemplary embodiment shown

30   in FIGS. 3 and 4 comprises a guard interval and two tone interleaved OFDM symbols for a total duration of 7.2 μs (0.8 + 2*3.2μs). It is noted that the preamble format 300

generally comprises N additional long training fields on each of N transmit antennas. Thus, the total duration of the preamble is 30.4 μs (8*3 + 4 + 2.4 μs) + N * 7.2 μs. In a typical four antenna implementation, the preamble duration is 59.2 μs. The channel estimation performance that has been observed for the preamble format 300 having

5   two OFDM symbols for each MIMO long training field is 1.76 dB less than that with an ideal channel estimation (i.e., this demonstrates the nominal channel estimation error).

                FIG. 5 illustrates a preamble format 500 incorporating features of the present invention. The preamble design 500 provides the dedicated legacy portion

10   510 with a signal field for backward compatibility and a dedicated MIMO training portion 520 for performance of the MIMO system. As shown in FIG. 5, the first MIMO long training field (HT-LTF) contains a repeated OFDM symbol 530-1, 530-2. The motivation for repeating the OFDM symbol is to allow for a re-estimation of the fine frequency offset. However, unlike the format 320, the "subsequent" N-1 MIMO

15   long training fields do not contain a repeated OFDM symbol. This leads a reduction in the overall length of the preamble. Therefore, the length of the preamble can now be computed as follows:

                For N = 1, length = 30.4 + 7.2 = 37.6 us

                For N=2 and greater, length = 37.6 + (N-1)*4 us

20   where N equals the number of spatial streams (or equivalently transmit antennas). In a typical four antenna implementation, the preamble duration is thus 49.6 μs. Note that by not repeating the OFDM symbol in subsequent MIMO long training fields, the error in channel estimation in the subsequent MIMO long training fields increases from 1.76dB to 3dB.

25   FIG. 6 illustrates a preamble format 600 incorporating features of the current invention. The preamble design 600 provides the dedicated legacy portion 610 with a legacy signal field for backwards compatibility and a dedicated MIMO long training portion 620 to achieve performance of the MIMO system. As shown in FIG 6, neither the first nor the subsequent MIMO Long Training Fields (HT-LTF) are

30   repeated. This leads to the shortest possible preamble design, whose length is given by (30.4 + N*4) us, where N is the number of spatial streams. For preamble format

600, the increase in channel estimation error is 3dB over that of an ideal channel estimation.

The present invention recognizes that shortening each MIMO long training field (HT-LTF) from two OFDM symbols to one OFDM symbol increases the channel estimation error while reducing the preamble overhead. It has been observed that the preamble formats 500, 600 having one OFDM symbol per MIMO long training field outperforms the preamble format 400 having two OFDM symbols per MIMO long training field (in the sense of throughput versus SNR (dB)) at high SNR and larger number of spatial streams (N). Meanwhile, at lower SNR, performance of the two formats is comparable

It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention.

I claim:

1.   A method for transmitting data in a multiple antenna communication
5   system having N transmit antennas, said method comprising the step of:
           transmitting a preamble having at least one long training field and an
extended portion having at least N additional long training fields on each of said N
transmit antennas, wherein one or more of said at least N additional long training
fields are comprised of only one OFDM symbol.
10

2.   The method of claim 1, wherein said preamble is a legacy preamble.

3.   The method of claim 2, wherein said legacy preamble further
comprises at least one short training symbol and one SIGNAL field.
15

4.   The method of claim 2, wherein said legacy preamble is an 802.11 a/g
preamble.

5.   The method of claim 1, wherein said extended portion further includes
20   a short training field for power estimation.

6.   The method of claim 1, wherein said extended portion further includes
a signal field identifying a preamble format.

25   7.   The method of claim 1, wherein said extended portion further
comprises one or more additional OFDM symbols for frequency offset estimation.

8.   The method of claim 1, wherein said extended portion comprises a first
high throughput long training field comprised of two repeated OFDM symbols and N-
30   1 high throughput long training fields comprised of only one OFDM symbol.

9.   The method of claim 1, wherein said extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

10.   A transmitter in a multiple antenna communication system, comprising:

            N transmit antennas for transmitting a preamble having at least one long training field and an extended portion having at least N additional long training fields on each of said N transmit antennas, wherein one or more of said at least N additional long training fields are comprised of only one OFDM symbol.

11.   The transmitter of claim 10, wherein said preamble is a legacy preamble.

12.   The transmitter of claim 11, wherein said legacy preamble further comprises at least one short training symbol and one SIGNAL field.

13.   The transmitter of claim 10, wherein said N additional long training fields are tone interleaved across said N transmit antennas.

14.   The transmitter of claim 10, wherein only said N additional long training fields are used for MIMO channel estimation.

15.   The transmitter of claim 10, wherein said extended portion further includes one or more of a short training field for power estimation and a signal field identifying a preamble format.

16.   The transmitter of claim 10, wherein said extended portion further comprises one or more additional OFDM symbols for frequency offset estimation.

17.   The transmitter of claim 10, wherein said extended portion comprises a first high throughput long training field comprised of two repeated OFDM symbols

and N-1 high throughput long training fields comprised of only one OFDM symbol.

18.   The transmitter of claim 10, wherein said extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

19.   A method for receiving data on at least one receive antenna transmitted by a transmitter having N transmit antennas in a multiple antenna communication system, said method comprising the steps of:

    receiving a preamble having at least one long training field and an extended portion having at least N additional long training fields on each of said N transmit antennas, wherein one or more of said at least N additional long training fields are comprised of only one OFDM symbol.

20.   The method of claim 19, wherein said preamble is a legacy preamble.

21.   The method of claim 19, wherein only said N additional long training fields are used for MIMO channel estimation.

22.   The method of claim 19, wherein said extended portion further includes one or more of a short training field for power estimation and a signal field identifying a preamble format.

23.   The method of claim 19, wherein said extended portion further comprises one or more additional OFDM symbols for frequency offset estimation.

24.   The method of claim 19, wherein said extended portion comprises a first high throughput long training field comprised of two repeated OFDM symbols and N-1 high throughput long training fields comprised of only one OFDM symbol.

25.   The method of claim 19, wherein said extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

26.   A receiver in a multiple antenna communication system having at least one transmitter having N transmit antennas, comprising:

at least one receive antenna for receiving a preamble having at least one long training field and an extended portion having at least N additional long training fields on each of said N transmit antennas, wherein one or more of said at least N additional long training fields are comprised of only one OFDM symbol.

27.   The receiver of claim 26, wherein said preamble is a legacy preamble.

28.   The receiver of claim 26, wherein only said N additional long training fields are used for MIMO channel estimation.

29.   The receiver of claim 26, wherein said extended portion further includes one or more of a short training field for power estimation and a signal field identifying a preamble format.

30.   The receiver of claim 26, wherein said extended portion further comprises one or more additional OFDM symbols for frequency offset estimation.

31.   The receiver of claim 26, wherein said extended portion comprises a first high throughput long training field comprised of two repeated OFDM symbols and N-1 high throughput long training fields comprised of only one OFDM symbol.

32.   The receiver of claim 26, wherein said extended portion comprises N high throughput long training fields comprised of only one OFDM symbol.

FIG. 1

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FIG. 2

3/6

FIG. 3

FIG. 4

5/6
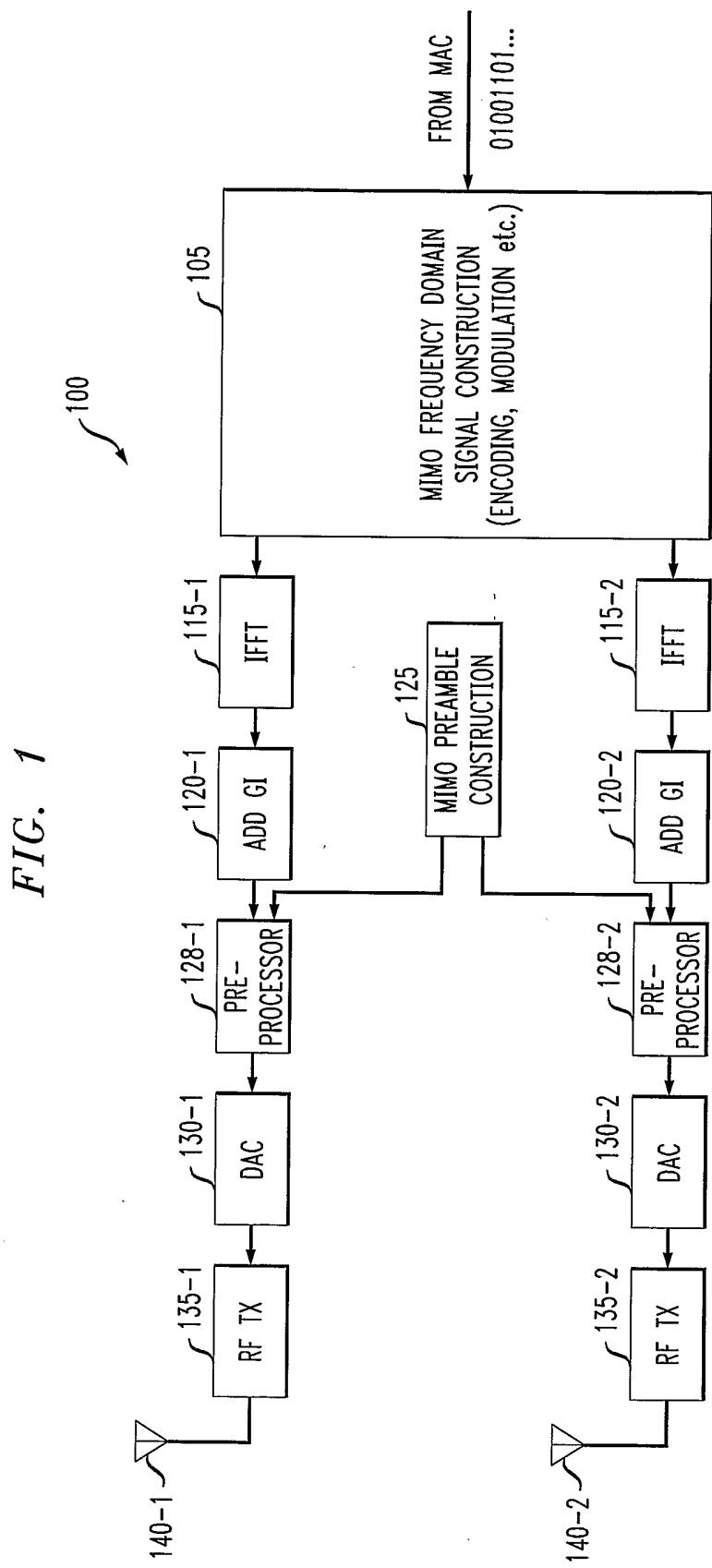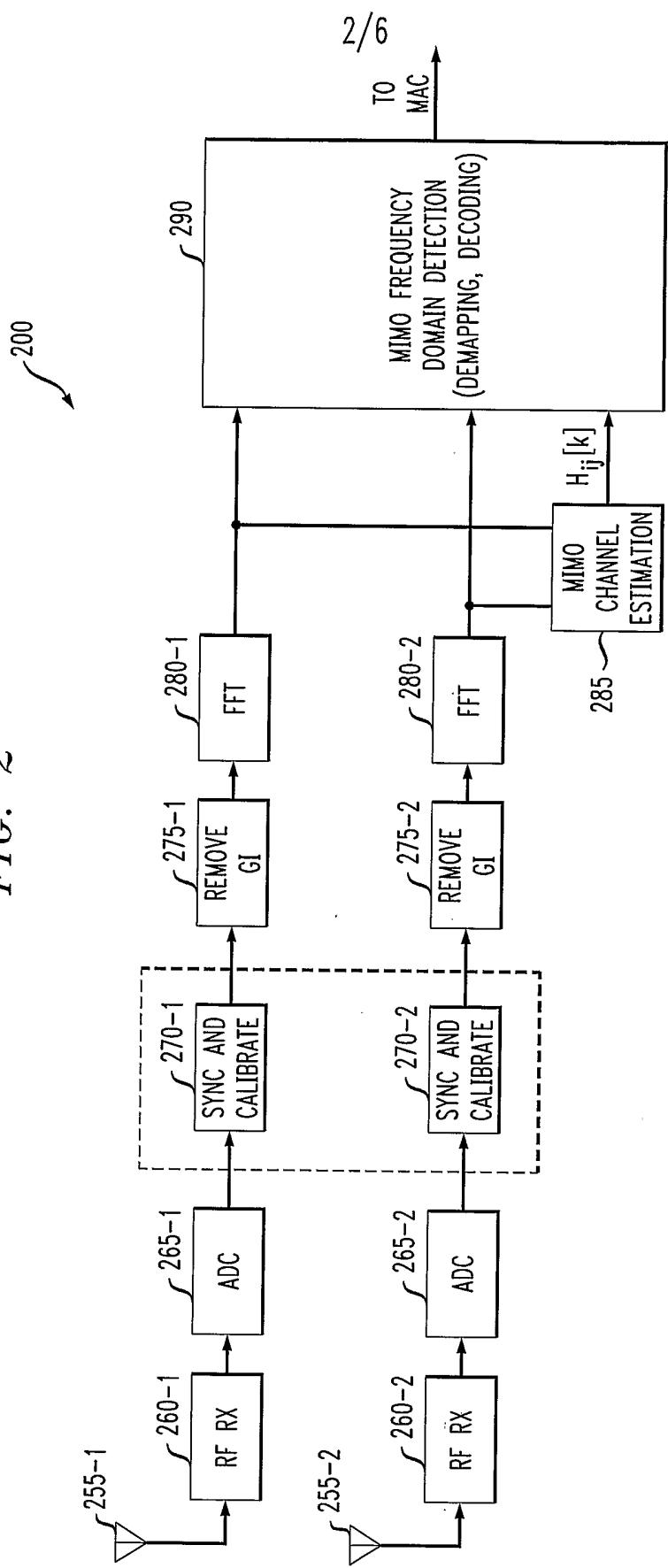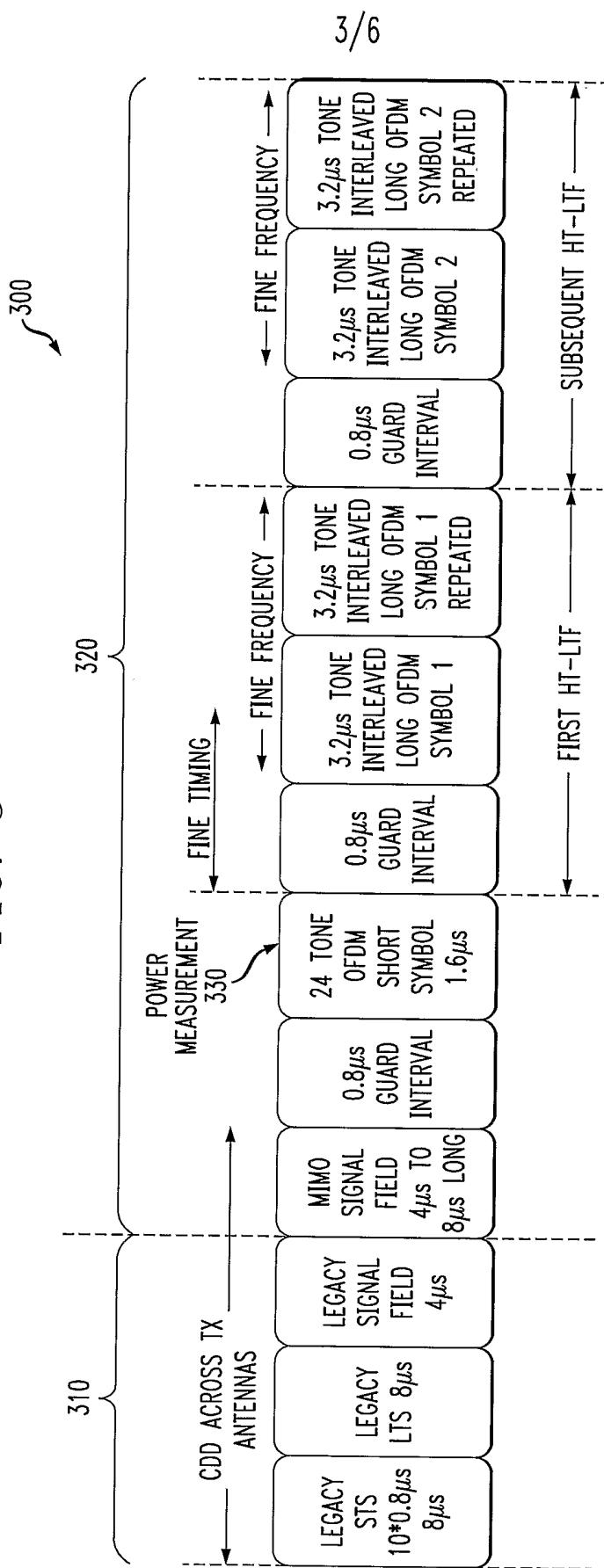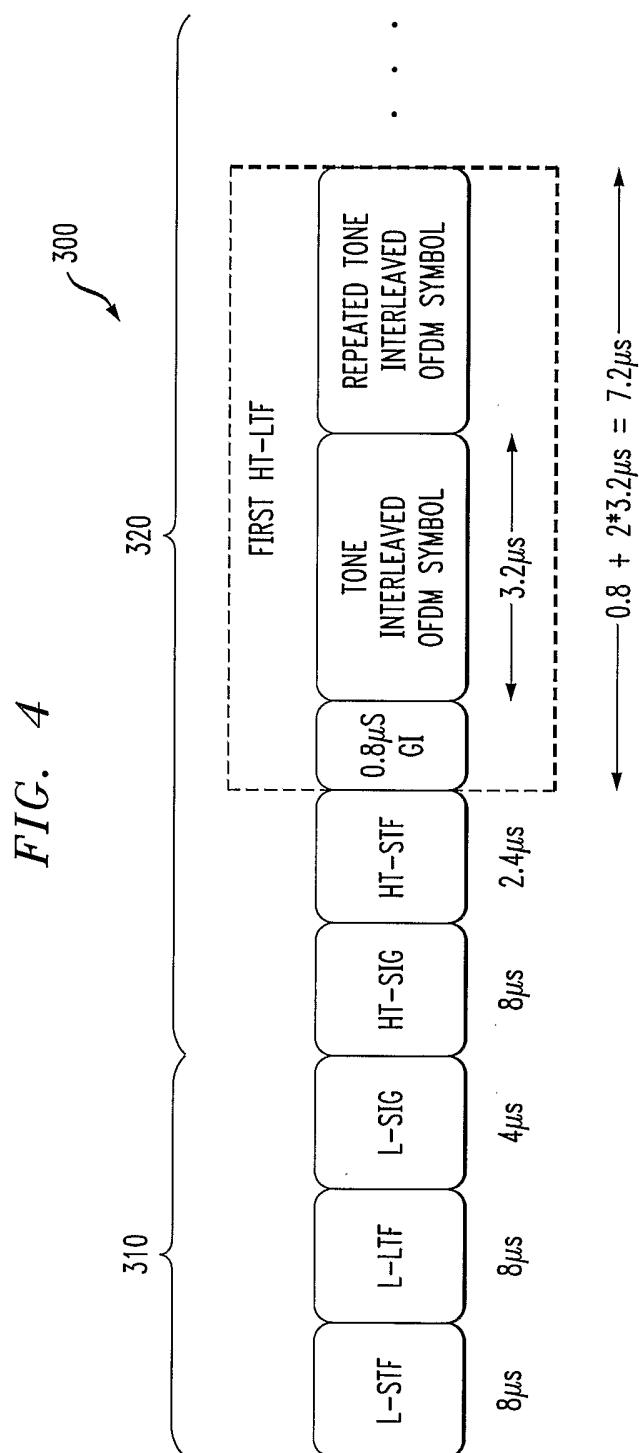
FIG. 5
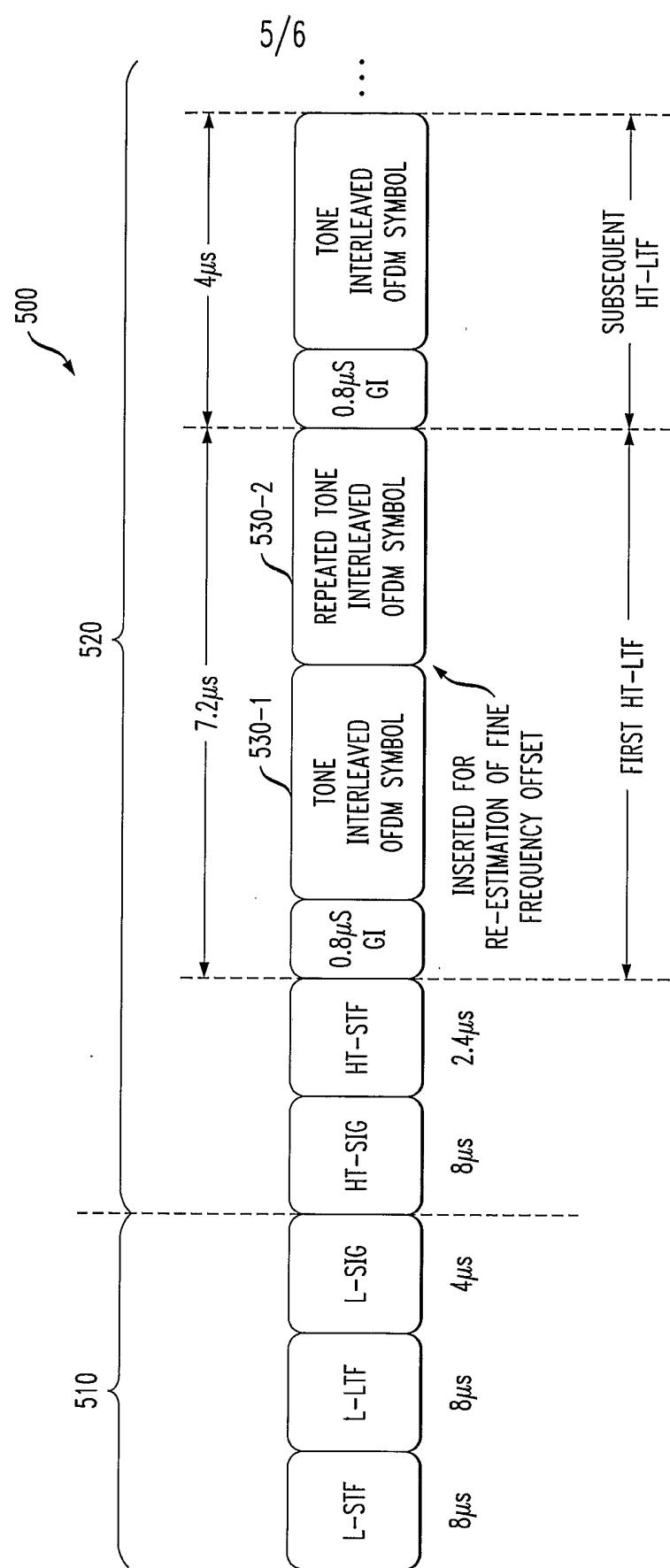
FIG. 6
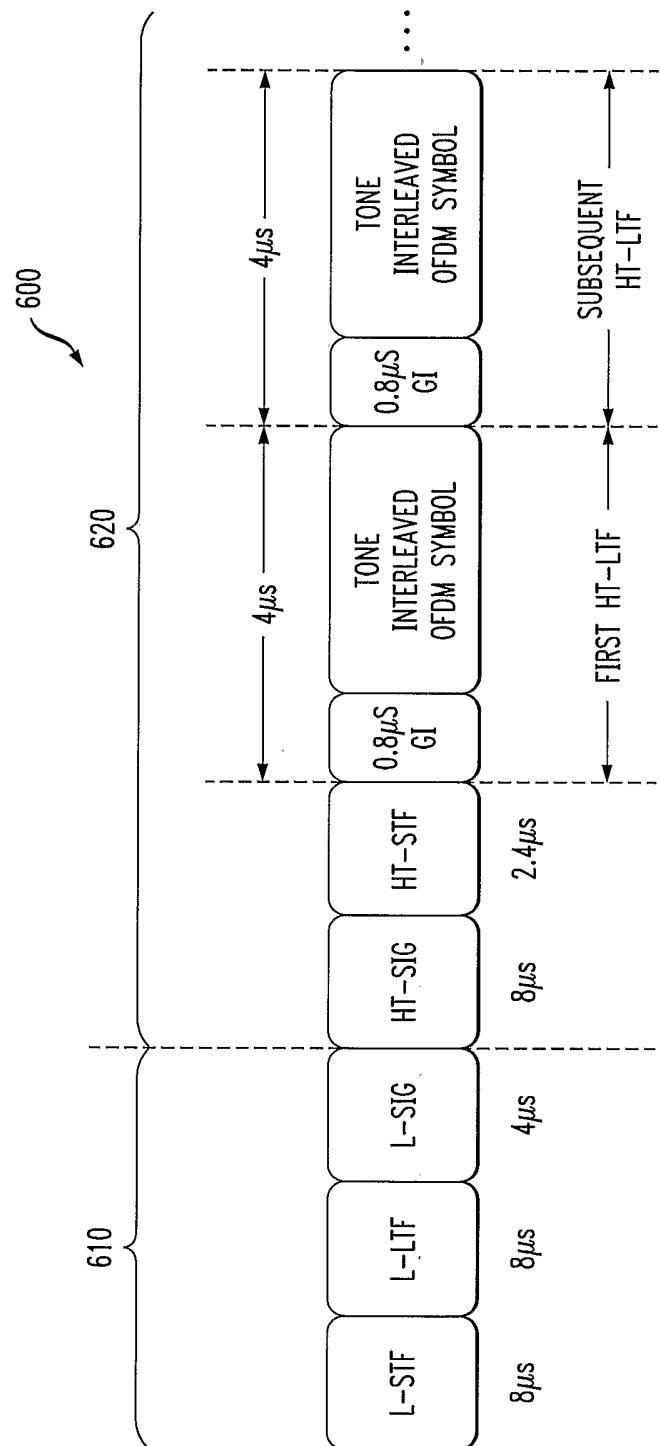
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV.   H04L27/26

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)
H04L

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/006700 A (AGERE SYSTEMS INC; KOPMEINERS, ROBERT, JOHN; SCHENK, TIM; VAN ZELST, A) 20 January 2005 (2005-01-20) page 1, line 25 – line 30 page 2, line 5 – line 10 page 2, line 19 – line 26 page 3, line 8 – line 13 page 4, line 20 – line 30 page 6, line 1 – line 5 page 7, line 5 – line 10 page 8, line 1 – line 10 page 9, line 15 – line 25 page 10, line 5 – line 15 -/--	1-32

| X | Further documents are listed in the continuation of Box C. | | X | See patent family annex. |

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Date of the actual completion of the international search	Date of mailing of the international search report
9 June 2006	19/06/2006

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/006588 A (AGERE SYSTEMS INC; BOER, JAN, H; DRIESEN, BAS; SCHENK, TIM; VAN ZELST,) 20 January 2005 (2005-01-20) page 1, line 15 - line 25 page 2, line 10 - page 3, line 15 page 4, line 25 - line 30 page 5, line 10 - line 15 page 7, line 25 - page 8, line 5 ─────	1-32

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			EP	1642435 A1	05-04-2006
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