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(54) **MODIFIED PREAMBLE STRUCTURE FOR IEEE 802.11A EXTENSIONS TO ALLOW FOR COEXISTENCE AND INTEROPERABILITY BETWEEN 802.11A DEVICES AND HIGHER DATA RATE, MIMO OR OTHERWISE EXTENDED DEVICES**

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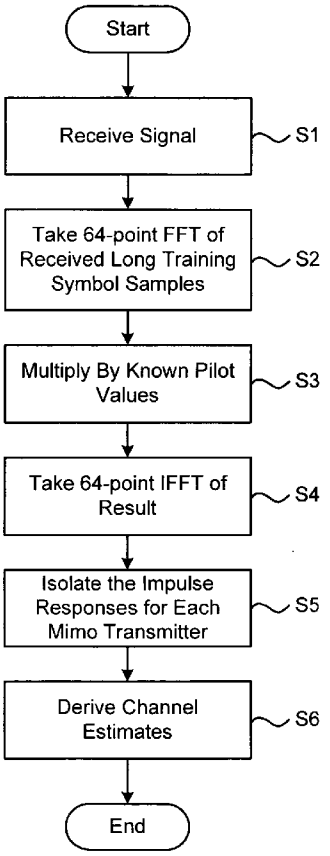
(57) **ABSTRACT**

A modified preamble is used by extended devices that operate at higher rates, MIMO or other extensions relative to strict 802.11a-compliant devices. The extended devices might use multiple antenna techniques (MIMO), where multiple data streams are multiplexed spatially and/or multi-channel techniques, where an extended transmitter transmits using more than one 802.11a channel at a time. Such extensions to IEEE 802.11a can exist in extended devices. The modified preamble is usable for signaling, to legacy devices as well as extended devices, to indicate capabilities and to cause legacy devices or extended devices to defer to other devices such that the common communication channel is not subject to unnecessary interference. The modified preamble. is also usable for obtaining MIMO channel estimates and/or multi-channel estimates. The modified preamble preferably includes properties that facilitate detection of conventional and/or extended modes ("mode detection") and provides some level of coexistence with legacy IEEE 802.11a devices.



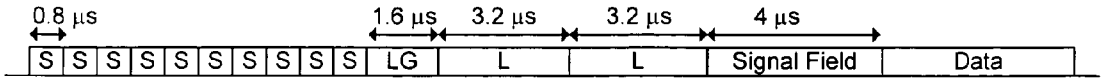


FIG. 1 (PRIOR ART)

```
L1 = { 0   1  -1  -1   1   1  -1   1  -1   1  -1  -1  -1  -1  -1   1
       1  -1  -1   1  -1   1  -1   1   1   1   1   0   0   0   0   0
       0   0   0   0   0   0   1   1  -1  -1   1   1  -1   1  -1   1
       1   1   1   1   1  -1  -1   1   1  -1   1  -1   1   1   1   1}
```

FIG. 2 (PRIOR ART)

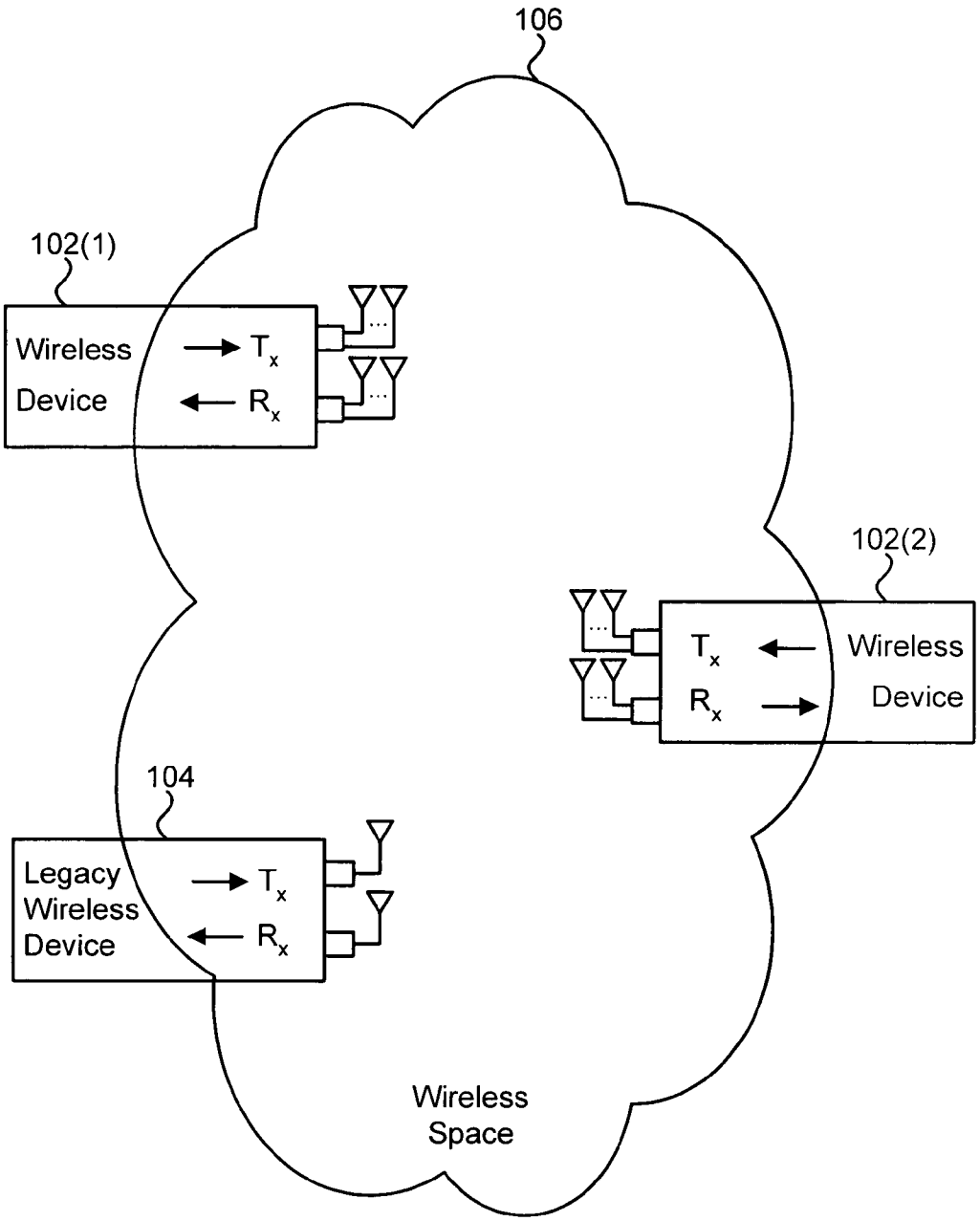

106
102(1)
Wireless
Device
T_x
R_x
102(2)
T_x
R_x
Wireless
Device
104
Legacy
Wireless
Device
T_x
R_x
Wireless
Space

FIG. 3

```
L2 = { 0   1  -1  -1   1   1  -1   1  -1   1  -1  -1  -1  -1  -1   1
       1  -1  -1   1  -1   1  -1   1   1   1   1  -1  -1  -1   1  -1
      -1  -1   1   1   1   1   1   1  -1  -1   1   1  -1   1  -1   1
       1   1   1   1   1  -1  -1   1   1  -1   1  -1   1   1   1   1}

L3 = { 0   1  -1  -1  -1  -1   1  -1  -1   1  -1  -1   1   1   1  -1
       1  -1  -1   1   1  -1   1  -1   1   1   1  -1   1   1  -1   1
      -1  -1   1   1  -1  -1  -1  -1  -1  -1   1   1   1  -1   1  -1
       1   1   1   1  -1   1   1  -1   1  -1   1  -1  -1  -1  -1  -1}

L4 = { 0  -1   1   1   1   1   1   1  -1  -1   1   1  -1   1  -1   1
       1   1   1   1   1  -1  -1   1   1  -1   1  -1   1   1   1   1
      -1   1  -1  -1   1   1  -1   1  -1   1  -1  -1  -1  -1  -1   1
       1  -1  -1   1  -1   1  -1   1   1   1   1  -1  -1  -1   1  -1
      -1  -1   1   1   1   1   1   1  -1  -1   1   1  -1   1  -1   1
       1   1   1   1   1  -1  -1   1   1  -1   1  -1   1   1   1   1
      -1   1  -1  -1   1   1  -1   1  -1   1  -1  -1  -1  -1  -1   1
       1  -1  -1   1  -1   1  -1   1   1   1   1  -1  -1  -1   1  -1}
```

FIG. 4

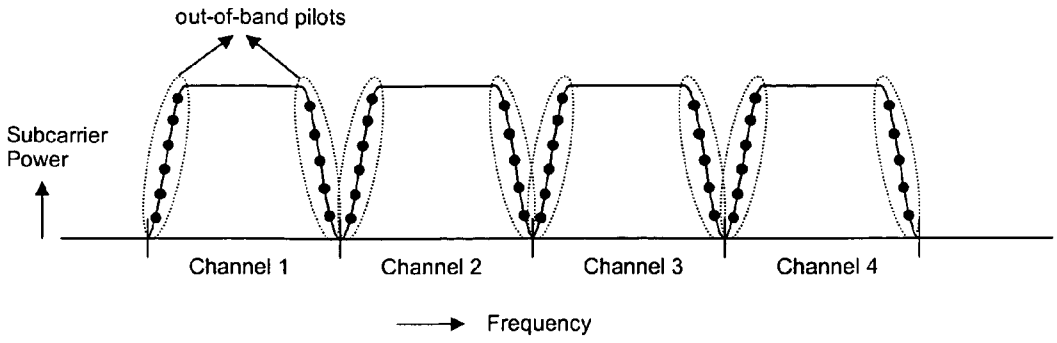


FIG. 5

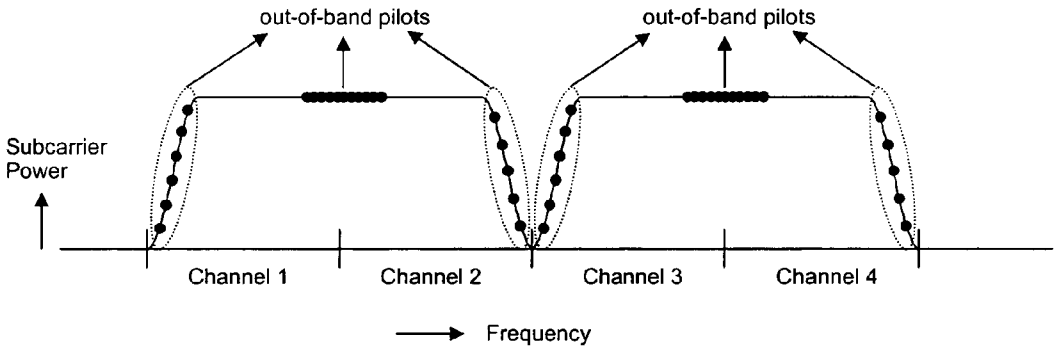


FIG. 6

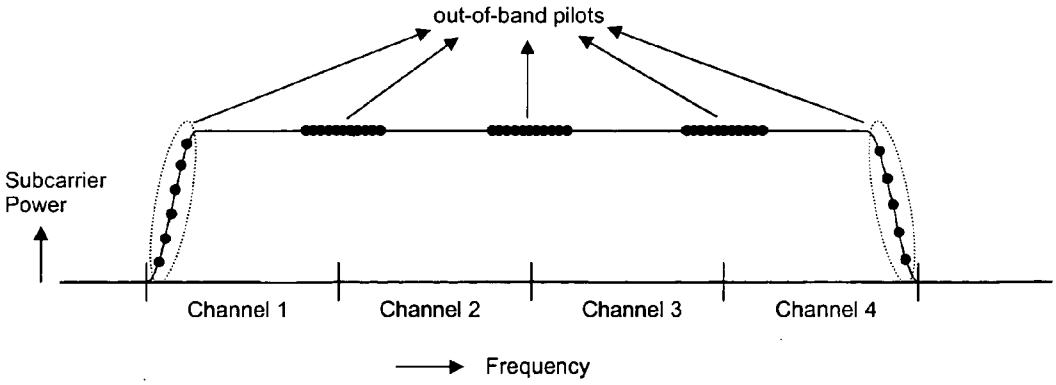


FIG. 7

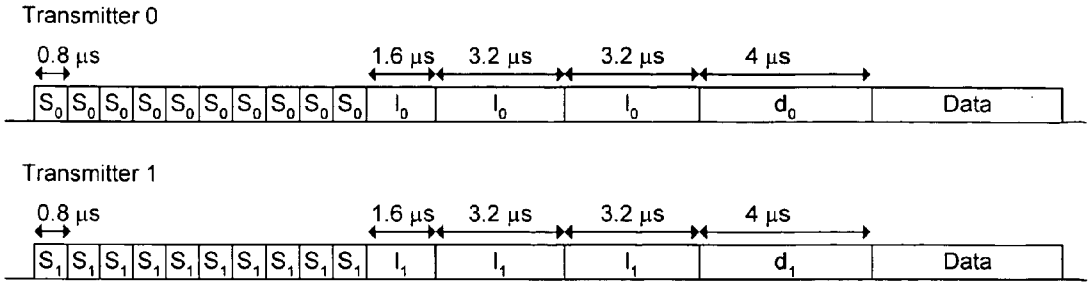

Transmitter 0
0.8 µs
1.6 µs
3.2 µs
3.2 µs
4 µs
S0 S0 S0 S0 S0 S0 S0 S0 S0 S0
I0
I0
I0
d0
Data
Transmitter 1
0.8 µs
1.6 µs
3.2 µs
3.2 µs
4 µs
S1 S1 S1 S1 S1 S1 S1 S1 S1 S1
I1
I1
I1
d1
Data

FIG. 8

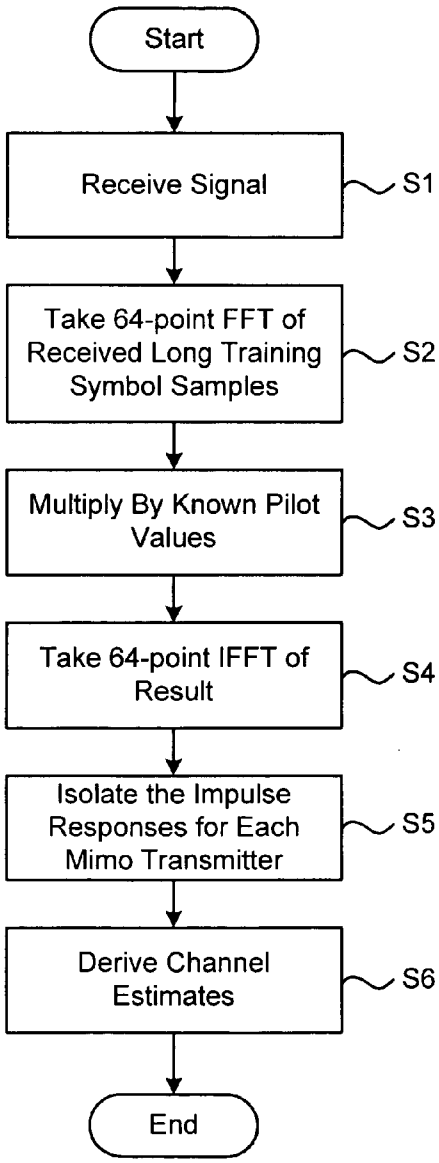

Start
Receive Signal
S1
Take 64-point FFT of Received Long Training Symbol Samples
S2
Multiply By Known Pilot Values
S3
Take 64-point IFFT of Result
S4
Isolate the Impulse Responses for Each Mimo Transmitter
S5
Derive Channel Estimates
S6
End

FIG. 9

MODIFIED PREAMBLE STRUCTURE FOR IEEE 802.11A EXTENSIONS TO ALLOW FOR COEXISTENCE AND INTEROPERABILITY BETWEEN 802.11A DEVICES AND HIGHER DATA RATE, MIMO OR OTHERWISE EXTENDED DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from co-pending U.S. Provisional Patent Application No. 60/461, 999, filed Apr. 9, 2003 entitled "MODIFIED PREAMBLE STRUCTURE FOR IEEE 802.11A EXTENSIONS," which is hereby incorporated by reference, as if set forth in full in this document, for all purposes.

BACKGROUND OF THE INVENTION

[0002] The IEEE 802.11a standard defines data rates of 6 Mbps (megabits per second) up to 54 Mbps. For some applications, higher data rates for given modulations and data rates higher than 54 Mbps are desirable. Other extensions, such as the use of MIMO (multiple-input, multiple-output antenna systems and other extensions might be desirable. In order to avoid conflicts with existing standardized communications and devices, extended devices that extend beyond the limits of the 802.11a standard and legacy devices that comply with the existing standard and are not necessarily aware of extended standards both need to coexist in a common communication space and even interoperate at times.

[0003] Coexistence is where differing devices can operate in a common space and still perform most of their functions. For example, an extended transmitter transmitting to an extended receiver might coexist with a legacy transmitter transmitting to a legacy receiver and the extended devices can communicate while the legacy devices communicate, or at least where the two domains are such that one defers to the other when the other is communicating. Coexistence is important so that the adoption and/or use of extended devices (i.e., devices that are outside, beyond or noncompliant with one or more standards with which legacy devices adhere and expect other devices to adhere) do not require replacement or disabling of existing infrastructures of legacy devices.

[0004] Interoperability is where an extended device and a legacy device can communicate. For example, an extended transmitter might initiate a transmission in such a manner that a legacy device can receive the data sent by the extended transmitter and/or indicate that it is a legacy device so that the extended transmitter can adjust its operations accordingly. For example, the extended transmitter might revert to standards compliant communications or switch to a mode that, while not fully standards compliant, is available to the legacy receiver. In another situation, an extended receiver might successfully receive data from a legacy transmitter.

[0005] The IEEE 802.11a standard defines a 20 microsecond long preamble with a structure as shown in **FIG. 1**, having short training symbols S (0.8 microseconds each), a guard interval LG, long training symbols L (3.2 microseconds each) and a signal field (4 microseconds). The preamble is followed by data. The first eight microseconds comprises ten identical short training symbols that are used for packet detection, automatic gain control and coarse frequency estimation. The second eight microseconds comprise two identical long training symbols, L, preceded by a guard interval LG that is the same pattern as the last half (1.6 microseconds) of the long training symbol L. The long training symbols can be used for channel estimation, timing, and fine frequency estimation.

[0006] **FIG. 2** shows a long training sequence, L_1, that is used to generate the signal representing the long training symbol in a conventional 802.11a preamble. This sequence represents values used over a plurality of subcarriers. As specified in the standard, the subcarriers span a 20 MHz channel and with 64 subcarriers, they are spaced apart by 312.5 kHz. By convention, used here, the first value in the sequence is the value for the DC subcarrier, followed by the value for the 1×312.5 kHz subcarrier, then the value for the 2×312.5=625 kHz subcarrier, etc., up to the 32nd value for the 31×312.5 kHz=9687.5 kHz subcarrier. The 33rd value corresponds to the −10 MHz subcarrier, followed by the −(10 MHz −312.5 kHz) subcarrier, and so on, with the 64 value being for the −312.5 kHz subcarrier.

[0007] As can be seen from **FIG. 1**, the DC value and the 28th through 38th values, corresponding to the edges of the 20 MHz channel, are zero. The output of a transmitter is a training symbol at a sample rate of 64 samples/symbol. The samples are obtained by taking a 64-point IFFT (inverse fast-Fourier transform) of the long training sequence, L_1 in this example. As used herein, a sequence in the frequency domain is expressed with uppercase letters (e.g., L(k)), while the corresponding time sequence is expressed with lowercase letters (e.g., l(k)).

[0008] One approach to obtaining higher data rates is the use of more bandwidth. Another approach, used by itself or as well as the use of more bandwidth, is MIMO (multiple-input, multiple-output) channels, where a plurality of transmitters transmit different data or the same data separated by space to result in possibly different multi-path reflection characteristics. In either case, care is needed for coexistence and interoperability between legacy devices and extended devices.

BRIEF SUMMARY OF THE INVENTION

[0009] A modified preamble is used by extended devices that operate at higher rates, MIMO or other extensions relative to strict 802.11a-compliant devices. The extended devices might use one or more of multiple antenna techniques (MIMO), where multiple data streams are multiplexed spatially and multi-channel techniques, where an extended transmitter transmits using more than one 802.11a channel at a time. Such extensions to IEEE 802.11a can exist in extended devices.

[0010] The modified preamble is usable for signaling, to legacy devices as well as extended devices, to indicate capabilities and to cause legacy devices or extended devices to defer to other devices such that the common communication channel is not subject to unnecessary interference. The modified preamble is also usable for obtaining MIMO channel estimates and/or multi-channel estimates.

[0011] The modified preamble preferably includes properties that facilitate detection of conventional and/or extended modes ("mode detection") and provides some level of coexistence with legacy IEEE 802.11a devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** illustrates the structure of a conventional 802.11a preamble.

[0013] **FIG. 2** shows a long training symbol sequence, L_1, used for a conventional 802.11a preamble.

[0014] **FIG. 3** illustrates several devices coupled via a wireless network.

[0015] **FIG. 4** illustrates other long training sequences, usable by extended devices.

[0016] **FIG. 5** illustrates one possible layout for out-of-band pilot tones for individual channels.

[0017] **FIG. 6** illustrates one possible layout for out-of-band pilot tones for commonly assigned adjacent individual channels, where the out-of-band signals between adjacent bands are not attenuated.

[0018] **FIG. 7** illustrates a layout for out-of-band pilot tones for four adjacent individual channels assigned to a single device, where the out-of-band signals between adjacent bands are not attenuated.

[0019] **FIG. 8** illustrates a modified preamble usable for multi-channel packets with or without MIMO.

[0020] **FIG. 9** is a flowchart illustrating one possible process for obtaining channel estimates for each transmitter signal in a MIMO system.

DETAILED DESCRIPTION OF THE INVENTION

[0021] The use of modified preambles is described herein. Such modified preambles can be used in packets sent over a wireless network, such as an 802.11a compliant wireless network. Such packets with modified preambles can be sent by transmitters according to embodiments of the present invention to be received by receivers according to embodiments of the present invention, as well as being received by legacy receivers that are not configured to receive and interpret the modified preambles as would be done with receivers according to embodiments of the present invention.

[0022] **FIG. 3** illustrates just one example of a wireless network being used for communications among transmitters and receivers as indicated. As shown, two wireless devices **102(1)**, **102(2)** might use and interpret the modified preambles, while a legacy wireless device **104** might not be expecting the modified preambles, but might hear signals representing such preambles. Extended wireless devices **102** might operate using multiple channels and/or multiple transmit antennas and/or multiple receive antennas. Devices might have a single transmit antenna and a single receive antenna, or more than one transmit antenna and/or more than one receive antenna. While separate transmit and receive antennas are shown, antennas might be used for both transmitting and receiving in some devices.

[0023] Border **106** is not a physical border, but is shown to represent a space within which signals can be received from devices within the space. Thus, as one device transmits a signal representing a packet within border **106**, other devices within border **106** pick up the signals and, as they are programmed, will attempt to determine if the signals represent packets and if so, then demodulate/decode the packets to obtain the data represented therein.

[0024] Many variations of a modified preamble might be used. An example is the preamble shown in **FIG. 1**, where the long training symbol is modified to use sequences such as one of the example sequences shown in **FIG. 4**.

[0025] Preferably, a modified preamble will be such that 1) an extended receiver (e.g., one that can advantageously handle modified preambles) can distinguish between MIMO packets (or other extended mode packets) and conventional 802.11a packets, 2) a legacy receiver (e.g., one that is not configured to receive and interpret the modified preambles and might not expect extended operations) can receive enough of a packet to determine either that the legacy receiver can understand the packet or can defer processing of incoming signals for a time, thereby allowing a measure of coexistence, 3) the modified preamble is usable for MIMO synchronization and channel estimation, and 4) the modified preamble is useful in a process of detecting the use of multi-channel transmission. In some embodiments of wireless devices according to the present invention, modified preambles are used that provide one, two, three or all of the preferable characteristics indicated above.

[0026] Combinations of Extensions

[0027] Multi-channel extended 802.11 systems might simultaneously transmit on several 20 MHz channels, whereas a legacy 802.11 a system only transmits on a single 20 MHz channel using a single antenna, or if the legacy system does transmit with more than one antenna, each of the antennas transmits the same 802.11a signal, possibly with some delay differences between signals. As a result, data rates can be increased over 802.11a data rates using multiple transmit antennas or multiple channels or a combination of both. Thus, in a communication channel, such as the airspace of a wireless network cloud, several types of packets might be present:

[0028] 1) Legacy SISO (single-input, single-output) 802.11a, 802.11b, or 802.11g packets transmitted in a single 20 MHz channel;

[0029] 2) Extended SISO in multiple 20 MHz channels (e.g., 40, 60, 80, or 100 MHz channels)

[0030] 3) Extended MIMO in a single 20 MHz channel;

[0031] 4) Extended MIMO in multiple 20 MHz channels (e.g., 40, 60, 80, or 100 MHz channels)

[0032] Several satisfactory modified preamble structures can be derived by one of ordinary skill in the art after reading this disclosure. Some examples are described below. Preferably, the unmodified preamble structure can provide interoperability and coexistence between SISO and MIMO systems at various channel widths and coexistence between extended mode systems and legacy systems.

[0033] MIMO Single Channel (20 MHz)

[0034] A modified preamble can use the same structure as the 802.11a preamble, with a different long training symbol determined from a long training symbol sequence LD. By keeping the same short symbols S and using the same timing structure as depicted in **FIG. 1**, a receiver using the extended mode can use the same hardware for detecting the repetitive

S and L symbols, even though the actual contents of the L symbols may be different for the 802.11a extensions.

[0035] Various embodiments of wireless devices might use various long training symbol sequences. In one example of a modification, the long training symbol sequence LD has one or more of the following features: 1) it is formulated such that channel estimation can be done for multiple transmitters, 2) it is such that it has a low cross-correlation with the unmodified 802.11a long training symbol sequence, and/or 3) it is usable in a relatively simple process of detecting whether the preamble is an 802.11a packet or an extended mode packet, usable in multipath channels. Suitable modified long training symbol sequences are shown as L_2 and L_3, in **FIG. 4**, but other variations should be apparent upon reading this description.

[0036] Channel Estimation

[0037] By allowing for channel estimation for multiple transmitters, MIMO or space-time coding techniques can be supported to achieve 802.11a extensions. One way to do this is by sending a different set of subcarriers from each transmitter. As an example, for the case of two transmitters, a device might modulate its OFDM subcarriers with the 64 values of L_3, shown in **FIG. 4**, where one transmitter transmits the odd subcarriers $\{1, 3, \ldots, 63\}$ and the other transmitter transmits the even subcarriers $\{0, 2, \ldots, 62\}$. Thus, one transmitter would take an IFFT of the odd subcarriers and transmit samples of that time varying signal and the other transmitter would take an IFFT of the even subcarriers and transmit samples of that time varying signal.

[0038] L_3 is a modified 802.11a long training symbol sequence, wherein some of the subcarriers of the standard 802.11a sequence L_1 (shown in **FIG. 2**) are inverted, and some subcarriers that are zero in L_1 are non-zero in L_3. The latter has some advantages for channel estimation, but is not necessary for the purpose of discriminating 802.11a packets from extended mode packets.

[0039] Low Cross-Correlation

[0040] The second criterion is that the new training sequence should have a low cross-correlation with the conventional IEEE 802.11a training sequence. One way to achieve this is to invert every other group of four subcarriers, which is applied to sequence L_2 to get a new sequence L_3 that is nearly orthogonal to both L_1 and L_2. Further, L_3 is constructed such that there is also a low cross-correlation between the even and odd elements of L_2 and L_3. These sequences L_2 and L_3 are shown in **FIG. 4**. The low cross-correlation is illustrated by Equation 1 and Equation 2 (note that in Equation 1, a high cross-correlation would have right-hand side values closer to −32 or 32, since the sum is not normalized here).

$$\sum_{k=0}^{31} L_2(2k)L_3(2k) = -1 \quad \text{(Equ. 1)}$$

$$\sum_{k=0}^{31} L_2(2k+1)L_3(2k+1) = 0 \quad \text{(Equ. 2)}$$

[0041] Mode Detection

[0042] The low cross-correlation between even and odd elements of L_2 and L_3 supports the third criterion, as it makes it possible to detect extended mode packets by looking at the correlation of L_2 and L_3 with the odd and even subcarriers of a received packet.

[0043] Various methods can be available for a receiver to detect from a received signal whether a transmitter transmitted a conventional 802.11a packet or an extended mode packet. One method for detecting what type of packet was sent will now be described.

[0044] In this method, enough of the signal is received to identify what should be the two repeated long training symbols, typically sampled as two identical repetitions of **64** samples for each receive antenna. An FFT (fast-Fourier transform) of the sum of the two identical repetitions of 64 samples is taken, generating an output sequence $s_i(k)$, comprising 64 complex values per receive antenna, containing channel amplitudes and phases, as well as phase shifts caused by the long training symbol sequence that was actually used (e.g., sequences such as L_1, L_2, L_3 or L_4).

[0045] From the output sequence $s_i(k)$, the receiver generates two other sequences, $r_s(k)$ and $r_m(k)$, by multiplying $s_i(k)$ by the sequences L_2 and L_3 for each receive antenna i, as illustrated by Equations 3a and 3b.

$$r_{si}(k) = \sum_{k=0}^{63} s_i(k)L_2(k) \quad \text{(Equ. 3a)}$$

$$r_{mi}(k) = \sum_{k=0}^{63} s_i(k)L_3(k) \quad \text{(Equ. 3b)}$$

[0046] Next, the receiver calculates two metrics, m_m and m_s, from $r_s(k)$ and $r_m(k)$ using a differential detection operation, such as that illustrated by Equations 4a and 4b.

$$m_s = \left\| \sum_{i=0}^{N-1} \sum_{k=2}^{26} [r_{si}(k)r_{si}^*(k-1) + r_{si}(k+37)r_{si}^*(k+36)] \right\| \quad \text{(Equ. 4a)}$$

$$m_m = \left\| \sum_{i=0}^{N-1} \sum_{k=0}^{11} [r_{mi}(2k+3)r_{mi}^*(2k+1) + r_{mi}(2k+41)r_{mi}^*(2k+39) + r_{mi}(2k+4)r_{mi}^*(2k+2) + r_{mi}(2k+42)r_{mi}^*(2k+40)] \right\| \quad \text{(Equ. 4b)}$$

[0047] If $m_m > c * m_s$, then the receiver might assume that the received signal represents a conventional 802.11a packet, otherwise the receiver assumes the packet is an extended mode packet. The constant c is preferably equal to 1, but may be different.

[0048] SISO/MIMO Multiple Channel

[0049] Some modified preamble structures described herein provide interoperability and coexistence between SISO multi-channel packets/devices and MIMO multi-chan-

nel packets/devices, as well as coexistence between multi-channel packets/devices and legacy packets/devices.

[0050] **FIG. 5** illustrates the case where out-of-band pilots are attenuated for 20 MHz channels used to transmit a MIMO signal. The preamble structure can be identical to a conventional 802.11a preamble, except that the long training symbol sequence may use what are otherwise considered out-of-band subcarriers. Some or all of these out-of-band subcarriers may also be used in the data symbols to increase the data rate.

[0051] In the case of **FIG. 5**, different channels may be used by different devices, but it is also possible that the same device transmits on several channels simultaneously. For instance, one device may transmit on channels **1** and **4** simultaneously, while channels **2** and **3** are used by other devices.

[0052] If two adjacent channels are used simultaneously by one device, then there is no need to attenuate the "out-of-band subcarriers" in the middle of this 40 MHz band. An example of this is shown in **FIG. 6**. The out-of-band subcarriers that are in between the two 20 MHz channels thus need not be attenuated. In **FIG. 4**, the sequence L_4 is the long training symbol sequence for a 40 MHz preamble, which contains all 128 subcarrier values for a 40 MHz channel long training symbol. The first 32 values are identical to the last 32 values of a 20 MHz preamble, corresponding to the subcarriers in the left part of a 20 MHz channel. One difference between L_4 and two separate 20 MHz long training sequences is that the DC subcarriers are at different locations, so at the position where a 20 MHz channel would normally have its DC subcarrier, the 40 MHz sequence can have a nonzero subcarrier value. In L_4, these are subcarrier numbers **33** and **97**, respectively.

[0053] With unattenuated out-of-band subcarriers, signaling information can be carried on those subcarriers during packet setup, such as signaling operating and/or extension modes during a preamble, and additional data can be carried on those subcarriers, to increase the datarate.

[0054] **FIG. 7** shows the case of four 20 MHz channels.

[0055] One example of a modified preamble is the preamble shown in **FIG. 1** modified as shown in **FIG. 8**. The long training symbol values for these out-of-band subcarriers can be the same as in the case of **FIG. 1**. The long training symbol is followed by a replica of the Signal field with identical subcarrier values in each of the 20 MHz channels. This ensures that a receiver that operates on just one of the 20 MHz channels will still be able to successfully decode at least the first part of the packet containing the Signal field and defer for the rest of the packet, as decoding the Signal field provides the receiver with information about the length of the packet and thus how long to defer. The same technique can be extended to an arbitrary number of channels.

[0056] **FIG. 8** shows a preamble for a two transmitter MIMO packet. The structure is the same as for 802.11a, but some differences are that a) l_0, l_1, d_0, d_1 may contain out-of-band subcarriers, b) s_1, l_1, d_1 can be cyclically shifted relative to s_0, l_0, d_0 or c) l_0 and l_1 can contain subcarrier sequences that have a low cross-correlation with the same subcarrier sequences of the 802.11a long training symbol sequence.

[0057] Interoperability

[0058] Interoperability between the different extended modes can be ensured by transmitting the same preamble and signal field in each 20 MHz channel. The preamble time structure can be the same as that of IEEE 802.11a, as illustrated in **FIG. 1**. For a 20 MHz MIMO transmitter, the long training symbol L can be modified to facilitate MIMO channel estimation and include out-of-band pilots. In one example of an extended transmitter using a plurality of channels, the transmitter transmits an identical copy of the preamble and signal field in each 20 MHz channel used by that transmitter where the out-of-band pilots only have to be attenuated at the edges of a multi-channel and not between adjacent channels of the multi-channel. The out-of-band subcarriers of the signal field in might contain different data bits for different 20 MHz channels, to signal information such as the transmitter's multi-band mode, MIMO mode, channel number, data rate, and/or coding rate.

[0059] By transmitting the same preamble and signal field in any 20 MHz channel, it is ensured that an extended device that only demodulates one 20 MHz channel at least is able to decode the signal field. From the information in the signal field, the single-channel extended device can either properly defer for the duration of the packet or find out what extended mode is used for this packet in the case that this information is encoded in the signal field. For instance, the receiver could detect from the signal field that the packet is transmitted over four adjacent channels, after which the extended receiver can decide to switch to a four-channel receiving mode.

[0060] Notice that it typically does not matter for a single-channel 20 MHz receiver whether the out-of-band subcarriers depicted in **FIGS. 5-7** are attenuated. For instance, if a single-channel receiver demodulates channel **2** out of the 4 transmitted channels shown in **FIG. 7**, the receive filter of that single-channel receiver will partly attenuate the out-of-band subcarriers as well as suppress the adjacent channels **1** and **3** to the point where these adjacent channels do not cause interference to the desired signal of channel **2**.

[0061] Coexistence

[0062] One method of having coexistence between extended devices and legacy IEEE 802.11a and IEEE 802.11g devices is by keeping the preamble structure in each 20 MHz channel the same as for IEEE 802.11a. IEEE 802.11a specifies an energy detect based defer behavior, which provides some level of coexistence. However, to guarantee that legacy devices properly defer for all extended mode packets down to received power levels of −82 dBm or other suitable levels, the receivers have to be able to successfully decode the signal field, which contains the length information of the packet.

[0063] Some ways to do this are described by Bangerter, B., et al., "High-Throughput Wireless LAN Air Interface", Intel Technology Journal, Vol. 7, Issue 3 (August 2003) (hereinafter "Bangerter") and Boer, J., et al., "Backwards Compatibility", IEEE 802.11 presentation, Document Number 802.11-03/714rO (September 2003) (hereinafter "Boer").

[0064] Bangerter describes the use of multiple 802.11a preambles spread in frequency such that 20 MHz channel legacy 802.11a devices will defer for multiple channel

devices, but additional advantages can be had through the use of out-of-band pilots or MIMO preambles, as described elsewhere herein.

[0065] Boer describes some possible MIMO preambles having some limited benefits. In one method described in Boer, each MIMO transmitter transmits an 802.11a preamble while the other transmitters transmit nothing. While this makes distinguishing easier, training is significantly longer and that reduces throughput. In another method described in Boer, each MIMO transmitter transmits a part of the 802.11a subcarriers. For example, for two transmitters, one transmitter transmits all odd subcarriers and the other transmitter transmits all even subcarriers. However, without more, mode detection based on the training symbols might not be possible with that technique.

[0066] A novel way of enabling coexistence or furthering coexistence for MIMO packets is to apply a cyclic delay shift on the long training symbol and Signal field IFFT outputs prior to applying the guard time extension. For example, assume L(k) and D(k) are the 64 subcarrier values for the long training symbol and Signal field symbol, respectively. For a conventional 802.11a single transmitter transmission, the time samples for the long training symbol are derived by taking the 64-point IFFT of L(k) to obtain l(i) and transmitting the samples of l(i). Thus, with the guard time, the long training symbol and guard time are constructed as [l(33:64) l (1:64) l (1:64)], i.e., the IFFT output is repeated twice and the last 32 samples are prepended to form the long training guard interval. As with the conventional timing, the long training guard interval (32 samples) is twice as long as the guard interval for 802.11a data symbols (16 samples). The signal field is formed by [d(49:64) d(1:64)], where d(1:64) are the 64 samples of the IFFT of D(k).

[0067] In the case of a two transmitter MIMO device, the first transmitter would transmit the long training symbol and signal field like that of 802.11a. The second transmitter would apply a cyclic shift such that instead of the IFFT output l(1:64), it uses the cyclically shifted samples ls=[l(33:64) l(1:32)] to construct the long training symbol samples [ls(33:64) ls(1:64) ls(1:64)]. For the signal field, it uses the shifted samples ds=[d(33:64) d(1:32)] to construct the signal field as [ds(49:64) ds(1:64)].

[0068] In a legacy 802.11a packet, one 3.2 microsecond repetition of the long training symbol L as shown in **FIG. 1** is expressed in the time domain as the IFFT of L(k), where L(k) contains 64 subcarrier values, of which 52 are non-zero. The time samples l(i) are given as shown in Equation 5, where the subcarrier values of L(k):

$$l(i) = \sum_{k=0}^{63} L(k)\exp\left(j\frac{2\pi ik}{64}\right) \quad \text{(Equ. 5)}$$

[0069] In the extended modes described herein, some possible modifications will be described. First, L(k) can contain more than 52 non-zero subcarriers. Second, in the case of MIMO transmission, l(i) can have a cyclic shift that may be different for each transmitter. The shifted signal $l_k(i)$ can be derived from l(i) as $l_k(i)=l([i+64-dk]\%64)$, where "%" denotes the modulo operator and dk is the cyclic delay of transmitter k in 20 MHz samples. This expression assumes a 20 MHz sampling rate, such that there are 64 samples in a 3.2 microsecond interval. An alternative method of generating the cyclic shift is to apply a phase ramp rotation to all subcarrier values of L(k) prior to calculating the IFFT, such as that shown by the example of Equation 6.

$$l_k(i) = \sum_{k=0}^{63} L(k)\exp\left(-j\frac{2\pi kd_k}{64}\right)\exp\left(j\frac{2\pi ik}{64}\right) \quad \text{(Equ. 6)}$$

[0070] A MIMO transmitter can have two or more transmit antennas (or antenna arrays, as the case may be). For a MIMO system with two transmit antennas and two different transmit data streams, preferred values for the cyclic delay values d_k are 0 and 32 samples, respectively. This corresponds to a cyclic delay of 1.6 microseconds between the two transmitters. For three transmitters, d_k can be 0, 22, and 43 samples, respectively. For four transmitters, d_k can be 0, 16, 32, and 48 samples, respectively.

[0071] At the receiver side, the channel estimates for each transmitter signal can be estimated by a process such as that shown in **FIG. 9**. As shown there, the process begins with receiving signals and sampling for the long training symbol (step **S1**). Then, a 64-point FFT of the received long training symbol samples is done (step **S2**), as is done for conventional 802.11a preamble reception. Next, each subcarrier is multiplied by known pilot values (step **S3**), and an IFFT of the result is taken to get a 64-point impulse response estimate (step **S4**).

[0072] In the case of a MIMO transmission, these 64 samples contain the cyclic shifted impulse responses of all different transmitters. With that, the receiver can isolate the impulse responses for each MIMO transmitter (step **S5**). For MIMO with two transmit streams, this can be done by separating the first 32 samples and last 32 samples. For four transmit streams, groups of 16 samples can be extracted.

[0073] From the extracted impulse responses per transmitter, channel estimates can be derived (step **S6**) for all subcarriers by taking a 64-point FFT of each impulse response, where the sample values are appended by zero values to get 64 input values.

[0074] Signaling Extended Modes

[0075] There are several different ways to signal what mode is used:

[0076] 1) Beaconing: Each access point regularly transmits beacons. By transmitting these beacons using a legacy 802.11a rate on all 20 MHz channels used by the access point, it can be ensured that any device can receive these beacons. The beacon can contain information about which channels are used simultaneously and what extended modes are supported, so each extended device can adjust its mode accordingly.

[0077] 2) Multiple transmitter detection: If a special long training symbol is used for MIMO transmitters such as the cyclic shifted symbol described herein or other techniques described herein, then these special long training properties can be used to detect whether a packet is a MIMO packet.

For instance, if the cyclic shifted long training symbol is used with two MIMO transmitters, the receiver can detect this by checking if the combined impulse response (obtained from step **S4** above) contains two distinct impulse responses separated by 32 samples.

[**0078**] 3) Signal field: The reserved bit of the Signal field can be used to signal the use of MIMO. It is also possible to extend the Signal field by transmitting an extra symbol. An example of this is shown in Boer. There is a reserved bit in the Signal field that is always zero for 802.11a devices but could be set to 1 to signal MIMO packets. It is also possible to send an extra signal field symbol after the normal 802.11a symbol to signal MIMO rates.

[**0079**] 4) Out-of-band pilots: The out-of-band pilots of the long training symbol that are not present in 802.11a can be used to signal different modes. For example, subcarriers **28** through **38** in L_1 are zero, but they might be set (as with L_2, L_3, etc.) to some arbitrary but known values. The receiver can use the presence of these subcarriers as a way to detect MIMO modes and the particular pattern of presence to detect among several modes.

[**0080**] 5) Out-of-band subcarriers in the Signal field: Extra subcarriers can be used to signal different extended modes. The use of extra subcarriers has advantages in that a) it does not cost extra preamble overhead, and b) a legacy 802.11a device ignores the out-of-band subcarriers.

1. A method of transmitting signals using a plurality of transmit antennas, the method comprising:

allocating the data to be transmitted among the plurality of transmit antennas, wherein at least one of the plurality of transmit antennas transmits some data that is not transmitted by all of the other of the plurality of transmit antennas;

transmitting a modified preamble from each of the plurality of transmit antennas, wherein the modified preamble is distinguishable at a receiver from a conventional 802.11a preamble.

2. The method of claim 1, wherein the plurality of transmitters transmit data in total at an extended rate above a corresponding 802.11a data rate.

3. The method of claim 1, wherein the modified preamble comprises a modified long training pattern distinct from a conventional 802.11a long training pattern.

4. The method of claim 3, wherein at least a part of the modified long training pattern has a low cross correlation with a corresponding part of the conventional 802.11a pattern, thereby facilitating discrimination based on cross correlation.

5. The method of claim 4, wherein the at least a part of the modified long training pattern is transmitted using more than one of the plurality of transmit antennas such that it is receivable and processable by one or more receivers.

6. A method of discriminating between a packet sent with a conventional 802.11a rate or with an extended rate, comprising:

receiving one or more signals from one or more transmitters, the one or more signals including a long training subcarrier;

multiplying the long training subcarrier with a conventional 802.11a long training pattern to form a first product;

multiplying the long training subcarrier with an extended 802.11a long training pattern to form a second product;

determining, from the first product and the second product, which long training pattern was more likely to have been sent for the received long training subcarrier; and

discriminating as to which type of packet was sent based on the more likely sent long training subcarrier.

7. A method of transmitting signals using a plurality of transmit channels, the method comprising:

allocating the data to be transmitted among the plurality of transmit channels, wherein at least one of the plurality of transmit channels transports some data that is not transmitted over all of the other of the plurality of transmit channels;

transmitting a modified preamble from each of the plurality of transmit channels, wherein the modified preamble is distinguishable at a receiver from a conventional 802.11a preamble and includes an out-of-band component.

8. The method of claim 7, wherein the plurality of transmit channels comprise a plurality of frequency channels.

9. The method of claim 8, wherein the plurality of frequency channels are adjacent 20 MHz channels.

10. A method of transmitting signals using a plurality of transmit channels, the method comprising:

allocating the data to be transmitted among the plurality of transmit channels, wherein at least one of the plurality of transmit channels transports some data that is not transmitted over all of the other of the plurality of transmit channels;

for at least one set of at least two adjacent transmit channels, transmitting data over the set wherein at least some data is encoded in out-of-band subcarriers at frequencies between frequencies allocated to the at least two adjacent transmit channels.

11. In a communications system having a channel divided into a plurality of adjacent frequency bands separated by out-of-band frequency ranges, wherein data is transmitted within the bands of the plurality of frequency bands, a method of increasing data capacity of the channel comprising:

for data to be transmitted from a transmitter, allocating a first portion of the data among the plurality of transmit frequency bands and allocating a second portion of the data to at least one out-of-band frequency range when the first portion is allocated to adjacent bands, wherein the at least one out-of-band frequency range includes an out-of-band frequency range between the adjacent bands;

transmitting the first portion within the plurality of transmit frequency bands; and

transmitting the second portion within the at least one out-of-band frequency range.

12. The method of claim 11, further comprising:

prior to transmitting at least the second portion of the data, transmitting one or more training symbols usable for a receiver to estimate transmission characteristics of the out-of-band frequency ranges; and

using received signal of the one or more training symbols to modify processing of a received signal corresponding to the second portion of the data to account for the transmission characteristics of the out-of-band frequency ranges.

13. A method of discriminating between a packet sent as a conventional 802.11a packet and a packet sent using an extended mode not normally supported under the conventional 802.11a standard, the method comprising:

receiving a signal from a wireless medium, wherein the signal was transmitted from an extended mode transmitter as a packet wherein packet data is preceded by a packet preamble and wherein the packet preamble is generated from a cyclically shifted 802.11a preamble;

demodulating the signal to obtain a demodulated signal;

decoding, from the demodulated signal, a packet data sequence including a cyclically shifted 802.11a preamble when receiving packet data from an extended mode transmitter and a conventional 802.11a preamble when receiving packet data from a conventional 802.11a transmitter; and

discriminating as to which type of packet was sent based on the received packet data sequence.

14. The method of claim 13, wherein the extended mode includes at least a MIMO extended mode wherein the packet preamble is generated from the cyclically shifted 802.11a preamble.

15. The method of claim 14, further comprising performing MIMO channel estimation using the received preamble data.

16. The method of claim 13, wherein the further comprising performing MIMO channel estimation using the received preamble data.

17. The method of claim 13, wherein the signal transmitted from an extended mode transmitter is such that legacy devices can decode a signal field of the preamble.

18. The method of claim 13, further comprising detecting that the signal transmitted used from an extended mode transmitter using a MIMO mode, the detecting using at least one out-of-band subcarrier

19. The method of claim 13, further comprising detecting that the signal transmitted used from an extended mode transmitter using a MIMO mode, the detecting including detecting a presence of cyclically shifted preamble components.

20. A method of transmitting a packet, using a MIMO transmitter having a plurality of antennas, over a wireless network wherein receivers operating as conventional 802.11a receivers might be present, the method comprising:

obtaining data fields of a packet to be transmitted;

generating preamble fields of the packet to be transmitted, including an extended mode preamble distinguishable at a receiver from a conventional 802.11a preamble, wherein a conventional 802.11a receiver can decode one or more fields of the extended mode preamble; and

transmitting the packet including the extended mode preamble.

21. The method of claim 20, wherein the fields of the extended mode preamble include a modified short training sequence.

22. The method of claim 20, wherein the fields of the extended code preamble include a modified long training sequence.

23. The method of claim 20, wherein the fields of the extended mode preamble include a modified signal field.

24. A method of communicating a packet, using a MIMO transmitter having a plurality of antennas, over a wireless medium to a MIMO receiver wherein receivers operating as conventional 802.11a receivers might be listening to transmissions in the wireless medium, the method comprising:

obtaining data fields of a packet to be transmitted;

generating preamble fields of the packet to be transmitted, including an extended mode preamble;

transmitting the packet, including the extended mode preamble, as a signal into the wireless medium;

receiving a representation of the signal from a wireless medium;

at a receiver, demodulating the signal to obtain a demodulated signal;

at the receiver, decoding, from the demodulated signal, a packet data sequence including data representing at least a portion of a preamble;

where the receiver is a MIMO receiver, processing the packet data sequence according to an extended mode operation; and

where the receiver is a conventional 802.11a receiver, processing the packet data sequence to determine at least one valid conventional 802.11a preamble field and deferring further data reception related to that packet data sequence after determining, from the preamble, that the packet data sequence represents a packet not in conformance with a conventional 802.11a packet.

25. The method of claim 24, wherein the fields of the extended mode preamble include a modified short training sequence.

26. The method of claim 24, wherein the fields of the extended mode preamble include a modified long training sequence.

27. The method of claim 24, wherein the fields of the extended mode preamble include a modified signal field.

28. A method of transmitting signals using a plurality of transmit channels, the method comprising:

allocating the data to be transmitted among the plurality of transmit channels, wherein at least one of the plurality of transmit channels transports some data that is not transmitted over all of the other of the plurality of transmit channels;

transmitting a modified preamble from each of the plurality of transmit channels, wherein the modified preamble is usable for performing channel estimation and at least a first part of the modified preamble for at least a first of the plurality of transmit channels is a cycli-

cally shifted version of a second part of the modified preamble for at least a second of the plurality of transmit channels.

29. The method of claim 28, wherein the first part and the second part comprise signal sequences with a low cross-correlation between long training symbols.

30. The method of claim 28, wherein the first part and the second part comprise signal sequences with a low cross-correlation between long training symbols.

31. The method of claim 28, further comprising MIMO synchronization.

32. The method of claim 28, wherein the data to be transmitted is allocated to a plurality of subcarriers, the subcarriers of the plurality of subcarriers are allocated among transmit channels, and each transmit channel is associated with a distinct antenna.

33. The method of claim 28, wherein the data to be transmitted is allocated to a plurality of subcarriers and some of the subcarriers of the plurality of subcarriers are inverted relative to other subcarriers of the plurality of subcarriers

34. The method of claim 28, wherein the data to be transmitted is allocated to a plurality of subcarriers inlcuding at least one out-of-band subcarrier.

35. The method of claim 28, further comprising estimating channel response by:

receiving signals and sampling for a long training symbol;

computing a 64-point FFT of the received long training symbol;

multiplying each subcarrier is multiplied by known pilot values;

computing an IFFT of the result of the multiplication, resulting in a 64-point impulse response estimate;

isolating each of a plurality of impulse responses, one per MIMO transmitter; and

deriving channel estimates for all subcarriers from the isolated impulse responses by taking a 64-point FFT of each of the plurality of impulse responses, where the sample values are appended by zero values to get 64 input values as needed.

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