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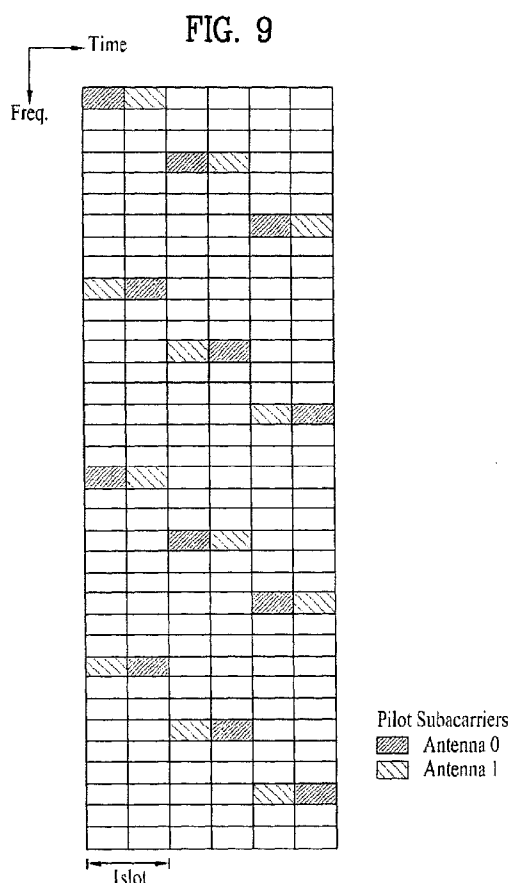
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## (54) Title: WIRELESS COMMUNICATION SYSTEM USING PILOT SUBCARRIER ALLOCATION



(57) Abstract: A wireless communication system using pilot subcarrier allocation and a method of allocating the pilot subcarriers for use in downlink and uplink communication in a multiple-input multiple-output (MIMO) antenna system using orthogonal frequency division multiplexing (OFDM) modulation are disclosed. The method includes providing a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and alternately allocating first pilot subcarriers for a first antenna and second pilot subcarriers for a second antenna in the time and frequency domains, wherein each of the alternating first pilot subcarriers and the second pilot subcarriers is separated by a multiple of 9 subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols.



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## WIRELESS COMMUNICATION SYSTEM USING PILOT SUBCARRIER ALLOCATION

### FIELD OF THE INVENTION

The present invention relates to a wireless communication system. In particular, the present invention relates to a method of allocating pilot subcarriers in the wireless communication system including a multiple-input multiple-output (MIMO) antenna system.

### DESCRIPTION OF THE RELATED ART

The Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard provides a technology of supporting a broadband wireless access and a protocol. The standardization has been progressed since 1999 and IEEE 802.16-2001 was approved in 2001. This has been established based on a single carrier physical layer called "WirelessMAN-SC". In the IEEE 802.16a which was approved in 2003, "WirelessMAN-OFDM" and "WirelessMAN-OFDMA" were added to a physical layer in addition to "WirelessMAN-SC". After the IEEE 802.16a standard was completed, a revised IEEE 802.16-2004 was approved in 2004. In order to correct bugs and errors of the IEEE 802.16-2004, IEEE 802.16-2004/Cor1 was completed in the form of "corrigendum" in 2005.

A MIMO antenna technology improves data transmission/reception efficiency using multiple transmission antennas and multiple reception antennas. The MIMO technology was introduced in the IEEE 802.16a standard and has been continuously updated.

The MIMO technology is divided into a spatial multiplexing method and a spatial

diversity method. In the spatial multiplexing method, since different data is simultaneously transmitted, data can be transmitted at a high speed without increasing the bandwidth of a system. In the spatial diversity method, since the same data is transmitted via multiple transmission antennas so as to obtain diversity gain, reliability of the data is increased.

A receiver needs to estimate a channel in order to restore data transmitted from a transmitter. Channel estimation indicates a process of compensating for distortion of a signal, which occurs by a rapid environment variation due to fading and restoring the transmission signal. In general, for channel estimation, the transmitter and the receiver need to know pilots.

In the MIMO system, a signal experiences a channel corresponding to each antenna. Accordingly, it is necessary to arrange the pilots in consideration of multiple antennas. While the number of pilots is increased as the number of antennas is increased, it is impossible to increase the number of antennas so as to increase a data transfer rate.

In the prior art, different pilot allocation structures have been designed and used according to permutation (dispersion/AMC) methods. This is because the permutation methods are separated from each other in time domain in the IEEE 802.16e system and thus structures differently optimized according to permutation methods are designed. If the permutation methods coexist in certain time instance, a unified basic data allocation structure is necessary.

In the prior art, since severe pilot overhead occurs, a transfer rate is decreased. In addition, since the same pilot structure is applied to adjacent cells or sectors, collision between the cells or the sectors may occur. Accordingly, there is a need for a method of efficiently allocating pilot subcarriers in the MIMO system.

### **SUMMARY OF THE INVENTION**

An object of the present invention is to provide a method of efficiently allocating pilot subcarriers in wireless communication system including a MIMO system. The object of the present invention can be achieved by providing a method of allocating pilot subcarriers for a plurality of antennas in the MIMO antenna system over a plurality of orthogonal frequency division multiplexing (OFDM) symbols and a plurality of subcarriers. The method includes allocating each of the pilot subcarriers for the plurality of antennas by the same number in every OFDM symbols. The pilot subcarriers form pairs of two pilot subcarriers and are allocated to be alternately arranged on two contiguous OFDM symbols in a time domain.

According to an embodiment of the present invention, a method of allocating pilot subcarriers for use in downlink and uplink communication in the MIMO antenna system using OFDM modulation is provided. The method includes providing a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and allocating pilot locations according to equation:

$$P_i = 18k + 9m_i + 3(\lfloor n_s/2 \rfloor \bmod 3)$$

where,  $P_i$  denotes pilot index of an  $i^{\text{th}}$  antenna,  $k=0,1,\dots,N_{\text{pilot}}$ ,  $i=(n_s+i) \bmod 2$ ,

and  $\lfloor n \rfloor$  denotes an integer smaller than  $n$ .

According to an embodiment of the present invention, the method of allocating pilot subcarriers for use in at least one of downlink and uplink communication in the MIMO antenna system using OFDM modulation includes providing a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and

alternately allocating first pilot subcarriers for a first antenna and second pilot subcarriers for a second antenna in at least one of the time and frequency domains,

wherein each of the alternating first pilot subcarriers and the second pilot subcarriers are separated by a multiple of a first predetermined number of subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols, wherein the first predetermined number is 9.

5 In an aspect of the present invention, each of the first pilot subcarriers separated by two OFDM symbols is shifted by a second predetermined number of subcarriers, and each of the second pilot subcarriers separated by two OFDM symbols is shifted by the second predetermined number of subcarriers to differentiate frequency selectivity, wherein the second predetermined number is a multiple of 3. Each OFDM  
10 symbol comprises first and second pilot subcarriers. Preferably, number of each of the first and second pilot subcarriers in each OFDM symbol is the same. Preferably, the second predetermined number is 3. The frame structure is used in one of uplink and downlink communications.

In another aspect of the present invention, the method further includes  
15 alternately allocating third pilot subcarriers for a third antenna and fourth pilot subcarriers for a fourth antenna in the time and frequency domains, wherein each of the alternating third pilot subcarriers and the fourth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols. Preferably, the first pilot  
20 subcarriers are adjacent to the third pilot subcarriers in the frequency domain and the second pilot subcarriers are adjacent to the fourth pilot subcarriers in the frequency domain. Preferably, the first pilot subcarriers and the third pilot subcarriers are separated by at least one subcarrier in the frequency domain and the second pilot subcarriers and the fourth pilot subcarriers are separated by at least one  
25 subcarrier in the frequency domain.

In one aspect of the present invention, the method may further include alternately allocating fifth pilot subcarriers for a fifth antenna and sixth pilot subcarriers for a sixth antenna in the time and frequency domains, wherein each of the alternating fifth pilot subcarriers and the sixth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols and alternatively allocating seventh pilot subcarriers for a seventh antenna and eighth pilot subcarriers for a eighth antenna in the time and frequency domains, wherein each of the alternating seventh pilot subcarriers and the eighth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols, wherein the fifth pilot subcarriers are adjacent to and positioned between the third and seventh pilot subcarriers in the frequency domain and the sixth pilot subcarriers are adjacent to and positioned between the fourth and eighth pilot subcarriers in the frequency domain. In another aspect of the present invention, the fifth pilot subcarriers and the seventh pilot subcarriers are separated by at least one subcarrier in the frequency domain and the sixth pilot subcarriers and the eighth pilot subcarriers are separated by at least one subcarrier in the frequency domain.

The frame structure may be used in a type of a full usage of subchannels (FUSC) permutation mode. The frame structure may be used in a type of an adaptive modulation and coding (AMC) permutation mode. Preferably, a starting location of the first pilot subcarriers in a first OFDM symbol is offset by 1 subcarrier.

According to an embodiment of the present invention, a wireless communication system using OFDM modulation for downlink and uplink communication includes a MIMO antenna, an OFDM modulator operably connected to the MIMO antenna, and

a processor operably connected to the OFDM modulator. The processor is configured to provide a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and allocating pilot locations according to

equation: 
$$P_i = 18k + 9m_i + 3(\lfloor n_s/2 \rfloor \bmod 3)$$

- 5 where,  $P_i$  denotes pilot index of an  $i^{\text{th}}$  antenna,  $k=0,1,\dots,N_{\text{pilot}}$ ,  $i=(n_s+i) \bmod 2$ , and  $\lfloor n \rfloor$  denotes an integer smaller than  $n$ .

According to an embodiment of the present invention, in the wireless communication system using OFDM modulation for downlink and uplink communication and including a MIMO antenna, an OFDM modulator operably  
10 connected to the MIMO antenna, and a processor operably connected to the OFDM modulator, the processor is configured to provide a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and alternately allocate first pilot subcarriers for a first antenna and second pilot subcarriers for a second antenna in at least one of the time and frequency domains, wherein each of  
15 the alternating first pilot subcarriers and the second pilot subcarriers is separated by multiple of a first predetermined number of subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols, wherein the first predetermined number is 9. Preferably, each of the first pilot subcarriers separated by two OFDM symbols is shifted by a second predetermined number of subcarriers, and each of  
20 the second pilot subcarriers separated by two OFDM symbols is shifted by the second predetermined number of subcarriers to differentiate frequency selectivity, wherein the second predetermined number is a multiple of 3.

In an aspect of the present invention, the processor includes a subcarrier allocator allocating symbols and pilots to the subcarriers for use in at least one of the



downlink and uplink communication. The processor may further include a channel encoder encoding an input stream and building a coded word, a mapper mapping the coded word to a symbol representing a position on signal constellation, and a MIMO processor processing the symbol.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The accompanying drawings, which are included to provide a further understanding of the invention, illustrate embodiments of the invention and together with the description serve to explain the principle of the invention.

FIG. 1 is a block diagram of a transmitter having multiple antennas.

FIG. 2 is a block diagram of a receiver having multiple antennas.

FIG. 3 shows a frame structure.

FIG. 4 shows a pilot arrangement of two transmission antennas in partial usage of subchannels (PUSC).

FIG. 5 shows a pilot arrangement of two transmission antennas in full usage of subchannels (FUSC).

FIG. 6 shows a pilot arrangement of four transmission antennas in the PUSC.

FIG. 7 shows a pilot arrangement of four transmission antennas in FUSC.

FIG. 8 is a graph showing cases of Table 2 by a ratio of pilot overhead and a ratio of guard subcarriers.

FIG. 9 shows the pilot arrangement of the two transmission antennas.

FIG. 10 shows the pilot arrangement of the four transmission antennas.

FIG. 11 illustrates the pilot arrangement of three or four transmission antennas by equation.

FIG. 12 shows the pilot arrangement of the two transmission antennas.

FIG. 13 shows the pilot arrangement of the two transmission antennas.

FIG. 14 shows the pilot arrangement of the four transmission antennas.

FIG. 15 shows the pilot arrangement of the four transmission antennas.

FIGs. 16~18 show some pilot subcarrier allocation structures in a system using  
5 eight antennas according to an embodiment of the present invention.

FIGs. 19 and 20 show embodiments of the present invention in which a pilot subcarrier allocation offset varies according to cells in a 4-Tx system and an 8-Tx system.

FIG. 21 shows another embodiment of the 8-Tx system shown in FIG. 20.

10 FIG. 22 shows a pilot subcarrier allocation pattern according to an embodiment of the present invention.

FIGs. 23 ~ 25 show pilot subcarrier allocation patterns in a 2-Tx system according to an embodiment of the present invention.

15 FIGs. 26 and 27 show pilot subcarrier allocation patterns in a 4-Tx system according to an embodiment of the present invention.

FIG. 28 shows a pilot subcarrier allocation pattern in a 4-Tx system according to an embodiment of the present invention.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

20 In the following detailed description, reference is made to the accompanying drawing figures which form a part hereof, and which show by way of illustration specific embodiments of the invention. It is to be understood by those of ordinary skill in this technological field that other embodiments may be utilized, and structural, electrical, as well as procedural changes may be made without departing from the

scope of the present invention. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or similar parts.

The following technology may be used in various wireless communication systems. A wireless communication system is widely provided in order to provide various communication services such as voice and packet data. This technology may be used in downlink or uplink. In general, the downlink indicates communication from a base station (BS) to a user equipment (UE) and the uplink indicates communication from the UE to the BS. The BS generally indicates a fixed station communicating with the UE and may also be called a node-B, a base transceiver system (BTS) or an access point. The UE may be fixed or moved and may also be called a mobile station (MS), a user terminal (UT), a subscriber station (SS) or a wireless device.

Hereinafter, an efficient pilot structure for a new system will be described. The new system will be described concentrating on an IEEE 802.16m system, but the same principle may apply to other systems.

A communication system may be a multiple-input multiple-output (MIMO) system or a multiple-input single-output (MISO) system. The MIMO system uses a plurality of transmission antennas and a plurality of reception antennas. The MISO system uses a plurality of transmission antennas and one reception antenna.

FIG. 1 is a block diagram of a transmitter having multiple antennas. Referring to FIG. 1, the transmitter 100 includes a channel encoder 120, a mapper 130, an MIMO processor 140, a subcarrier allocator 150 and an orthogonal frequency division multiplexing (OFDM) modulator 160. The channel encoder 120, mapper 130, MIMO processor 140, and subcarrier allocator 150 may be embodied as separate components or combined in a single processor of the transmitter 100.

The channel encoder 120 encodes an input stream according to a predefined coding method and builds a coded word. The mapper 130 maps the coded word to a symbol representing a position on signal constellation. A modulation scheme of the mapper 130 is not restricted and may include an m-phase shift keying (m-PSK) scheme or an m-quadrature amplitude modulation (m-QAM) scheme.

The MIMO processor 140 processes the input symbol by a MIMO method using a plurality of transmission antennas 190-1, ..., and 190-Nt. For example, the MIMO processor 140 can perform precoding based on codebook.

The subcarrier allocator 150 allocates the input symbol and pilots to subcarriers. The pilots are arranged according to the transmission antennas 190-1, ..., and 190-Nt. The pilots are known by both the transmitter 100 and a receiver (200 of FIG. 2), which are used for the channel estimation or the data demodulation, and are also called reference signals.

The OFDM modulator 160 modulates the input symbol and outputs OFDM symbols. The OFDM modulator 160 may perform an inverse fast Fourier transform (IFFT) with respect to the input symbol and further insert a cyclic prefix (CP) after performing the IFFT. The OFDM symbols are transmitted via the transmission antennas 190-1, ..., and 190-Nt.

FIG. 2 is a block diagram of a receiver having multiple antennas. Referring to FIG. 2, the receiver 200 includes an OFDM demodulator 210, a channel estimator 220, an MIMO post-processor 230, a demapper 240 and a channel decoder 250. The channel estimator 220, MIMO post-processor 230, demapper 240 and channel decoder 250 may be embodied as separate components or combined in a single processor of the receiver 200.

Signals received via reception antennas 290-1, ..., and 290-Nr are Fast Fourier

transformed (FFT) by the OFDM demodulator 210. The channel estimator 220 estimates channels using pilots. The MIMO post-processor 230 performs a post-process corresponding to the MIMO processor 140. The demapper 240 demaps the input symbol to the coded word. The channel decoder 250 decodes the coded word and restores original data.

FIG. 3 is an example of a frame structure. A frame is a data sequence during a fixed time period used by a physical specification, which refers to section 8.4.4.2 of IEEE standard 802.16-2004 "Part 16: Air Interface for Fixed Broadband Wireless Access Systems" (hereinafter, referred to as reference Document 1).

Referring to FIG. 3, the frame includes a downlink (DL) frame and an uplink (UL) frame. Time division duplex (TDD) is a scheme in which the uplink and downlink transmission are separated in time domain but share the same frequency. Normally, the DL frame precedes the UL frame. The DL frame starts in the order of Preamble, Frame Control Header (FCH), Downlink (DL)-MAP, Uplink (UL)-MAP and burst regions (DL burst #1~5 and UL burst #1~5). A guard time for separating the DL frame and the UL frame from each other is inserted at both an intermediate portion of the frame (between the DL frame and the UL frame) and a last portion of the frame (following the UL frame). A transmit/receive transition gap (TTG) is a gap defined between a downlink burst and a subsequent uplink burst. A receive/transmit transition gap (RTG) is a gap defined between an uplink burst and a subsequent downlink burst.

The preamble is used for initial synchronization between the BS and the UE, cell search, frequency offset estimation and channel estimation. The FCH includes information regarding the length of the DL-MAP message and the coding scheme of the DL-MAP. The DL-MAP is a region where the DL-MAP message is transmitted.

The DL-MAP message defines the access of a downlink channel. The DL-MAP message includes a configuration change count of a Downlink Channel Descriptor (DCD) and a BS identifier (ID). The DCD describes a downlink burst profile applied to a current frame. The downlink burst profile refers to the property of a downlink physical channel, and the DCD is periodically transmitted by the BS through the DCD message.

The UL-MAP is a region where the UL-MAP message is transmitted. The UL-MAP message defines the access of an uplink channel. The UL-MAP message includes a configuration change count of an Uplink Channel Descriptor (UCD), and an effective start time of the uplink allocation defined by the UL-MAP. The UCD describes an uplink burst profile. The uplink burst profile refers to the property of an uplink physical channel, and the UCD is periodically transmitted by the BS through the UCD message.

Hereinafter, a slot is a minimum data allocation unit and is defined by a time and a subchannel. The number of subchannels depends on a FFT size and time-frequency mapping. The subchannel includes a plurality of subcarriers and the number of subcarriers per subchannel varies according to a permutation method. The permutation indicates mapping of a logical subchannel to a physical subcarrier. The subchannel includes 48 subcarriers in full usage of subchannels (FUSC) and the subchannel includes 24 or 16 subcarriers in partial usage of subchannels (PUSC). A segment indicates at least one subchannel set.

In order to map data to physical subcarriers in a physical layer, two steps are generally performed. In a first step, data is mapped to at least one data slot on at least one logical subchannel. In a second step, the logical subchannel is mapped to the physical subchannel. This is called permutation. Reference document 1

discloses a permutation method such as FUSC, PUSC, Optimal-FUSC (O-FUSC), Optional-PUSC (O-PUSC) and Adaptive modulation and coding (AMC). A set of OFDM symbols using the same permutation method is called a permutation zone and one frame includes at least one permutation zone.

5       The FUSC and the O-FUSC are used only for the downlink transmission. The FUSC is composed of one segment including all subchannel groups. The subchannels are mapped to the physical subcarriers distributed via all physical channels. The mapping is changed according to OFDM symbols. The slot is composed of one subchannel on one OFDM symbol. The methods of allocating  
10       pilots in the O-FUSC and FUSC are different from each other.

      The PUSC is used for both the downlink transmission and the uplink transmission. In the downlink, each physical channel is divided into clusters including 14 contiguous subcarriers on two OFDM symbols. The physical channel is mapped in the unit of six groups. In each group, the pilots are allocated to the  
15       clusters at fixed positions. In the uplink, the subcarriers are divided into tiles composed of four contiguous physical subcarriers on three OFDM symbols. The subchannel includes six tiles. The pilots are allocated to corners of the tiles. The O-PUSC is used only for the uplink transmission and the tile is composed of three contiguous physical subcarriers on three OFDM symbols. The pilots are allocated  
20       to the centers of the tiles.

      FIGs. 4 and 5 show a pilot arrangement of two transmission antennas in the PUSC and FUSC, respectively. FIGs. 6 and 7 show a pilot arrangement of four transmission antennas in the PUSC and FUSC, respectively. They refer to section 8.4.8.1.2.1.1, section 8.4.8.1.2.1.2, section 8.4.8.2.1, and section 8.4.8.2.2 of IEEE  
25       standard 802.16-2004/Cor1-2005 "Part 16: Air Interface for Fixed and Mobile

Broadband Wireless Access Systems; Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1" (hereinafter, referred to as Reference Document 2).

Referring to FIGs. 4 to 7, pilot overhead is large when the allocation of the subcarrier is performed according to the PUSC or the FUSC. In particular, the overhead is larger when one transmission antenna is used compared to when at least two transmission antennas is used, in consideration of pilot overhead per transmission antenna.

Table 1 shows the pilot overhead according to the number of transmission antennas in each permutation method.

Table 1

Number of transmission antennas	PUSC	FUSC	O-FUSC
1	14.28% (14.28%)	9.75% (9.75%)	11.1% (11.1%)
2	14.28% (7.14%)	9.75% (4.78%)	11.1% (5.55%)
4	28.55% (7.14%)	18.09% (4.52%)	22.21% (5.55%)

The pilot overhead is a value obtained by dividing the number of subcarriers allocated to the pilots by the number of all subcarriers which are used. The value in parenthesis indicates the pilot overhead per transmission antenna. Further,



according to Reference Document 2, if four or three transmission antennas are used, mapping of the data to the subchannels is performed after puncturing or truncation with respect to channel encoded data.

Now, a pilot structure for multiple antennas according to the present invention will be described. Design criteria for an optimal pilot structure are as follows.

(1) The pilot overhead in a single antenna is about 4 to 9% in a time-frequency domain. (2) One slot may include 48 subcarriers on two contiguous OFDM symbols. (3) The pilot subcarriers are uniformly distributed in the time-frequency domain. (4) The pilot overhead per transmission antenna is similarly maintained and the total pilot overhead is increased as the number of transmission antennas is increased. In consideration of the total pilot overhead, the total pilot overhead is equally maintained so as not to exceed 20% in at least three transmission antennas.

(5) Even when the number of transmission antennas is increased, mapping of the data to the subchannels is not influenced.

In order to derive a possible candidate group using the above-described condition, the following requirements can be expressed by equations and the candidate group satisfying the requirements can be derived.

$$(N_{used}-2*N_p) \bmod N_{sub} = 0$$

$$(N_{used}-2*N_p) \bmod N_{sub} = 0$$

$$(N_{used}-N_p) \bmod N_{sub} = 0$$

$$0.04 \leq N_p \leq 0.09$$

$$N_g = N_{fft} - N_{used} - 1 \text{ (DC subcarrier)}$$

$$(N_{used}-N_p) / N_{sub.sym} \geq N_{sch.pusc}$$

where,  $N_{used}$  denotes the number of used subcarriers,  $N_p$  denotes the number of pilot subcarriers,  $N_g$  denotes the number of guard subcarriers,  $N_{fft}$  denotes a FFT

size,  $N_{\text{sub}}$  denotes the number of subcarriers per subchannel,  $N_{\text{sub.sym}}$  denotes the number of subcarriers allocated to the subchannel on one OFDM symbol, and  $N_{\text{sch.pusc}}$  denotes the number of subchannels which can be generated in the existing DL-PUSC.

5 Table 2 shows 26 candidate groups according to the design criteria.

Table 2

#	FFT Size	Used SCs	Pilot SCs	Guard SCs	# of Subch - 1 antenna	# of Subch - 2 antennas	# of Subch - 4 antennas	Pilot Overhead -1 antenna	Data Ratio	Guard Ratio	Pilot Spacing
(1)	2048	1656	72	391	66	63	60	4.3478	80.859	19.092	11.5
(2)	2048	1656	96	391	65	61	57	5.7971	80.859	19.092	8.625
(3)	2048	1680	72	367	67	64	61	4.2857	82.031	17.92	11.6667
(4)	2048	1680	96	367	66	62	58	6.7143	82.031	17.92	8.75
(5)	2048	1680	120	367	65	60	55	7.1429	82.031	17.92	7
(6)	2048	1704	72	343	68	65	62	4.2254	83.203	16.748	11.833
(7)	2048	1704	96	343	67	63	59	5.6338	83.203	16.748	8.875
(8)	2048	1704	120	343	66	61	56	7.0423	83.203	16.748	7.1
(9)	2048	1728	72	319	69	66	63	4.1667	84.375	15.576	12
(10)	2048	1728	96	319	68	64	60	5.5556	84.375	15.576	9
(11)	2048	1728	120	319	67	62	57	6.9444	84.375	15.576	7.2
(12)	2048	1728	144	319	66	60	54	8.3333	84.375	15.576	6
(13)	2048	1752	72	295	70	67	64	4.1096	85.547	14.404	12.1667
(14)	2048	1752	96	295	69	65	61	5.4795	85.547	14.404	9.125
(15)	2048	1752	120	295	68	63	58	6.8493	85.547	14.404	7.3
(16)	2048	1752	144	295	67	61	55	8.2192	85.547	14.404	6.08
(17)	2048	1776	72	271	71	68	65	4.0541	86.719	13.232	12.333
(18)	2048	1776	96	271	70	66	62	5.4054	86.719	13.232	9.25
(19)	2048	1776	120	271	69	64	59	6.7568	86.719	13.232	7.4
(20)	1024	816	48	207	32	30	28	5.8824	79.688	20.215	8.5
(21)	1024	840	48	183	33	31	29	5.7143	82.031	17.871	8.75
(22)	1024	864	48	159	34	32	30	5.5556	84.375	15.527	9
(23)	1024	864	72	159	33	30	27	8.3333	84.375	15.527	6
(24)	1024	888	48	135	35	33	31	5.4054	86.719	13.184	9.25
(25)	1024	888	72	135	34	31	28	8.1081	86.719	13.184	6.1665
(26)	512	432	24	79	17	16	15	5.5556	84.375	15.43	9

The used subcarriers (used SCs), the pilot subcarriers (Pilot SCs) and the guard subcarriers (Guard SCs) are obtained according to the FFT size, and the subchannel according to the number of transmission antennas is obtained. The used subcarrier is a value excluding a DC subcarrier. For example, in the case (1), the number of subchannels in one transmission antenna is (the number of used subcarriers – the number of pilot subcarriers)/(the number of subcarriers allocated to the subchannels

on one OFDM symbol) =  $1656 - 72/24 = 66$ .

FIG. 8 is a graph showing cases of Table 2 by a ratio of pilot overhead and a ratio of guard subcarriers. Referring to FIG. 8, among cases (1) to (26) shown in Table 2, in consideration of the system bandwidth or the FFT size, it can be seen that cases which are most suitable for 5 to 20 MHz or 512 to 2048 FFT size in the same design criteria are cases (10), (22) and (26). In Table 2, the cases (10), (22) and (26) have a spacing of 9 pilots. That is, in one embodiment of the present invention, the arrangement of the pilots at a spacing of 9 subcarriers is provided.

Table 3 shows the subcarrier allocation.

Table 3

Parameter	Value			Comments
	2048	1024	512	
# of DC Subcarriers	1	1	1	Index 1024/512/256 (counting from 0)
# of Guard Subcarriers, Left	160	80	40	—
# of Guard Subcarriers, Right	159	79	39	—
# of Used Subcarriers ( $N_{used}$ )	1729	865	433	Number of all subcarriers used within a symbol, including pilots & a DC carrier
# of Pilot Subcarriers ( $N_{pilot}$ )	96	48	24	—
Pilot Subcarrier Index	$18k + 9m_i + 3(\lfloor n_s / 2 \rfloor \bmod 3)$ $k = 0, 1, \dots, N_{pilot}$ $m_i = (n_s + i) \bmod 2, i = 0, 1$			$n_s$ denotes a symbol index, in which index '0' should be the first symbol of the current zone. DC carrier is excluded for the calculation of the pilot subcarrier index.
# of Data Subcarriers (in each symbol per subch.)	1632 (24)	816 (24)	408 (24)	—

The subchannels are mapped to subcarriers excluding the subcarriers used after allocating the pilot subcarriers. At this time, a general PUSC or FUSC permutation method is applicable.

According to the above mentioned method, it is possible to improve throughput by 6 to 13% in the PUSC/FUSC. For example, while 60 subchannels can be obtained in the PUSC and 64 subchannels can be obtained in the FUSC according to the prior art, 68 subchannels can be obtained according to the above mentioned method. If a new permutation method is applied in consideration of the multiple antennas, capability can be prevented from deteriorating due to data puncturing or truncation.

The equation shown in the pilot subcarrier index of Table 3 represents a pilot index  $P_i$  of an  $i^{\text{th}}$  antenna. This is expressed by the following equation again.

Equation 1

$$P_i = 18k + 9m_i + 3(\lfloor n_s/2 \rfloor \bmod 3)$$

where,  $k=0,1,\dots,N_{\text{pilot}}$ ,  $m_i=(ns+i) \bmod 2$ ,  $i=0, 1$ ,  $\lfloor n \rfloor$  denotes an integer smaller than  $n$ . In Equation 1, a factor "18" indicates that the number of subcarriers of the subchannel on one OFDM symbol is 18, a factor "9" indicates that the pilot subcarriers are arranged at a spacing of 9 subcarriers, and a factor "3" indicates that the subcarriers are shifted at a spacing of three subcarriers in the unit of a slot. In this case, each slot occupies 2 consecutive OFDM symbols in time domain.

FIG. 9 is an example of the pilot arrangement of two transmission antennas. Referring to FIG. 9, one slot includes 72 subcarriers on two contiguous OFDM symbols, and the pilot subcarriers for a first antenna (antenna 0) and the pilot subcarriers for a second antenna (antenna 1) are arranged at a spacing of 9 subcarriers on each OFDM symbol. In addition, on the first OFDM symbol and the second OFDM symbol, the pilot subcarriers for the first antenna (antenna 0) and the pilot subcarriers for the second antenna (antenna 1) are alternately arranged.

In a second slot, the pilot subcarriers are shifted from the pilot subcarriers

allocated to the first slot by three subcarriers. In a third slot, the pilot subcarriers are shifted from the pilot subcarriers allocated to the second slot by three subcarriers. As a result, the same pilot arrangement is repeated in every three slots.

In the pilot arrangement, the pilots can be moved at a constant spacing in the time domain or the frequency domain, and thus, do not have absolute positions. The pilot subcarriers may be shifted by at a constant time interval or/and a subcarrier spacing while a spacing between the pilot subcarriers is maintained.

FIG. 10 is an example of the pilot arrangement of four transmission antennas. Referring to FIG. 10, the pilot subcarriers for four transmission antennas (antenna 0, antenna 1, antenna 2, and antenna 3) are contiguous in the frequency domain or in the time domain. The pilot subcarriers for the transmission antennas are arranged at a spacing of 12 subcarriers.

In a second slot, the pilot subcarriers are shifted from the pilot subcarriers allocated to the first slot by six subcarriers. As a result, the same pilot arrangement is repeated every two slots.

In the four transmission antennas, since the number of pilots is larger than the number of the two transmission antennas, the pilot spacing is wider than the pilot spacing in the two transmission antennas and the cyclic period of the repeated slot is decreased.

FIG. 11 illustrates the pilot arrangement of three or four transmission antennas by equation. Referring to FIG. 11,  $G_0$ ,  $G_1$ ,  $G_2$ , and  $G_3$  are defined in a  $2 \times 2$  region including two OFDMs ( $i=0, 1$ ) and two subcarriers. For example, in the four transmission antennas, the pilot carriers are arranged as shown in Table 4, which is equal to the arrangement of FIG. 10.

Table 4

	Antenna 0	Antenna 1	Antenna 2	Antenna 3
Pilot Subcarrier Index	$G_0$	$G_1$	$G_2$	$G_3$

In the three transmission antennas, the pilot subcarriers are arranged as shown in Table 5.

Table 5

$\lfloor n_2/2 \rfloor \bmod 2$		0	1	2
Pilot Subcarrier Index	Antenna 0	$G_0, G_3$	$G_2$	$G_1$
	Antenna 1	$G_1$	$G_0, G_3$	$G_2$
	Antenna 2	$G_2$	$G_1$	$G_0, G_3$

In order to express the pilot arrangement for the four transmission antennas by equation, six pilot subcarriers  $P_0^i, P_1^i, P_2^i, P_3^i, P_4^i$ , and  $P_5^i$  are considered on OFDM symbols ( $i=0,1$ ), as shown in Table 6.

Table 6

	$m_i=0$	$m_i=1$
$k=\text{even}$	$P_0^i = \{\text{PilotSub}(k, m_i)\}$ $P_1^i = \{\text{PilotSub}(k, m_i) + 1\}$	$P_2^i = \{\text{PilotSub}(k, m_i) + 3\}$
$k=\text{odd}$	$P_3^i = \{\text{PilotSub}(k, m_i) - 5\}$	$P_4^i = \{\text{PilotSub}(k, m_i) - 3\}$ $P_5^i = \{\text{PilotSub}(k, m_i) - 2\}$

where,  $\text{PilotSub}(k, m_i) = 18k + 9m_i + 6(\lfloor n_2/2 \rfloor \bmod 2)$ .

Accordingly, in one slot, a pilot subcarrier set may be mapped to the four pilot subcarriers  $G_0, G_1, G_2$ , and  $G_3$  as shown in Equation 2.

Equation 2

$$G_i = P_0^i + P_2^i + P_4^i \text{ and } G_{i+2} = P_1^i + P_3^i + P_5^i$$

where,  $i=0,1$ .

According to the pilot structure, the pilot overhead satisfying the design criteria is obtained and the overhead is decreased from the prior art by 5% or more. The

pilot overhead is 5.55% in the two transmission antennas, 5.55% in the three transmission antennas, and 4.16% in the four transmission antennas.

Even when the number of transmission antennas is increased, the mapping of data to the subchannels is not influenced. Accordingly, the permutation method can  
5 be simply performed.

In a method of generating distributed subchannels used in the existing IEEE 802.16-2004 standard, pilot subcarriers for the first antenna and the second antenna are first allocated and subchannels are constructed using residual subcarriers. In a third antenna and a fourth antenna, since the pilot subcarriers are allocated and  
10 used using the allocated subchannels, the subchannels of the same number are constructed regardless of the number of antennas. However, according to the pilot structure, a necessary number of pilot subcarriers are allocated according to the number of antennas and the subchannels are constructed using the residual subcarriers. Accordingly, the number of subchannels is increased while optimizing  
15 the pilot overhead.

FIG. 12 is another example of the pilot arrangement of two transmission antennas. Referring to FIG. 12, the pilot subcarriers for one antenna are arranged on one OFDM symbol at a spacing of nine subcarriers. That is, the pilot subcarriers for the first antenna (antenna 0) are arranged on the first OFDM symbol at a spacing of  
20 nine subcarriers, and the pilot subcarriers for the second antenna (antenna 1) are arranged on the second OFDM symbol at a spacing of nine subcarriers.

In a second slot, the pilot subcarriers are arranged by shifting the pilot subcarriers allocated to the first slot by three subcarriers. In a third slot, the pilot subcarriers are arranged by shifting the pilot subcarriers allocated to the second slot  
25 by three subcarriers. As a result, the same pilot arrangement is repeated every

three slots.

FIG. 13 is another example of the pilot arrangement of two transmission antennas. Referring to FIG. 13, the arrangement of the pilot subcarriers in one slot is equal to that of the embodiment shown in FIG. 9. However, in a second slot, the pilot subcarriers are shifted from the pilot subcarriers by four subcarriers. As a result, the same pilot arrangement is repeated every two slots.

Referring to FIG. 14, the pilot subcarriers for the transmission antennas (antenna 0, antenna 1, antenna 2, and antenna 3) are arranged at a spacing of 12 subcarriers and are arranged by shifting the frequency position in the unit of two OFDM symbols in every slot. In a second slot, the pilot subcarriers are shifted from the pilot subcarriers allocated to the first slot by six subcarriers. As a result, the same pilot arrangement is repeated every two slots.

FIG. 15 is another example of the pilot arrangement of four transmission antennas (antenna 0, antenna 1, antenna 2, and antenna 3). Referring to FIG. 15, the pilot subcarriers for the transmission antennas are arranged at a spacing of 12 subcarriers and the pilot subcarriers for the antennas are alternately arranged between two subsequent OFDM symbols in one slot. By alternately arranging 2 pilot subcarriers in two subsequent OFDM symbols, that is, by equally allocating each of pilot subcarriers for each antenna in 1 OFDM symbol, transmission power for each antenna can be balanced in certain time instance. In FIG. 15, two pilot subcarriers for respective two antennas are paired, and each of the two pairs of pilot subcarriers are alternatively allocated in two OFDM symbols.

Hereinafter, an efficient pilot allocation structure according to an embodiment of the present invention is described. A structure for allocating the pilot subcarriers efficiently shifts the pilot structure between contiguous cells in order to avoid collision



between pilot subcarriers.

In the following embodiment of the present invention, as an example, a basic resource block unit is composed of 18 subcarriers (vertical axis) \* six OFDM symbols (horizontal axis). However, the method of allocating the pilot subcarriers according to the present invention is also applicable to other basic resource block units by expanding the same method to a subframe or a frame.

In the following embodiment, the horizontal axis denotes a set of OFDM symbols in the time domain and the vertical axis denotes the subcarriers in the frequency domain. P1, P2, P3, P4, P5, P6, P7 and P8 denote the pilot subcarriers corresponding to the antennas 1, 2, 3, 4, 5, 6, 7 and 8, respectively.

FIGs. 16~18 are pilot subcarrier allocation structures in a system using eight antennas according to an embodiment of the present invention. The pilots of the first transmission antenna (P1) and the pilots of the second transmission antenna (P2), the pilots of the third transmission antenna (P3) and the pilots of the fourth transmission antennas (P4), the pilots of the fifth transmission antenna (P5) and the pilots of the sixth transmission antennas (P6), and the pilots of the seventh transmission antenna (P7) and the pilots of the eighth transmission antennas (P8) are respectively paired with each other and allocated so as to be contiguous to each other on two OFDM symbols, as shown in FIGs. 16~18. Further, the structure for consecutively allocating the pilot subcarriers for the antennas at a spacing of 18 subcarriers in the frequency axis is provided. That is, the pilot subcarriers are allocated at a spacing of a subchannel including 18 subcarriers.

Specifically, Fig. 16 shows a pilot pattern shifted and allocated at the subcarrier spacing of 2 per unit of two OFDM symbols. Fig. 17 shows a pilot pattern shifted and allocated at the subcarrier spacing of 6 per unit of two OFDM symbols. Fig. 18

shows a pilot pattern shifted and allocated at the subcarrier spacing of 6 per unit of two OFDM symbols, as in Fig. 17, but having additional 1 subcarrier offset.

In an aspect of the present invention, the pilot subcarriers for the antennas are equally allocated in each OFDM symbol, and the pilot subcarrier pattern is shifted and allocated at a predetermined spacing in a unit of two OFDM symbols. In another aspect of the present invention, the pilots for eight transmission antennas may be allocated to be shifted by a predetermined subcarrier spacing per each of the pilots for the antennas or pilot subcarrier pairs, instead of being contiguously allocated, as shown in FIGs. 16 ~ 18.

The pilot allocation may have the same allocation structure regardless of a regular subframe or an irregular subframe. A part of the pilots allocated according to an embodiment of the present invention may be used in a common pilot and the other part thereof may be used in a dedicated pilot. All the allocated pilots may be applied to the dedicated pilot or the common pilot. This embodiment is characterized in that the pilots for all antennas are equally allocated in one OFDM symbol for power balancing of the antenna per OFDM symbol. In the method of allocating the pilot subcarriers according to the above-described embodiment, a shift offset for pilot allocation may vary according to cells.

FIGs. 19 and 20 show that a pilot subcarrier allocation offset varies according to cells in a 4-Tx system and an 8-Tx system. In particular, FIG. 19 shows that the pilot subcarrier allocation offset is differently set to cells A, B and C in the 4-Tx system. And FIG. 20 shows that the pilot subcarrier allocation offset is differently set to the cells A, B and C in the 8-Tx system.

That is, the pilot allocation structure can be differently applied to the cells A, B and C. The applied shift offset value is applied in the number of subcarriers of 1 to

18. The 18 subcarriers correspond to the basic resource block size.

The shift offset value may be an integral multiple of the basic resource block size. Although the shift offset value is applied to the frequency axis in the present embodiment, it may be applied to the time axis.

5 If the number of contiguous cells is three or more and the above-described principle is expanded and applied, the structures shown in FIGs. 19 and 20 may be repeatedly used or may be applied in a state of being shifted by a predetermined subcarrier offset or a predetermined OFDM symbol offset.

FIG. 21 shows another embodiment of the 8-Tx system shown in FIG. 20. FIG.  
10 22 shows a pilot subcarrier allocation pattern according to another embodiment of the present invention.

In the eight transmission antennas, the pilots may not be allocated for all eight antennas due to the pilot overhead. That is, when the pilots are allocated only for the antennas 1, 2, 3 and 4, the overhead can be reduced. For example, such pilot  
15 allocation structure is applicable to a SFBC-CDD method. In the pilot allocation pattern shown in FIG. 22, a method of shifting and using the pilot pattern between contiguous cells is equal to that of the above-described embodiment.

FIGs. 23 ~ 25 show pilot subcarrier allocation patterns in a 2-Tx system according to another embodiment of the present invention. The principle according to  
20 the above-described embodiment is equally applied to the pilot patterns shown in FIGs. 23 ~ 25. Thus, the pilot subcarriers for the first antenna and the pilot subcarriers for the second antenna form pairs and are contiguously arranged in two contiguous OFDM symbol areas. The pilot subcarriers for all antennas are set to be included in each of the OFDM symbol areas by the same number in order to equally  
25 set the transmission power allocated to the antennas at a specific time.

Preferably, the pilot subcarrier pairs are allocated at a spacing of nine subcarriers, in consideration of optimal granularity for the pilot subcarrier allocation in a coherence bandwidth. Further, the pairs of the pilot subcarriers for the first antenna and the pilot subcarriers for the second antenna are shifted by a predetermined number of subcarriers in a unit of two OFDM symbols. Although FIGs. 23 and 24 show that the shifted subcarrier spacing is a spacing corresponding to three subcarriers, for example, the subcarrier indexes are increased by three subcarriers, the shifted subcarrier spacing may be a predetermined multiple of three subcarriers, for example, six subcarriers, and may be applied such that the indexes are decreased by three subcarrier indexes. Fig. 25 shows that the shifted subcarrier spacing is set to be 6 subcarriers. Fig. 25 may also be construed that the shifted subcarrier spacing is applied such that the indexes are decreased by 3 subcarrier indexes.

As described above, the reason why the frequency-domain shift is set at a spacing corresponding to three subcarriers or the multiple of three subcarriers is because the pilot subcarriers are allocated in a unit of nine subcarriers and the pilot subcarrier allocation pattern is repeated with a predetermined period. The pilot pattern shown in FIGs. 23 ~ 25 may be equally and repeatedly applied to the time/frequency domain in the frame or the subframe. The positions of the pilots for the antenna 1 and the positions of the pilots for the antenna 2 may be exchanged without departing from the principal of this embodiment.

In the pilot allocation structure shown in FIG. 23, the pilot allocation indexes for the antennas are represented in detail as follows.

<Pilot allocation index for Fig. 23>

**Antenna 1 –**

18k+1 when s is 0

18k+10 when s is 1

18k+4 when s is 2

18k+13 when s is 3

5 18k+7 when s is 4

18k+16 when s is 5

#### Antenna 2-

18k+10 when s is 0

18k+1 when s is 1

10 18k+13 when s is 2

18k+4 when s is 3

18k+16 when s is 4

18k+7 when s is 5

k: subcarrier index (k=0, 1, ...),

15 s : [OFDM symbol index] mod 6

(OFDM symbol index = 0,1,2,...)

And, in the pilot allocation structure shown in FIG. 24, the pilot allocation indexes for the antennas may be represented in detail as follows.

<Pilot allocation index for Fig. 24>

#### 20 Antenna 1 –

18k when s is 0

18k+9 when s is 1

18k+3 when s is 2

18k+12 when s is 3

25 18k+6 when s is 4

18k+15 when s is 5

**Antenna 2-**

18k+9 when s is 0

18k when s is 1

5 18k+12 when s is 2

18k+3 when s is 3

18k+15 when s is 4

18k+6 when s is 5

k: subcarrier index (k=0, 1, ...),

10 s: [OFDM symbol index] mod 6

(OFDM symbol index = 0,1,2,...)

In addition, in the pilot allocation structure shown in FIG. 25, the pilot allocation indexes for the antennas may be represented in detail as follows.

<Pilot allocation index for Fig. 25>

15 **Antenna 1 –**

18k when s is 0

18k+9 when s is 1

18k+6 when s is 2

18k+15 when s is 3

20 18k+3 when s is 4

18k+12 when s is 5

**Antenna 2-**

18k+9 when s is 0

18k when s is 1

25 18k+15 when s is 2

18k+6 when s is 3

18k+12 when s is 4

18k+3 when s is 5

k: subcarrier index (k=0, 1, ...),

s: [OFDM symbol index] mod 6

(OFDM symbol index = 0,1,2,...)

5

10 In the pilot allocation structure according to the above-described embodiment, if a preamble OFDM symbol is transmitted to a foremost portion of the subframe in a predetermined period, the pilot subcarriers may be changed so as to be applied to a second OFDM symbol and the subsequent OFDM symbols.

15

FIGs. 26 and 27 show pilot subcarrier allocation patterns in a 4-Tx system according to another embodiment of the present invention. The basic pilot allocation methods of FIGs. 26 and 27 are equal to those of the above-described embodiments. However, in the present embodiment, the pilot subcarriers for the four antennas are allocated to be contiguous to each other in contiguous four OFDM symbol areas.

In the pilot allocation structure shown in FIG. 26, the pilot allocation indexes for the antennas may be represented in detail as follows.

<Pilot allocation index for Fig. 26>

#### **Antenna 1 –**

20

18k+1 when s is 0

18k+10 when s is 1

18k+4 when s is 2

18k+13 when s is 3

18k+7 when s is 4

25

18k+16 when s is 5

**Antenna 2-**

18k+10 when s is 0

18k+1 when s is 1

18k+13 when s is 2

5 18k+4 when s is 3

18k+16 when s is 4

18k+7 when s is 5

k: subcarrier index (k=0, 1, ...),

s: [OFDM symbol index] mod 6

10 (OFDM symbol index = 0,1,2,...)

**Antenna 3 –**

18k+4 when s is 0

18k+13 when s is 1

18k+7 when s is 2

15 18k+16 when s is 3

18k+10 when s is 4

18k+1 when s is 5

**Antenna 4-**

18k+13 when s is 0

20 18k+4 when s is 1

18k+16 when s is 2

18k+7 when s is 3

18k+1 when s is 4

18k+10 when s is 5

25 k: subcarrier index (k=0, 1, ...),



$s: [\text{OFDM symbol index}] \bmod 6$

(OFDM symbol index = 0, 1, 2, ...)

In the pilot allocation structure shown in FIG. 27, the pilot allocation indexes for the antennas may be represented in detail as follows.

5 <Pilot allocation index for Fig. 27>

**Antenna 1 –**

18k when s is 0

18k+9 when s is 1

18k+3 when s is 2

10 18k+12 when s is 3

18k+6 when s is 4

18k+15 when s is 5

**Antenna 2-**

18k+9 when s is 0

15 18k when s is 1

18k+12 when s is 2

18k+3 when s is 3

18k+15 when s is 4

18k+6 when s is 5

20 k: subcarrier index (k=0, 1, ...),

s: [OFDM symbol index] mod 6

(OFDM symbol index = 0, 1, 2, ...)

**Antenna 3 –**

18k+3 when s is 0

25 18k+12 when s is 1

18k+6 when s is 2

18k+15 when s is 3

18k+9 when s is 4

18k when s is 5

5      **Antenna 4-**

18k+12 when s is 0

18k+3 when s is 1

18k+15 when s is 2

18k+6 when s is 3

10      18k when s is 4

18k+9 when s is 5

k: subcarrier index (k=0, 1, ...),

s: [OFDM symbol index] mod 6

(OFDM symbol index = 0,1,2,...)

15      FIG. 28 shows a pilot subcarrier allocation pattern in a 4-Tx system according to another embodiment of the present invention. The principle described in the above-described embodiments is similarly applied to the pilot pattern of FIG. 28. However, FIG. 26 shows an example that the pairs of pilots are arranged at the spacing of two subcarriers when the subcarriers for the first antenna and the subcarriers for the second antenna form a pair of pilots, and the subcarriers for the third antenna and the subcarriers for the fourth antenna form another pair of pilots. That is, in the present embodiment, the allocation may be performed such that two pairs of pilots are allocated to be contiguous to each other or not to be contiguous to each other.

25      The above-described functions may be performed by a processor such as a microprocessor, a controller, a microcontroller or an application specific integrated

circuit (ASIC) which is coded so as to perform the functions. The design, development and implementation of the code are apparent to those skilled in the art on the basis of the description of the present invention.

5 A method of allocating pilot subcarriers according to the present invention is applicable to an IEEE 802.16m system. As described above, a basic principle such as pilot arrangement for equally allocating transmission power to antennas or pilot shift pattern setting is also applicable to other wireless communication systems by the same method.

10 It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

**What is claimed is:**

1. A method of allocating pilot subcarriers for use in at least one of downlink and uplink communication in a multiple-input multiple-output (MIMO) antenna system using orthogonal frequency division multiplexing (OFDM) modulation, the method comprising:

providing a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain; and

allocating pilot locations according to equation:

$$P_i = 18k + 9m_i + 3(\lfloor n_s/2 \rfloor \bmod 3)$$

where,  $P_i$  denotes pilot index of an  $i^{\text{th}}$  antenna,

$k=0, 1, \dots, N_{\text{pilot}}$ ;

$i=(n_s+i) \bmod 2$ ; and

$\lfloor n \rfloor$  denotes an integer smaller than  $n$ .

2. A method of allocating pilot subcarriers for use in at least one of downlink and uplink communication in a multiple-input multiple-output (MIMO) antenna system using orthogonal frequency division multiplexing (OFDM) modulation, the method comprising:

providing a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain; and

alternately allocating first pilot subcarriers for a first antenna and second pilot subcarriers for a second antenna in at least one of the time and frequency domains, wherein each of the alternating first pilot subcarriers and the second pilot subcarriers are separated by a multiple of a first predetermined number of subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols,

wherein the first predetermined number is 9.

3. The method of claim 2, wherein each of the first pilot subcarriers separated by two OFDM symbols is shifted by a second predetermined number of subcarriers and each of the second pilot subcarriers separated by two OFDM symbols is shifted by the second predetermined number of subcarriers to differentiate frequency selectivity, wherein the second predetermined number is a multiple of 3.

4. The method of claim 2, wherein each OFDM symbol comprises the first and second pilot subcarriers.

5. The method of claim 4, wherein number of each of the first and second pilot subcarriers in each OFDM symbol is the same.

6. The method of claim 3, wherein the second predetermined number is 3.

7. The method of claim 2, wherein the frame structure is used in one of uplink and downlink communications.

8. The method of claim 2, further comprising:

alternately allocating third pilot subcarriers for a third antenna and fourth pilot subcarriers for a fourth antenna in the time and frequency domains, wherein each of the alternating third pilot subcarriers and the fourth pilot

subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols.

5 9. The method of claim 8, wherein the first pilot subcarriers are adjacent to the third pilot subcarriers in the frequency domain and the second pilot subcarriers are adjacent to the fourth pilot subcarriers in the frequency domain.

10 10. The method of claim 8, wherein the first pilot subcarriers and the third pilot subcarriers are separated by at least one subcarrier in the frequency domain and the second pilot subcarriers and the fourth pilot subcarriers are separated by at least one subcarrier in the frequency domain.

11. The method of claim 9, further comprising:

15 alternately allocating fifth pilot subcarriers for a fifth antenna and sixth pilot subcarriers for a sixth antenna in the time and frequency domains, wherein each of the alternating fifth pilot subcarriers and the sixth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous  
20 OFDM symbols; and

alternatively allocating seventh pilot subcarriers for a seventh antenna and eighth pilot subcarriers for a eighth antenna in the time and frequency domains, wherein each of the alternating seventh pilot subcarriers and the eighth pilot subcarriers are separated by the multiple of the first  
25 predetermined subcarriers in the frequency domain and further allocated in

two contiguous OFDM symbols,

wherein the fifth pilot subcarriers are adjacent to and positioned between the third and seventh pilot subcarriers in the frequency domain and the sixth pilot subcarriers are adjacent to and positioned between the fourth and eighth pilot subcarriers in the frequency domain.

12. The method of claim 10, further comprising:

alternately allocating fifth pilot subcarriers for a fifth antenna and sixth pilot subcarriers for a sixth antenna in the time and frequency domains, wherein each of the alternating fifth pilot subcarriers and the sixth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols; and

alternatively allocating seventh pilot subcarriers for a seventh antenna and eighth pilot subcarriers for a eighth antenna in the time and frequency domains, wherein each of the alternating seventh pilot subcarriers and the eighth pilot subcarriers are separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols,

wherein the fifth pilot subcarriers and the seventh pilot subcarriers are separated by at least one subcarrier in the frequency domain and the sixth pilot subcarriers and the eighth pilot subcarriers are separated by at least one subcarrier in the frequency domain.

13. The method of claim 2, wherein the frame structure is used in a type

of a full usage of subchannels (FUSC) permutation mode.

14. The method of claim 2, wherein the frame structure is used in a type of an adaptive modulation and coding (AMC) permutation mode.

5

15. The method of claim 2, wherein a starting location of the first pilot subcarriers in a first OFDM symbol is offset by at least one subcarrier.

10

16. A wireless communication system using orthogonal frequency division multiplexing (OFDM) modulation for downlink and uplink communication, the wireless communication system comprising:

a multiple-input multiple-output (MIMO) antenna;

an OFDM modulator operably connected to the MIMO antenna; and

15

a processor operably connected to the OFDM modulator, wherein the processor is configured to provide a frame structure comprising OFDM symbols in time domain and subcarriers in frequency domain and allocate pilot locations according to equation:

$$P_i = 18k + 9m_i + 3(\lfloor n_s/2 \rfloor \bmod 3)$$

where,  $P_i$  denotes pilot index of an  $i^{\text{th}}$  antenna,

20

$k=0, 1, \dots, N_{\text{pilot},i}$

$i=(n_s+i) \bmod 2$ ; and

$\lfloor n \rfloor$  denotes an integer smaller than  $n$ .

25

17. A wireless communication system using orthogonal frequency division multiplexing (OFDM) modulation, the wireless communication system



comprising:

a multiple-input multiple-output (MIMO) antenna;

an OFDM modulator operably connected to the MIMO antenna; and

a processor operably connected to the OFDM modulator, wherein the

processor is configured to provide a frame structure comprising OFDM

symbols in time domain and subcarriers in frequency domain and alternately

allocate first pilot subcarriers for a first antenna and second pilot subcarriers

for a second antenna in at least one of the time and frequency domains,

wherein each of the alternating first pilot subcarriers and the second pilot

subcarriers is separated by a multiple of a first predetermined number of

subcarriers in the frequency domain and further allocated in two contiguous

OFDM symbols,

wherein the first predetermined number is 9.

18. The wireless communication system of claim 17, wherein each of the first pilot subcarriers separated by two OFDM symbols is shifted by a second predetermined number of subcarriers and each of the second pilot subcarriers separated by two OFDM symbols is shifted by the second predetermined number of subcarriers to differentiate frequency selectivity, wherein the second predetermined number is a multiple of 3.

19. The wireless communication system of claim 17, wherein each OFDM symbol comprises the first and second pilot subcarriers.

20. The wireless communication system of claim 19, wherein number of

each of the first and second pilot subcarriers in each OFDM symbol is the same.

21. The wireless communication system of claim 18, wherein the second  
5 predetermined number is 3.

22. The wireless communication system of claim 17, wherein the frame  
structure is used in one of uplink and downlink communications.

10 23. The wireless communication system of claim 19, wherein the  
subcarrier allocator is further configured to alternately allocate third pilot  
subcarriers for a third antenna and fourth pilot subcarriers for a fourth  
antenna in the time and frequency domains, each of the alternating third pilot  
subcarriers and the fourth pilot subcarriers being separated by the multiple of  
15 the first predetermined subcarriers in the frequency domain and further  
allocated in two contiguous OFDM symbols.

24. The wireless communication system of claim 23, wherein the first  
pilot subcarriers are adjacent to the third pilot subcarriers in the frequency  
20 domain and the second pilot subcarriers are adjacent to the fourth pilot  
subcarriers in the frequency domain.

25. The wireless communication system of claim 23, wherein the first  
pilot subcarriers and the third pilot subcarriers are separated by at least one  
25 subcarrier in the frequency domain and the second pilot subcarriers and the

fourth pilot subcarriers are separated by at least one subcarrier in the frequency domain.

26. The wireless communication system of claim 24, wherein the subcarrier allocator is further configured to:

alternately allocate fifth pilot subcarriers for a fifth antenna and sixth pilot subcarriers for a sixth antenna in the time and frequency domains, each of the alternating fifth pilot subcarriers and the sixth pilot subcarriers being separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols; and

alternately allocate seventh pilot subcarriers for a seventh antenna and eighth pilot subcarriers for a eighth antenna in the time and frequency domains, each of the alternating seventh pilot subcarriers and the eighth pilot subcarriers being separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols,

wherein the fifth pilot subcarriers are adjacent to and positioned between the third and seventh pilot subcarriers in the frequency domain and the sixth pilot subcarriers are adjacent to and positioned between the fourth and eighth pilot subcarriers in the frequency domain.

27. The wireless communication system of claim 25, wherein the subcarrier allocator is further configured to:

alternately allocate fifth pilot subcarriers for a fifth antenna and sixth pilot

subcarriers for a sixth antenna in the time and frequency domains, each of the alternating fifth pilot subcarriers and the sixth pilot subcarriers being separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous OFDM symbols;  
5 and

alternately allocate seventh pilot subcarriers for a seventh antenna and eighth pilot subcarriers for a eighth antenna in the time and frequency domains, each of the alternating seventh pilot subcarriers and the eighth pilot subcarriers being separated by the multiple of the first predetermined subcarriers in the frequency domain and further allocated in two contiguous  
10 OFDM symbols,

wherein the fifth pilot subcarriers and the seventh pilot subcarriers are separated by at least one subcarrier in the frequency domain and the sixth pilot subcarriers and the eighth pilot subcarriers are separated by at least one  
15 subcarrier in the frequency domain.

28. The wireless communication system of claim 17, wherein the frame structure is used in a type of a full usage of subchannels (FUSC) permutation  
20 mode.

29. The wireless communication system of claim 17, wherein the frame structure is used in a type of an adaptive modulation and coding (AMC) permutation mode.

30. The wireless communication system of claim 17, wherein a starting location of the first pilot subcarriers in a first OFDM symbol is offset by at least one subcarrier.

5           31. The system of claim 17, wherein the processor comprises:  
a subcarrier allocator allocating symbols and pilots to the subcarriers for use in at least one of the downlink and uplink communication.

10           32. The wireless communication system of claim 31, wherein the processor further comprises:  
a channel encoder encoding an input stream and building a coded word;  
a mapper mapping the coded word to a symbol representing a position on signal constellation; and  
a MIMO processor processing the symbol.

15

20

25

FIG. 1

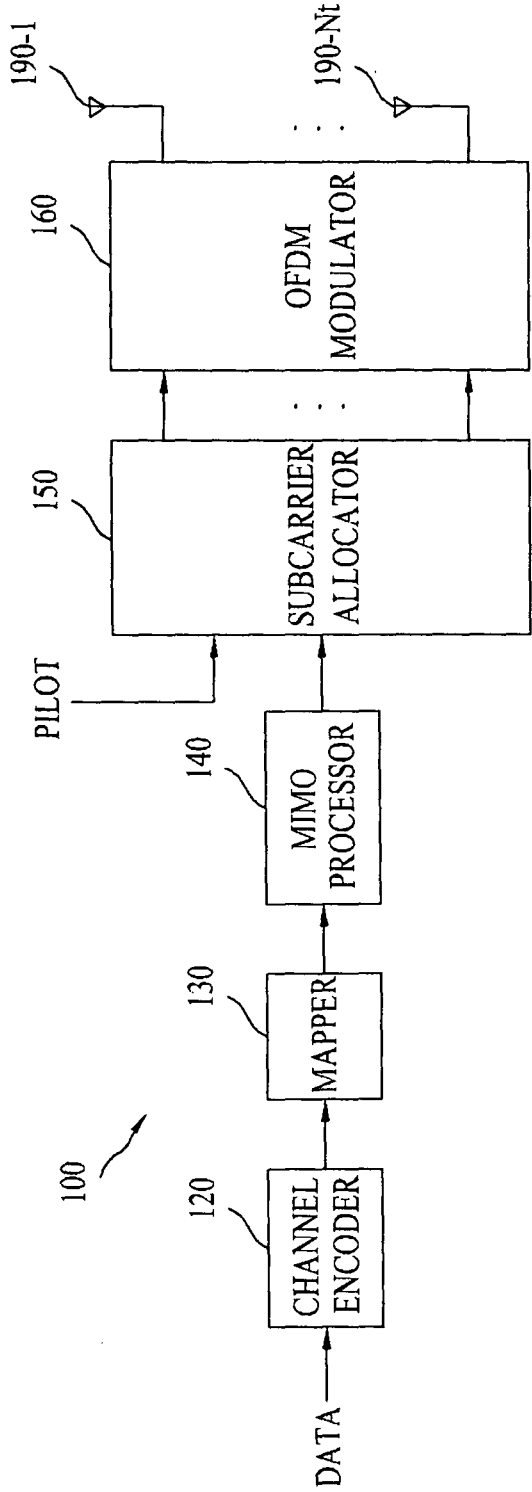


FIG. 2

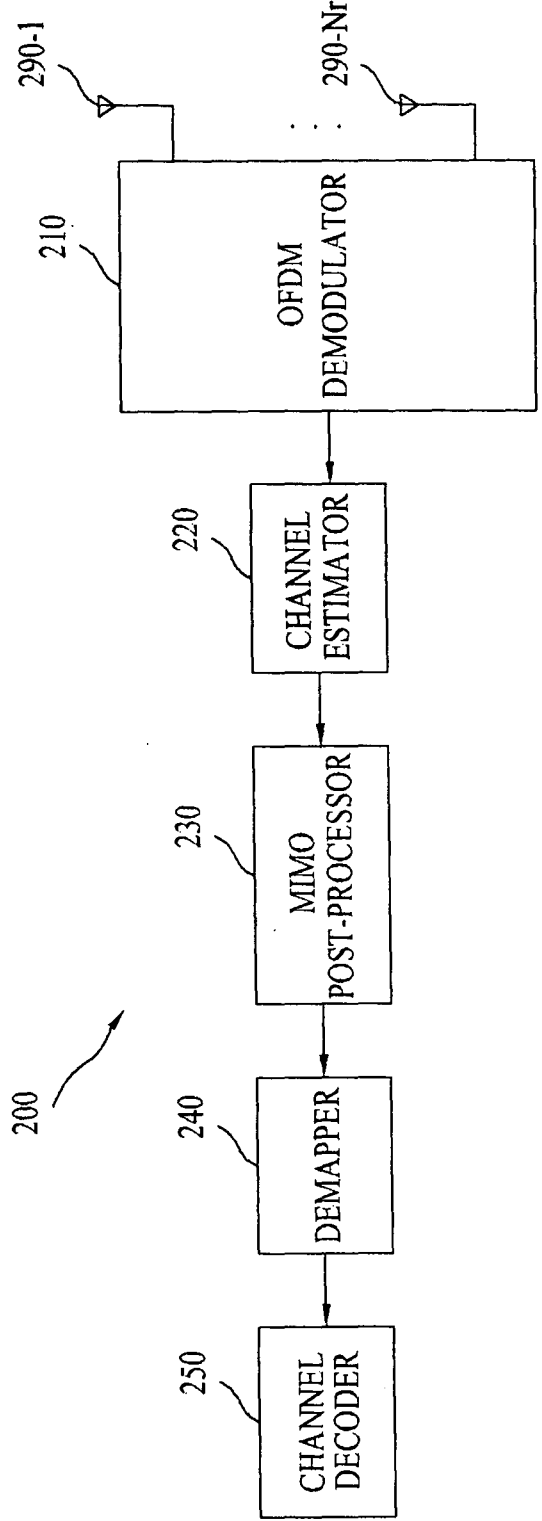


FIG. 3

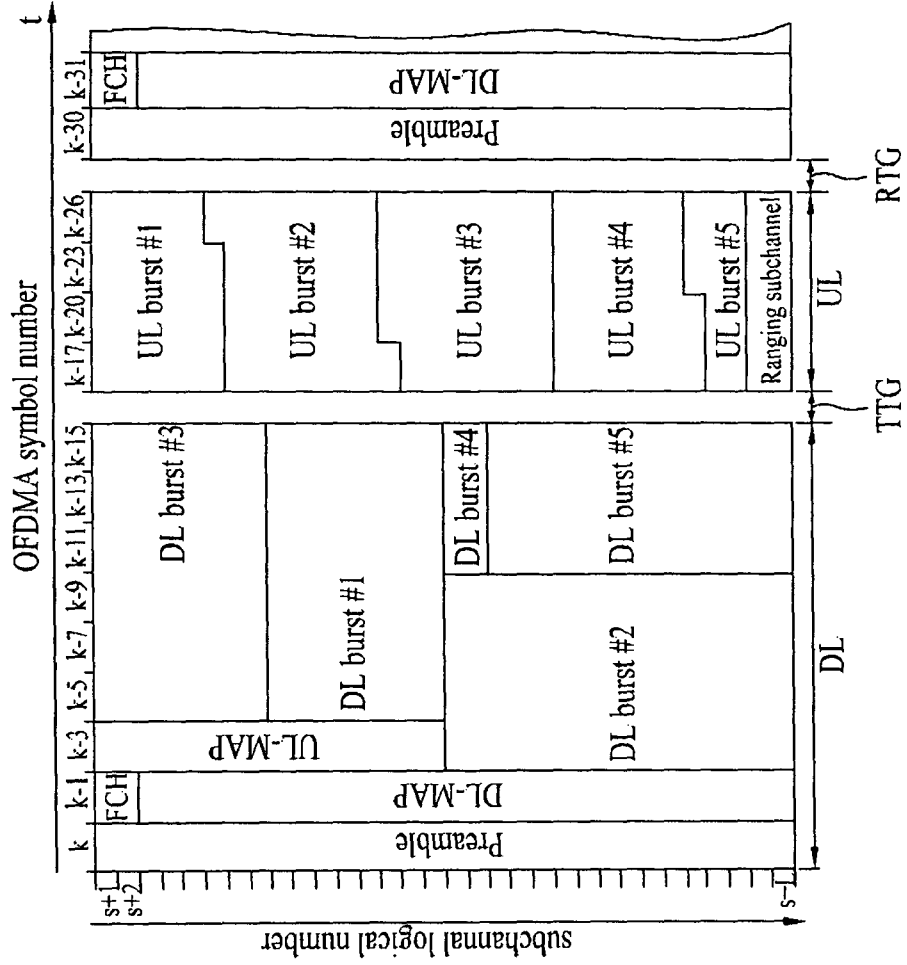




FIG. 4

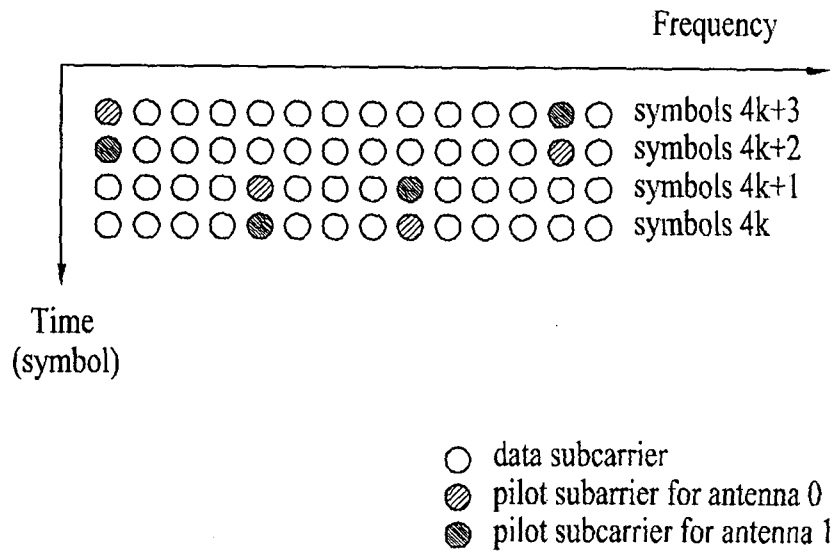


FIG. 5

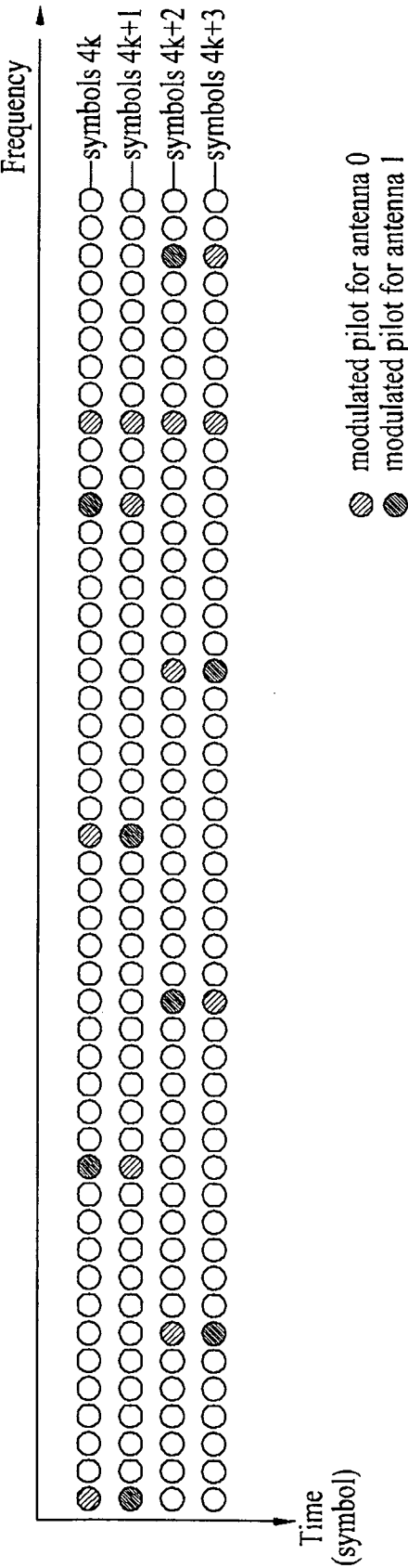


FIG. 6

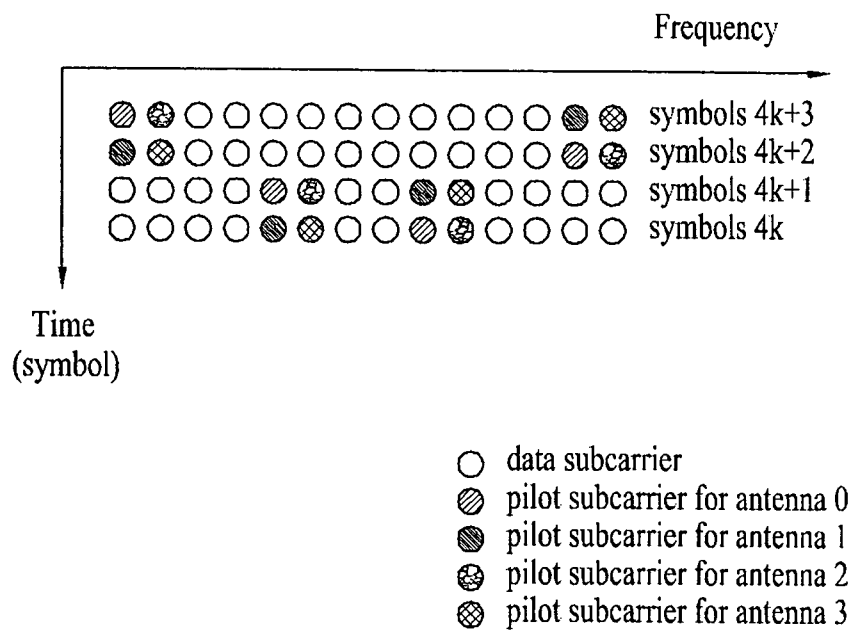


FIG. 7

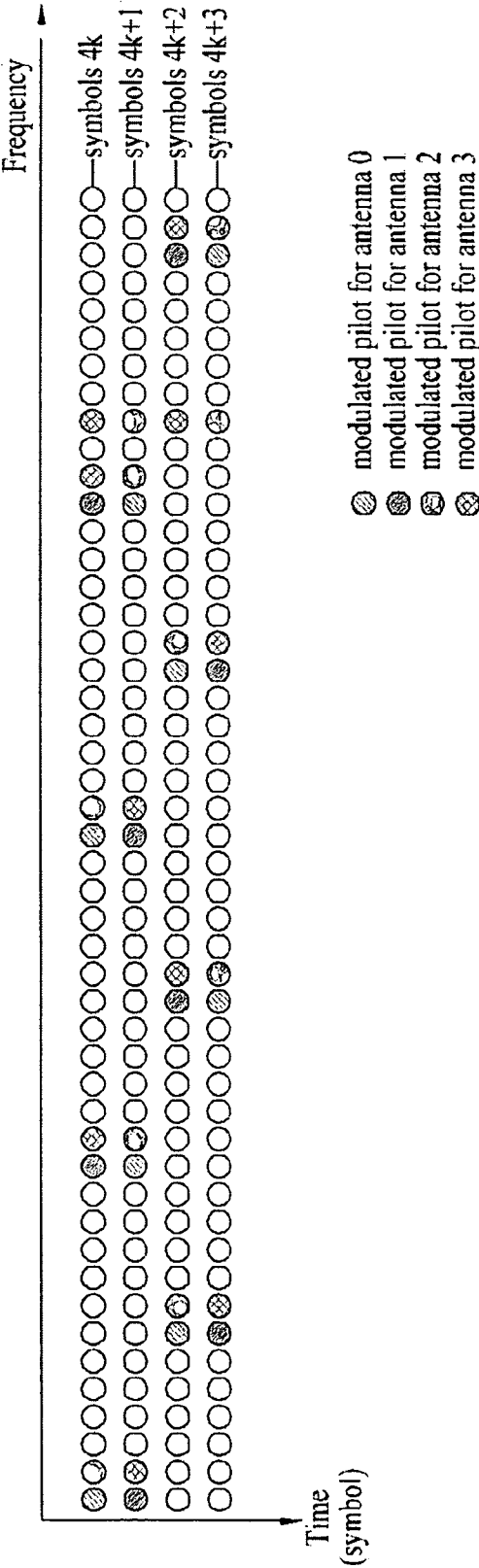


FIG. 8

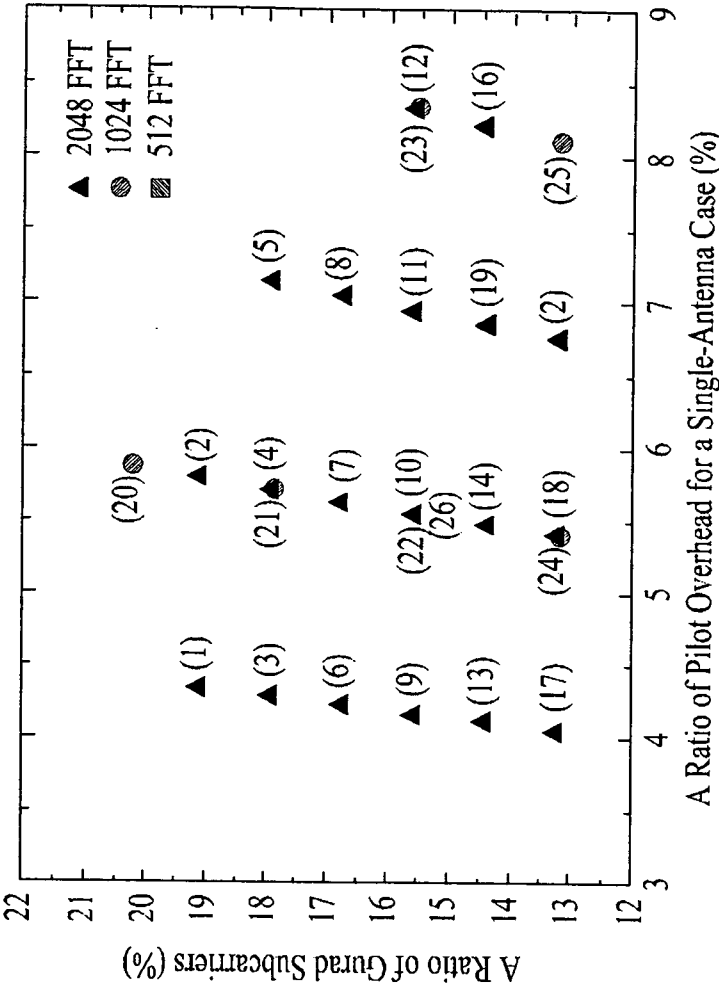


FIG. 9

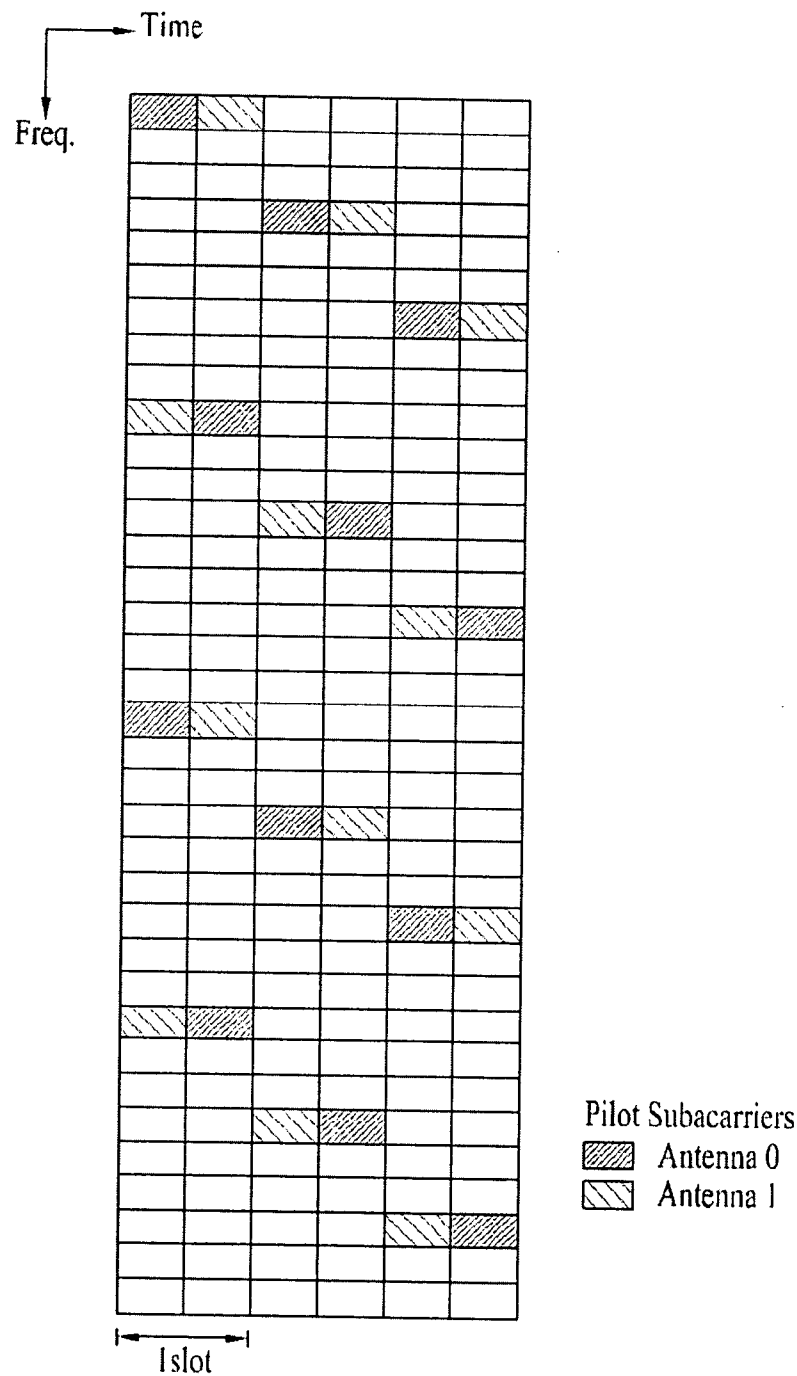


FIG. 10

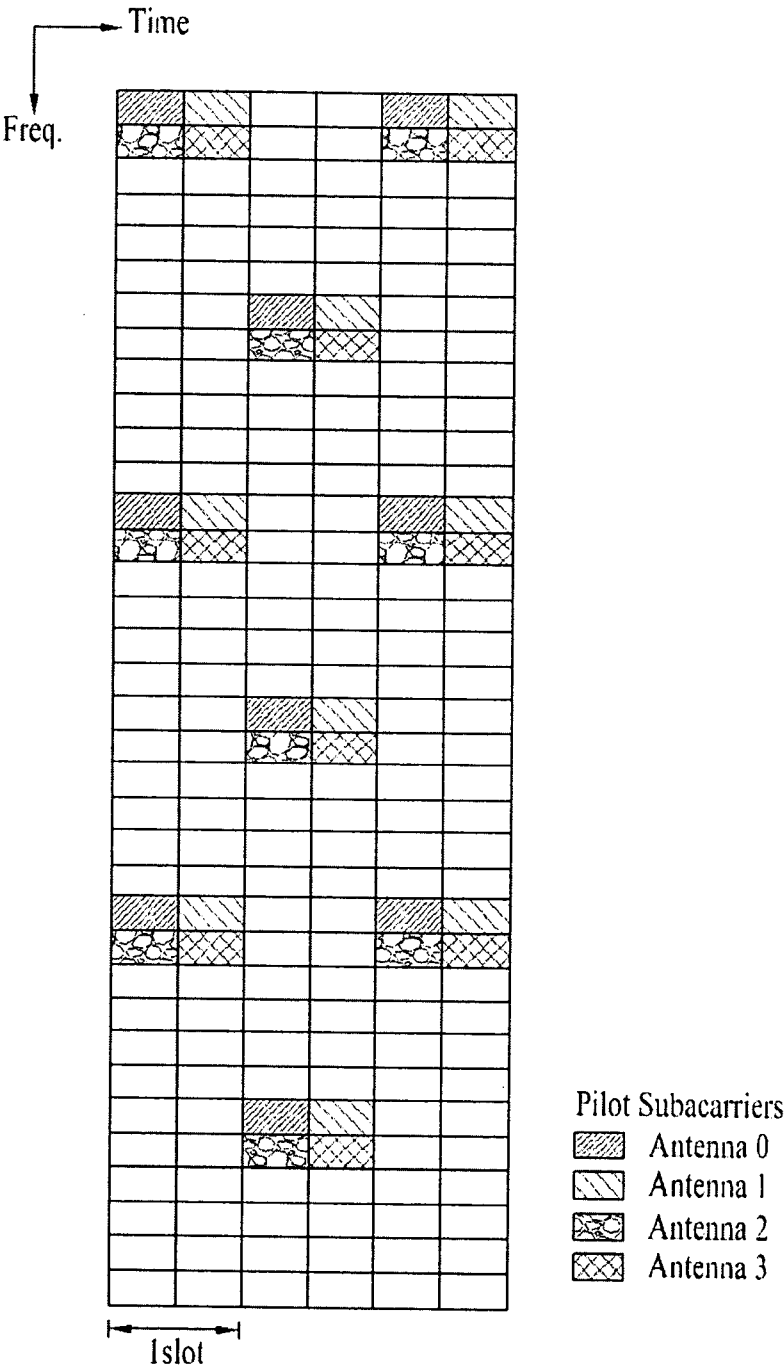


FIG. 11

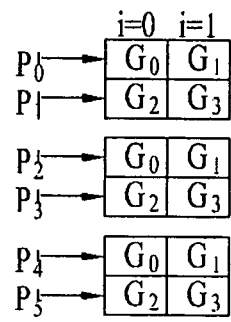




FIG. 12

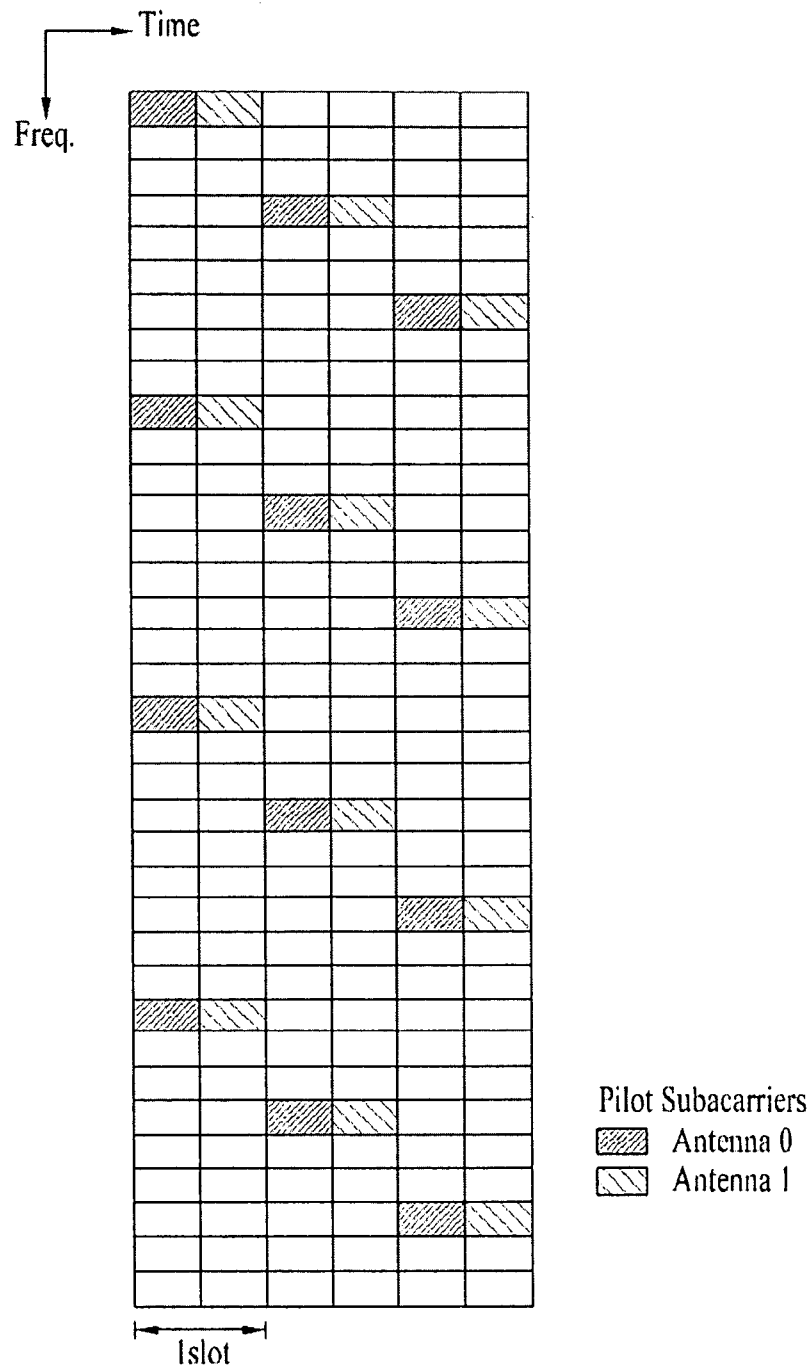


FIG. 13

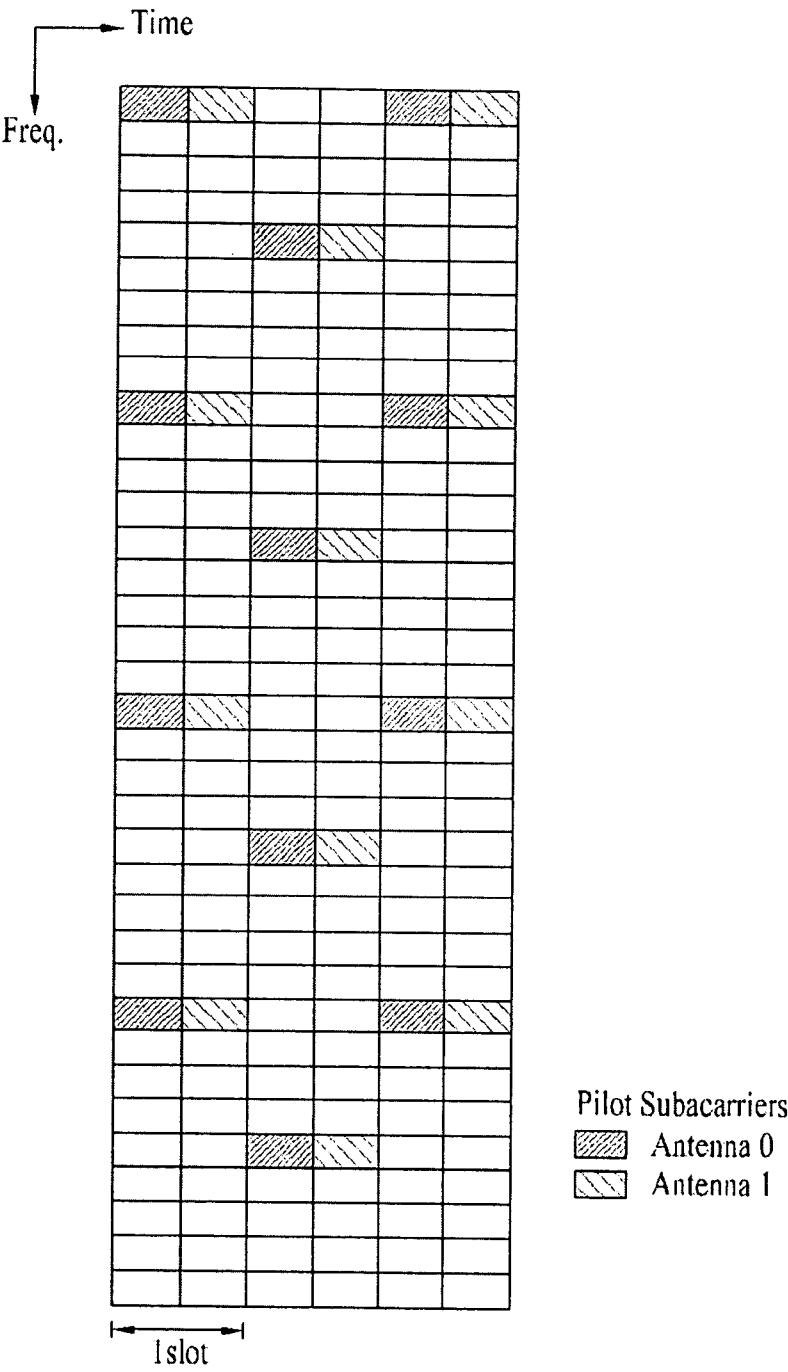


FIG. 14

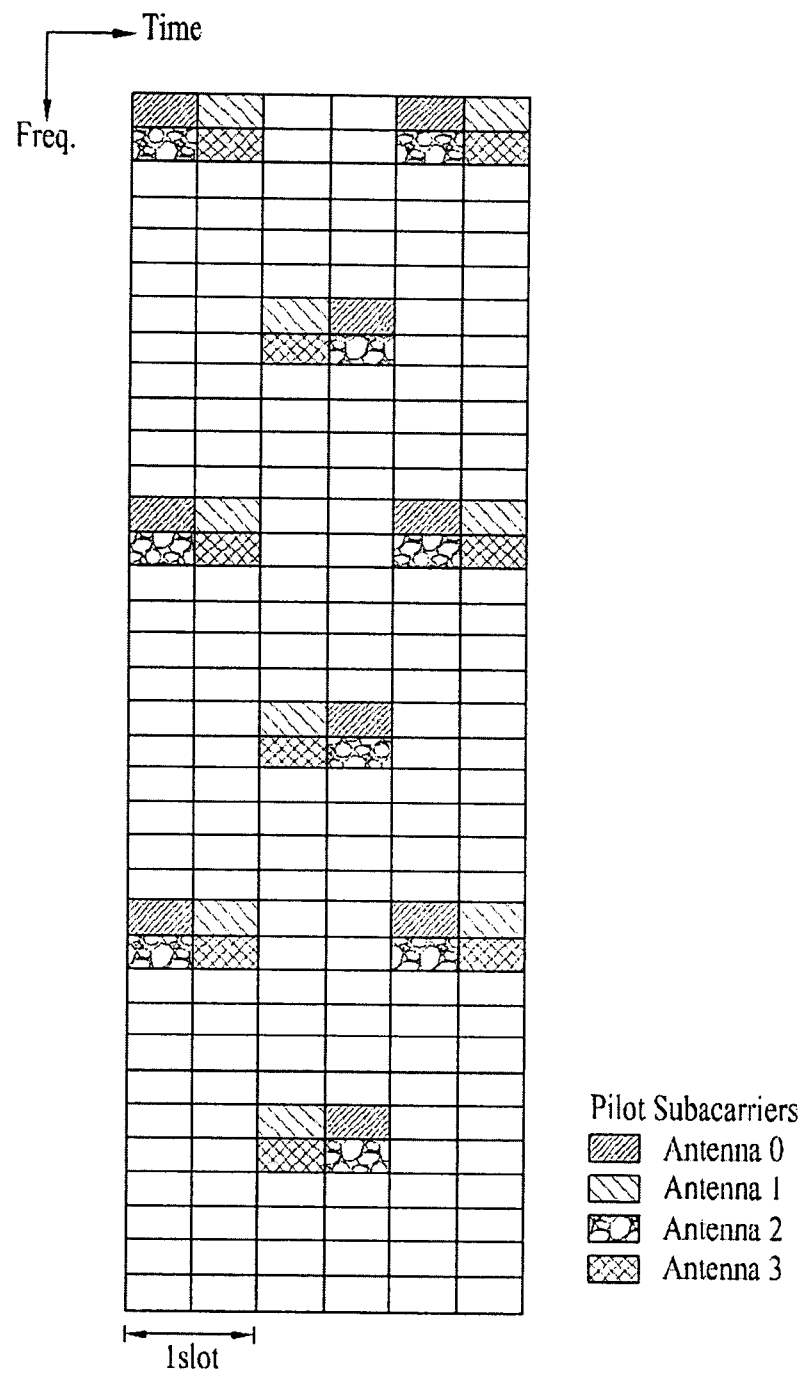


FIG. 15

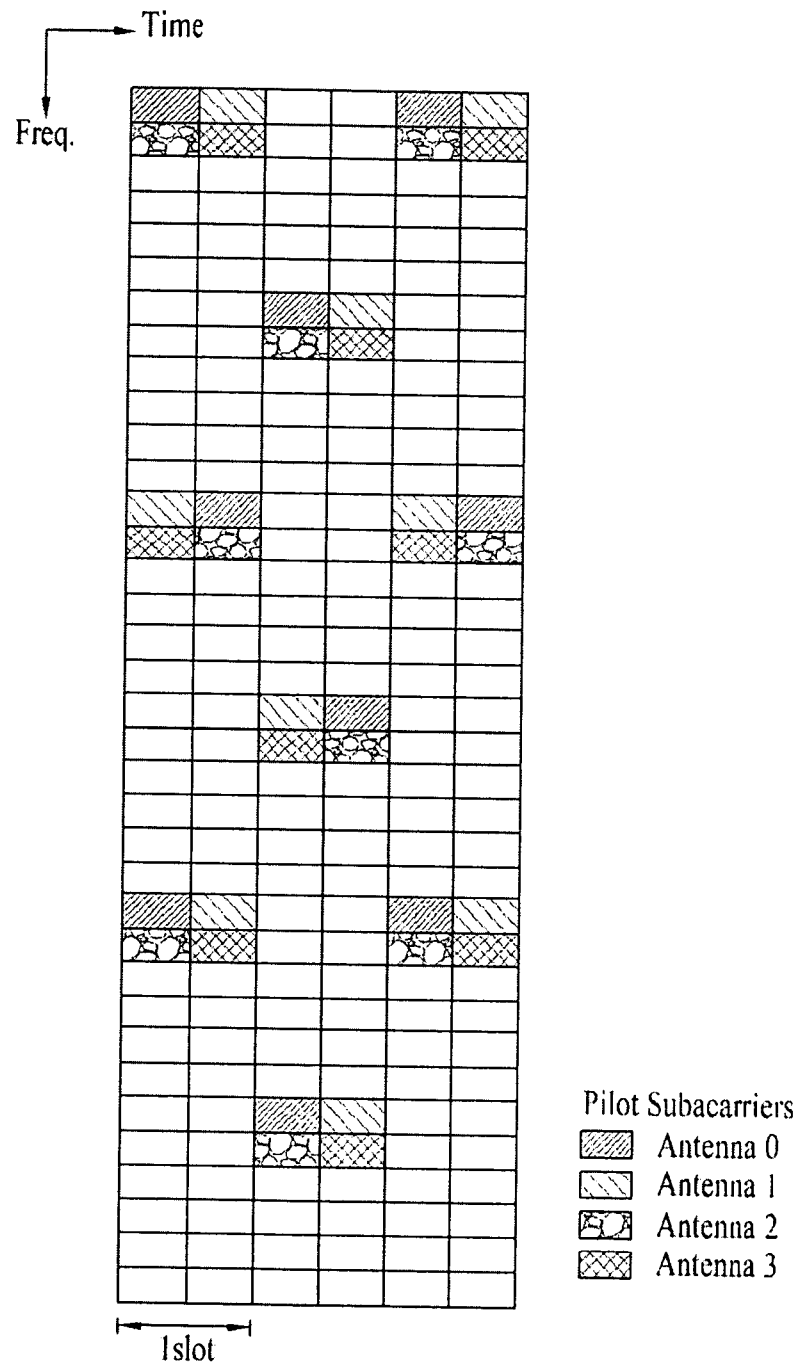


FIG. 16

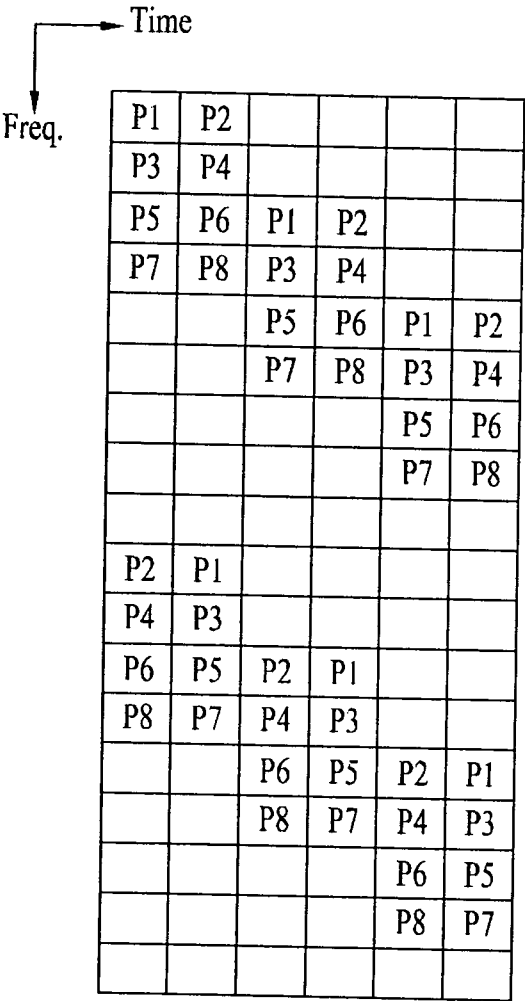


FIG. 17

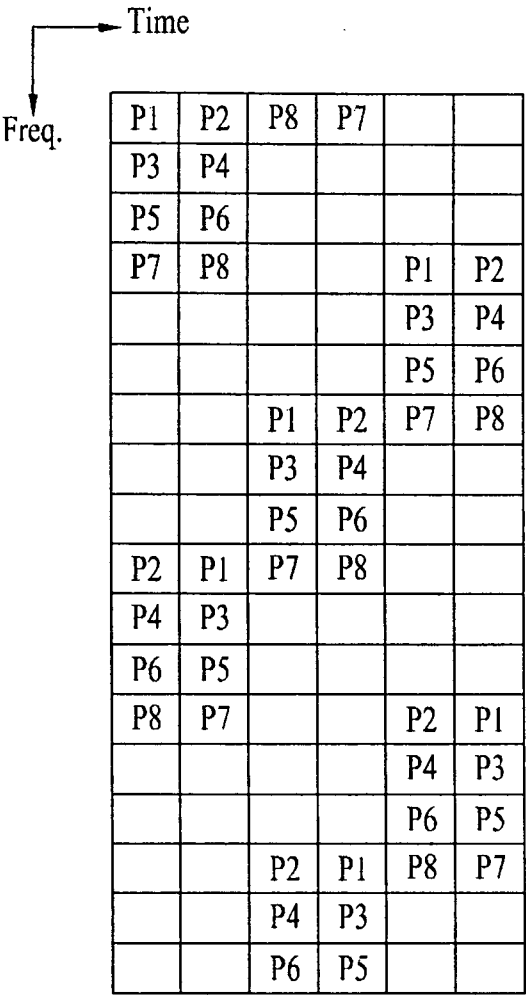


FIG. 18

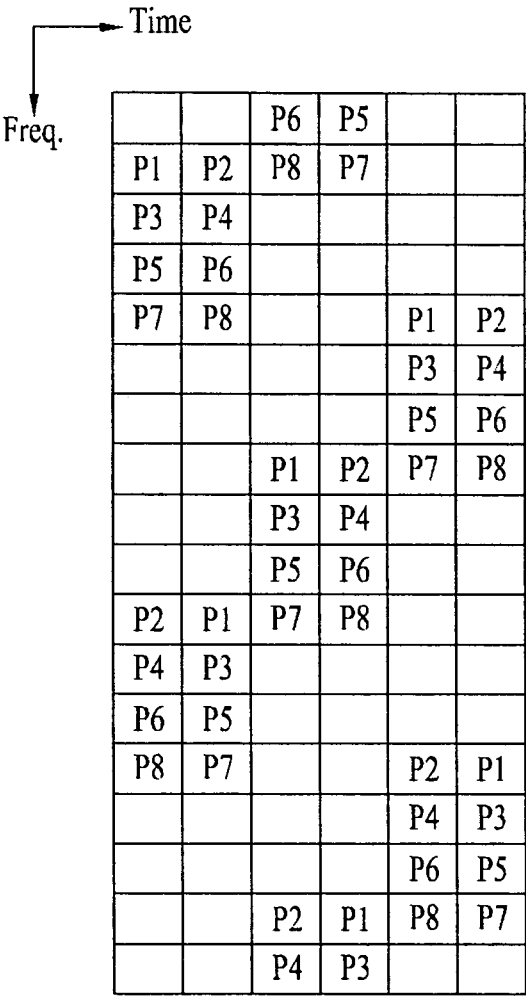






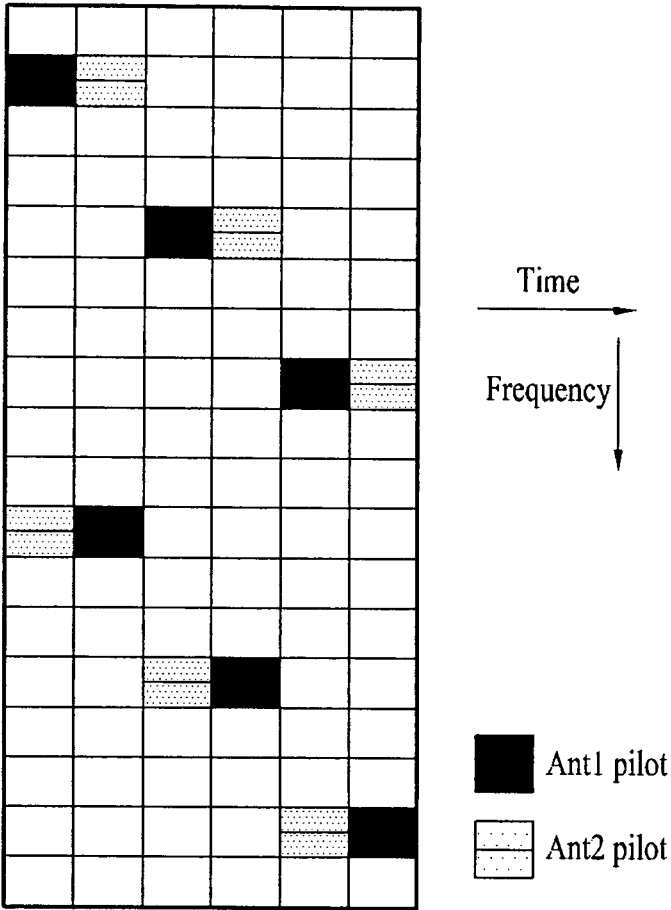




FIG. 22

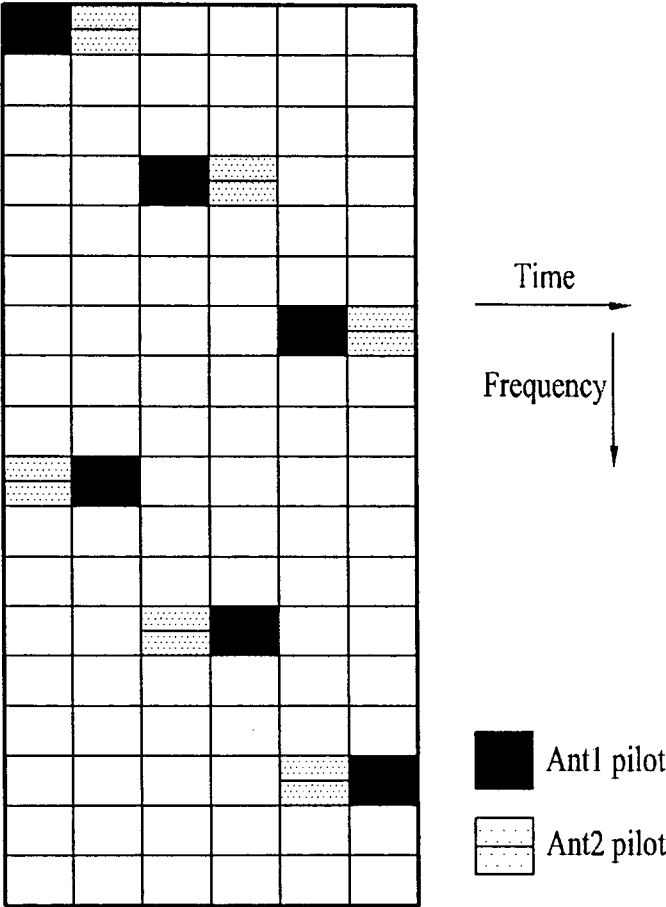
P1	P2				
P3	P4				
				P1	P2
				P3	P4
		P1	P2		
		P3	P4		
P2	P1				
P4	P3				
				P2	P1
				P4	P3
		P2	P1		
		P4	P3		

FIG. 23



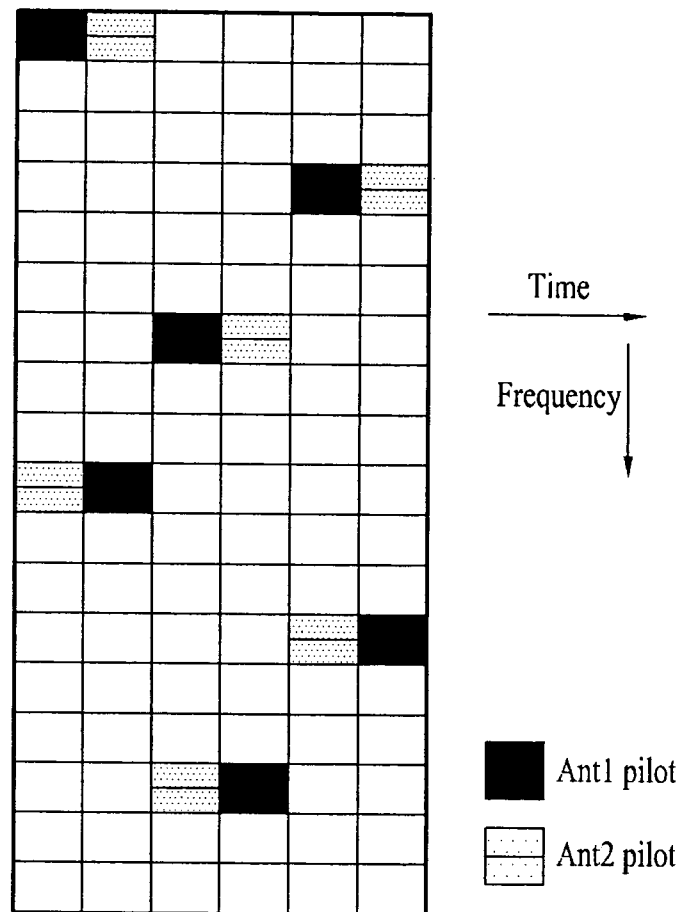
Pilot overhead : 11.11%

FIG. 24



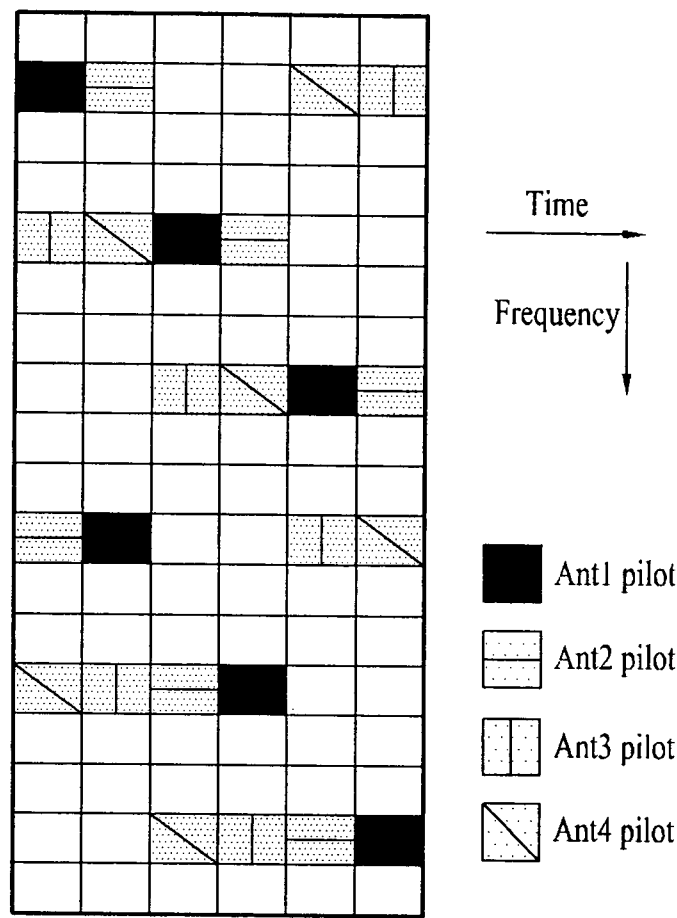
Pilot overhead : 11.11%

FIG. 25



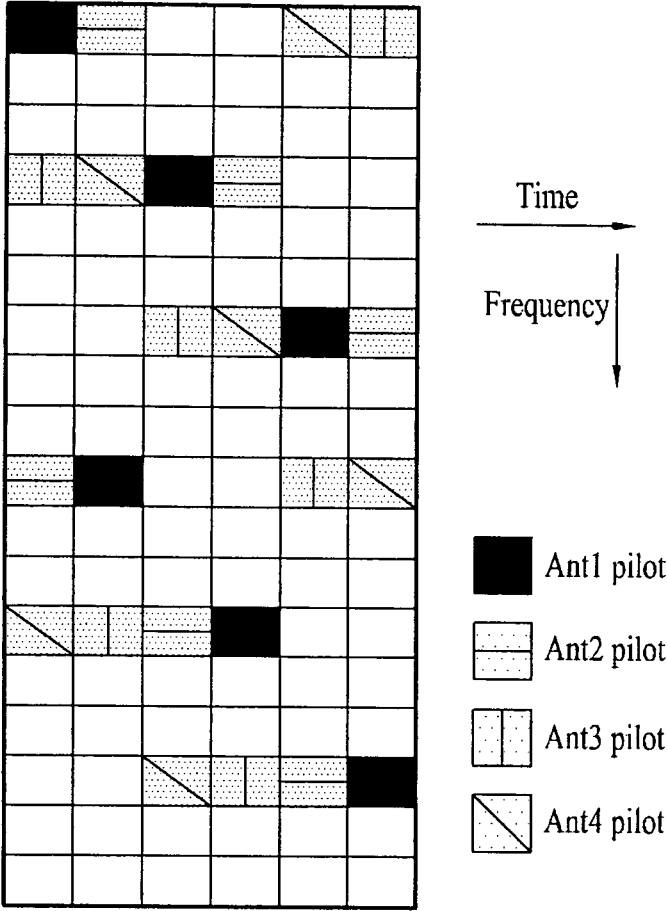
Pilot overhead : 11.11%

FIG. 26



Pilot overhead : 22.22%

FIG. 27



Pilot overhead : 22.22%



FIG. 28

P1	P2	P4	P3		
P3	P4			P1	P2
		P1	P2	P3	P4
P2	P1	P3	P4		
P4	P3			P2	P1
		P2	P1	P4	P3