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Re:	Call for Technical Comments Regarding IEEE Project P802.16j (IEEE 802.16j-07/019)	
Abstract	The document describes methods for supporting uplink transmissions of RS with multiple antennas	
Purpose	The document is provided as input for the IEEE 802.16j baseline document.	
Notice		
Release		
Patent Policy		

Uplink MIMO/Cooperative MIMO Transmissions for Relay Station with Multiple Antennas

1. Introduction

MIMO (Multiple Input Multiple Output)/cooperative MIMO techniques can greatly increase the spectrum efficiency and improve the BER (Bit-Error-Rate) performance of wireless networks by exploring the spatial domain freedom and signal processing. IEEE 802.16-2004/16e standards [1][2] have adopted MIMO/cooperative MIMO techniques for enhancing the system performance. However, the supported antenna number of MS (Mobile Station) is only 1 or 2. Therefore, in the uplink, IEEE 802.16-2004/16e standards only support MIMO/cooperative MIMO transmissions with antenna number of 1 or 2.

From the usage model [3], antenna array can be adopted by RS (Relay Station). Therefore, RS may have the same number of antennas as BS (Base Station) in IEEE 802.16-2004/16e, i.e. 3 or 4 antennas. Generally, RS serves many MSs and shall relay data of all these MSs to BS, thus the spectrum efficiency and BER performance of the relay link are very important. To improve the spectrum efficiency and BER performance of the relay link, uplink MIMO/cooperative MIMO transmissions should be supported for RS with 3 or 4 antennas.

In this contribution, a signaling method is proposed to support uplink MIMO/cooperative MIMO transmissions of RS with 3 or 4 antennas.

2. Uplink MIMO/cooperative MIMO transmissions

In IEEE 802.16-2004/16e standards [1][2], the supported transmit antenna number of MS is 1 or 2. Fig.1. shows an example of uplink transmission in IEEE 802.16-2004/16e network.

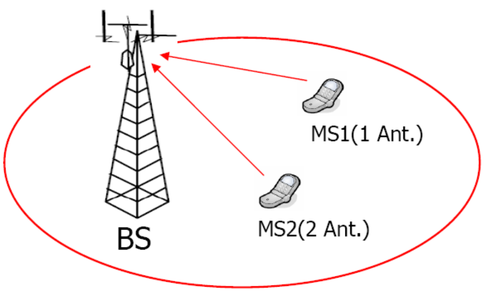


Fig. 1 Uplink transmission in IEEE 802.16-2004/16e network

The uplink MIMO/cooperative MIMO transmission in IEEE 802.16-2004/16e [1][2] mainly has the following procedure.

1) MS negotiates with BS about its uplink MIMO/cooperative MIMO capabilities.
2) MS sends request to BS for uplink transmission when it has data to be transmitted.
3) BS determines the uplink MIMO/cooperative MIMO method of MS and informs MS of the allocated resource and the MIMO/cooperative MIMO method for uplink transmission by IE (Information Element).

4) MS maps data symbols and pilot symbols to the allocated resource according to the pre-defined data mapping rules and pilot patterns indicated in the IE.

5) BS performs channel estimation and signal detection to detect the received data.

The problem with IEEE 802.16-2004/16e standards is that they can only support uplink MIMO/cooperative MIMO transmission methods for MS with 1 or 2 antennas.

Firstly, in IEEE 802.16-2004/16e, the SBC-REQ and SBC-RSP messages are used for MS to negotiate its uplink MIMO/cooperative MIMO capabilities with BS. Table.1 shows the TLV field of SBC-REQ and SBC-RSP messages in IEEE 802.16e [2]. From Table.1, it can be seen that the supported uplink MIMO/cooperative MIMO methods are only: 1) STTD (space time transmit diversity) of 2 antennas. 2) SM (spatial multiplexing) with vertical coding of 2 antennas. 3) Cooperative SM.

Therefore, the SBC-REQ and SBC-RSP messages in IEEE 802.16-2004/16e do not support RS with 3 or 4 antennas to negotiate the uplink MIMO/cooperative MIMO capabilities with BS.

Table.1 TLV field of SBC-REQ and SBC-RSP messages for MS negotiating its uplink MIMO/cooperative MIMO capabilities with BS

Type	Length	Value	Scope
157	1	Bit #0: 2-antenna STTD Bit #1: 2-antenna SM with vertical coding Bit #2: single-antenna cooperative SM Bit #3–7: *Reserved*	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

Secondly, in IEEE 802.16-2004/16e, BS informs MS of the allocated resource and the uplink MIMO/cooperative MIMO method by IEs. The main IEs for uplink MIMO/cooperative MIMO transmissions are MIMO_UL_Basic_IE and MIMO_UL_Enhanced_IE. Both of the IEs only support MIMO/cooperative MIMO method for MS with 1 or 2 antennas. If MS has more than 2 antennas, these two IEs can not be used.

Therefore, new uplink IE is needed for supporting uplink MIMO/cooperative MIMO transmissions of RS with 3 or 4 antennas.

Thirdly, in uplink MIMO/cooperative MIMO transmissions in IEEE 802.16-2004/16e, MS shall map the MIMO encoded data symbols to the tile with proper pilot patterns. Here, the MIMO encoding mainly refer to the STFC (space-time-frequency coding), which in uplink are only defined for 2 transmit antennas in IEEE 802.16-2004/16e. Therefore, there is no definitions that how to assign pilot pattern for RS with 3 or 4 antennas and how to map the MIMO encoded data (with STFC matrices defined for 3 or 4 transmit antennas) to the data subcarriers of the tile.

Therefore, pilot pattern and data mapping rule should be defined for RS with 3 or 4 antennas.

Fourthly, IEEE 802.16-2004/16e support uplink cooperative MIMO transmissions of at most two MSs. However, consider the Manhattan model as shown in Fig.2. If RS is carefully placed, it is possible for RS to have LOS (line-of-sight) channel to BS. Therefore, if four RSs can be supported to simultaneously perform uplink cooperative transmissions to BS, the spectrum efficiency will be greatly increased.

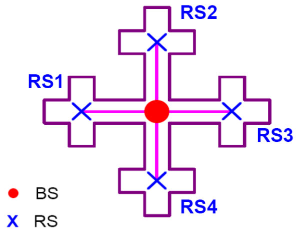


Fig.2 Manhattan Model

Consider another example shown in Fig.3. In this example, both RS 1 and RS 2 have four transmit antennas and have NLOS (non-line-of-sight) channel to BS. However, the number of the supported data streams by the two channels can be different. In this case, an efficient way to utilize the channels is that BS first measures channels of RS 1 and RS 2 to obtain the number of the supported streams of each channel. Then BS adapts the cooperative MIMO transmission method, such as C(1,3), C(2,2), C(3,1), etc., of RS 1 and RS 2. Here, $C(M_1,M_2)$ means that RS 1 uses M_1 antennas and RS 2 uses M_2 antennas in cooperative transmissions. Through this kind of channel-aware cooperative MIMO transmissions, the uplink spectrum efficiency can be greatly improved.

Therefore, the flexible channel-aware cooperative MIMO transmissions shall be supported for RSs, which is not supported by IEEE 802.16-2004/16e.

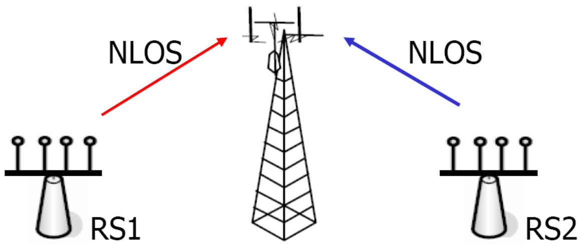


Fig.3 Cooperative MIMO transmission according to the channel conditions

3. Proposed Method

The proposed method aims at providing a signaling method to support uplink MIMO/cooperative MIMO transmissions of RS with 3 or 4 antennas. To this end, the following functions are needed.

Firstly, a method should be provide for RS with 3 or 4 antennas to negotiate its MIMO/cooperative MIMO capabilities with BS. This target can be achieved on the basis of SBC-REQ and SBC-RSP messages. A new TLV field can be added to support the negotiation of MIMO/cooperative MIMO capability between RS and BS.

Secondly, concrete MIMO/cooperative MIMO coding matrices of 3 or 4 transmit antennas should be defined for uplink transmissions.

Currently, IEEE 802.16-2004/16e standards support BS with 3 or 4 antennas. Therefore, some MIMO coding matrices of 3 or 4 transmit antennas have been defined for downlink. Although new MIMO coding matrices can be defined, these downlink MIMO coding matrices are preferred to be reused for the uplink. The detailed formats of the downlink MIMO coding matrices are defined in subclasues 8.4.8.3.3, 8.4.8.3.4 and 8.4.8.3.5 [1][2].

Thirdly, IE should be defined to inform RS of the used uplink MIMO/cooperative MIMO methods and the allocated resource. The IE should be very flexible to support all kind of MIMO methods, such as spatial multiplexing, STFC, etc, and channel-aware cooperative MIMO transmissions. Such an IE is provided, as is shown in the text proposal. The supported uplink MIMO/cooperative MIMO transmission methods are shown in Table.2. In Table.2, $C(M_1,M_2,\ldots,M_N)$ means that there are N RSs involved in the uplink cooperative MIMO transmission, the first RS uses M_1 antennas, the second RS uses M_2 antennas, …, and the N^{th} RS uses M_N antennas.

Table.2 The supported MIMO/cooperative MIMO transmission methods

UL MIMO Modes	2 Ant. RS	3 Ant. RS	4 Ant. RS
Spatial Multiplexing	Matrix B and C	Matrix C with antenna selection	Matrix C with antenna selection
Space-time-frequency Coding	Matrix A	Matrix A1, A2 and A3 Matrix B1, B2 and B3	Matrix A1, A2 and A3 Matrix B1, B2, B3, B4, B5 and B6
Cooperative MIMO	$C(1,1), C(1,2), C(2,1), C(2,2), C(1,3), C(3,1), C(1,1,1), C(1,1,2), C(1,2,1), C(2,1,1), C(1,1,1,1)$		

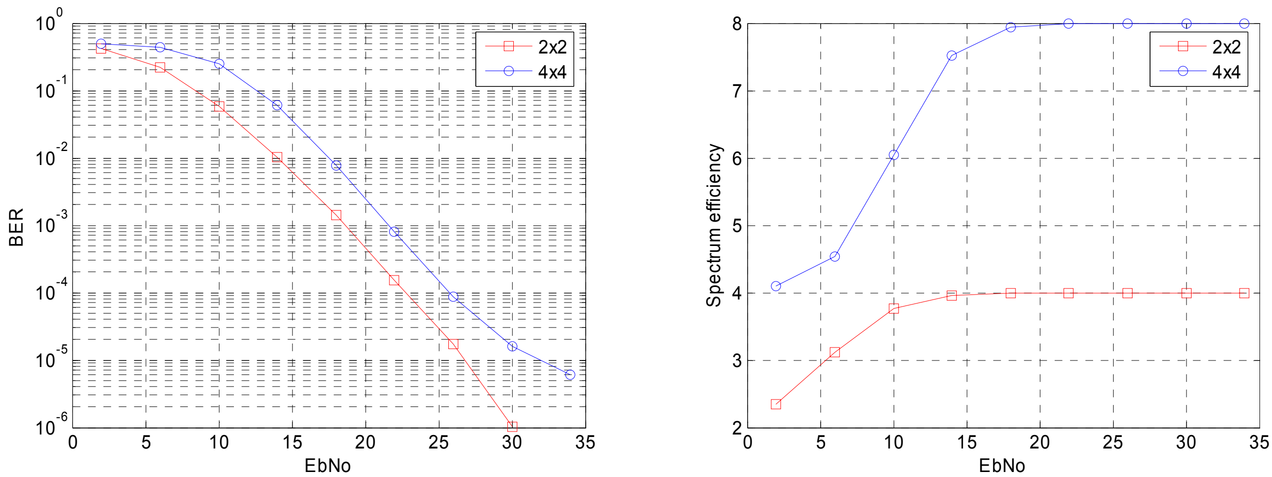
Fourthly, pilot pattern used by different transmit antenna should be defined RS. Four kinds of pilot patterns, i.e. pilot pattern A, pilot pattern B, pilot pattern C and pilot pattern D, have been defined in IEEE 802.16-2004/16e. It is restricted that that single-antenna MS can only use either pilot pattern A or pilot pattern B [1][2]. To enable flexible channel-aware cooperative MIMO transmissions, this restriction should be removed for RS. In the proposed method, if RS only uses one antenna for uplink transmission, any of the four pilot patterns can be used. The used pilot pattern is determined by BS and informed by IE. When the used antenna number of RS is three, the first antenna shall use pilot pattern A, the second antenna shall use pilot pattern B and the third antenna shall use pilot pattern C. When the used antenna number of RS is four, the first antenna shall use pilot pattern A, the second antenna shall use pilot pattern B, the third antenna shall use pilot pattern C and the forth antenna shall use pilot pattern D.

Fifthly, data mapping rules should be defined to map the data symbols after MIMO encoding to the tile. For MIMO coding matrices of 2 transmit antennas, the data mapping can follow the same way as defined in subclause 8.4.8.1.5. However, for MIMO coding matrices of 3 or 4 transmit antennas, new data mapping rule should be provided. There are two concerns of the data mapping rule. First, when the channel changes fast in time and/or frequency domain, the data mapping rules should enable the maximization of the space-time-frequency diversity. Second, all of the MIMO coding matrices contained in the same tile should have the similar performance so as to enable easy scheduling. Such a data mapping rule is provided in the text proposal.

Simulations are performed to verify whether channel estimation on the basis of current pilot patterns [1][2] can support four-streams data transmission or not and to show the advantages of the 4-antenna UL transmission compared with original 2-antenna UL transmissions.

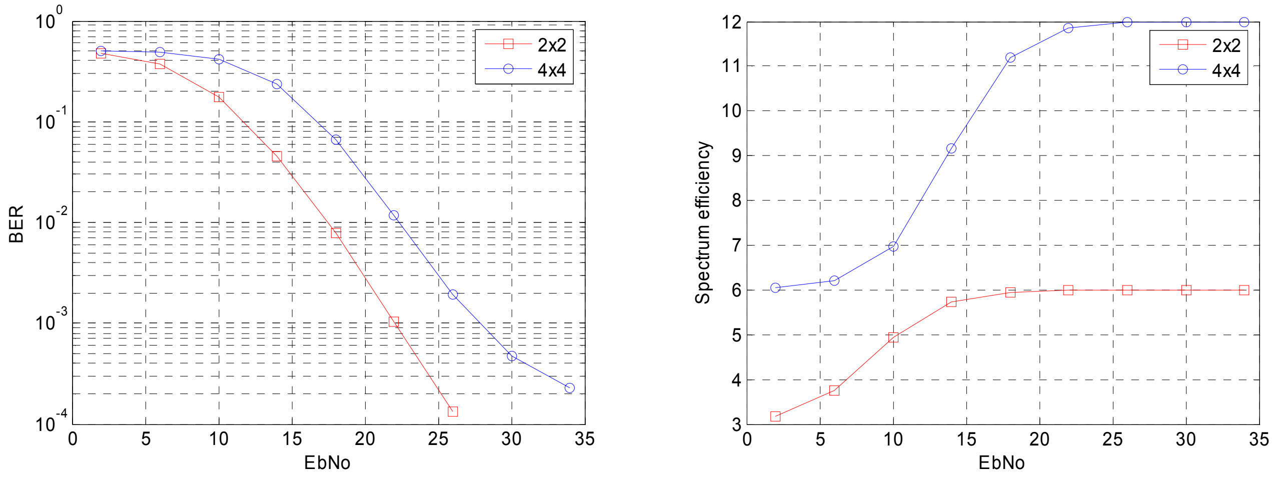
Two kinds of antenna configurations are simulated, one is both BS and RS have 2 antennas, the other is both BS and RS have 4 antennas. The channels used in simulations are SUI-3 channel model in [4]. The modulations in simulations are 16QAM and 64QAM because relay link generally will have good channel qualities and thus should support high order modulations. Convolutional channel coding and interleaver are the same as IEEE 802.16-2004 standard [1], to be specific, the convolutional coding with generator polynomial $(171, 133)_{OCT}$ is used and code rate is fixed to 1/2 in the simulations. The subcarrier permutation is PUSC, and data and pilots are mapped to sub-carriers according to the structure of tile in IEEE 802.16e standard [2]. For 2 antenna transmissions, antenna 1 uses pilot pattern A and antenna 2 uses pilot pattern B. For 4 antenna transmissions, different transmit antennas use different pilot patterns, i.e. transmit antenna 1 uses pilot pattern A, transmit antenna 2 uses pilot pattern B, transmit antenna 3 uses pilot pattern C and transmit antenna 4 uses pilot pattern D. In the simulation, at the transmitter, independent data streams are transmitted from different transmit antennas, i.e. spatial multiplexing. At the receiver, the MMSE receiver with soft-output [5] is utilized for signal detection and Viterbi algorithm is adopted for channel decoding. The channel estimation algorithm is the classic LS (least square) channel estimation for both 2x2 and 4x4 systems.

The performances of 2x2 and 4x4 spatial multiplexing transmissions are shown in the Fig.4 and Fig.5 for 16QAM and 64QAM respectively. From the simulation results, it can be seen that: 1) Current uplink pilot patterns in 16e can support four data streams transmissions. 2) The spectrum efficiency of 4x4 system is almost doubled compared with 2x2 system for both cases.



(a) (b)

Fig.4 Performance of 2x2 and 4x4 UL transmissions, 16QAM: (a)BER (b)Spectrum efficiency



(a) (b)

Fig.5 Performance of 2x2 and 4x4 UL transmissions, 64QAM: (a)BER (b)Spectrum efficiency

The advantages of the proposed scheme are:

1) High flexibility.

All kinds of MIMO/cooperative MIMO transmission methods, such as spatial multiplexing, STFC, antenna selection and grouping, etc., are supported. The spectrum efficiency and BER performance of the relay link can be greatly improved by flexibly utilizing these kinds of MIMO/cooperative MIMO transmission schemes.

2) Full compatibility.

The uplink MIMO related IEs of IEEE 802.16-2004/16e can be used for MS. The proposed IE is used for RS. The proposed method has no impact on the usage of the existing uplink MIMO related IEs of IEEE 16-2004/16e and requires no modifications of MSs.

4. Summary

RS serves many MSs and shall relay data of all these MSs to BS, thus the spectrum efficiency and BER performance of the relay link are very important. To increase the spectrum efficiency and BER performance of the relay link, uplink MIMO/cooperative MIMO transmissions shall be supported for RS with 3 or 4 antennas.

5. Proposed Text

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8.4.5.4.4.1 UL-MAP extended IE format

[change Table 290a(.16e)/Table 427(Rev2) as indicated]

Table 427——Extended UIUC Code Assignment for UIUC=15

Extended UIUC (hexadecimal)	Usage
00	Power_control_IE
01	Mini-subchannel_allocation_IE
02	AAS_UL_IE
03	CQICH_Alloc_IE
04	UL Zone IE
05	PHYMOD_UL_IE
06	MIMO_UL_Basic_IE
07	UL-MAP_Fast_Tracking_IE
08	UL_PUSU_Burst_Allocation_in_Other_Segment_IE
09	Fast_Ranging_IE
0A	UL Allocation Start IE
0B	RS-RNG_RSP_Allocation_IE
0C	UL_Burst_Receive_IE
~~0D…0F~~ 0D	~~*Reserved*~~ MIMO_UL_Extended_IE
0E0F	*Reserved*

[Insert new subclause 8.4.5.4.31]

8.4.5.4.31 MIMO UL Extended IE format

In the UL-MAP, a MIMO-enabled MR-BS shall transmit MIMO_UL_Extened_IE to RS to indicate the MIMO configuration and pilot patterns of the subsequent uplink allocations described in this IE. This IE may be used either for MIMO-enabled RS or for an RS that supports only collaborative SM.

Table 320w——MIMO UL Extended IE format

Syntax	Size	Notes
MIMO_UL_Extended_IE() {		
Extended UIUC	4bits	MIMO_UL_Extended_IE()= 0x0D
Length	8bits	variable
Num_Assign	4bits	Number of burst assignment
For (j=0;j<Num_assign;j++) {		
Num_CID	2bits	
For (i=0; i<Num_CID; i++) {		
CID	16bits	RS basic CID
UIUC	4bits	
Antenna_Indicator	4bits	Indicates the antennas used for transmission 0: antenna is not used 1: antenna is used
If (single antenna is used) {		
Pilot Pattern Indicator	2bits	Indicates pilot pattern 0b00: pilot pattern A 0b01: pilot pattern B 0b10: pilot pattern C 0b11: pilot pattern D
}elseif (dual antennas are used){		
Matrix_Indicator	2bits	Indicates transmission matrix 0b00= Matrix A (see 8.4.8.3.3) 0b01= Matrix B (see 8.4.8.3.3) 0b10= Matrix C (see 8.4.8.3.3) 0b11= *Reserved*
Pilot Pattern Indicator	1bits	0: pilot pattern A/B 1: pilot pattern C/D
}elseif (three antennas are used){		
Matrix_Indicator	2bits	Indicates transmission matrix 0b00= Matrix A (see 8.4.8.3.4) 0b01= Matrix B (see 8.4.8.3.4) 0b10= Matrix C (see 8.4.8.3.4) 0b11= *Reserved*
If (Matrix_Indicator==0b00 or 0b01) {		

Antenna_Grouping_Indicator	2bits	Indicating the index of the antenna grouping index
		if (Matrix_indicator== 0b00)
		0b000~0b010=0b101110~0b110000 in table 298g
		else
		0b000~0b010=0b110001~0b110011 in table 298g

}		
}else{		
Matrix_Indicator	2bits	Indicates transmission matrix 0b00= Matrix A (see 8.4.8.3.5) 0b01= Matrix B (see 8.4.8.3.5) 0b10= Matrix C (see 8.4.8.3.5) 0b11= *Reserved*
If (Matrix_Indicator== 0b00 or 0b01) {		

Antenna Grouping Index	3bits	Indicating the index of the antenna grouping index
		if (Matrix_indicator== 0b00)
		0b000~0b010=0b101110~0b110000 in table 298g
		else
		0b000~0b101=0b110001~0b110110 in table 298g

}		
}		
}		
Duration	10bits	In OFDMA slots (see 8.4.3.1)
}		
Padding		
}		

Antenna_Indicator: A field that specifies which antenna(s) is/are used for uplink transmission. For example, if this field is set to 0b1100, a 3-antenna RS will use the first and second antenna for uplink transmissions. The last bit, which shall be set to zero in this case, is skipped.

Pilot Pattern Indicator: A field that specifies which pilot pattern(s) is/are used. When the used antenna number is three, the first antenna shall use pilot pattern A, the second antenna should use pilot pattern B and the third antenna should use pilot pattern C. When the used antenna number is four, the first antenna shall use pilot pattern A, the second antenna should use pilot pattern B, the third antenna should use pilot pattern C and the forth antenna shall use pilot pattern D.

Matrix_Indicator: A field that specifies the used MIMO coding matrices, i.e. space-time-frequency coding matrices, for uplink. All the uplink MIMO coding matrices in this IE are reused from the downlink, which are defined in 8.4.8.3.3, 8.4.8.3.4 and 8.4.8.3.5.

8.4.8.1.5 Uplink using STC

[Insert the following sentences and figures at the end of 8.4.8.1.5]

For RS using three antennas, the MIMO coding matrices defined in 8.4.8.3.4 shall be mapped to the tile according to Figure 249b.

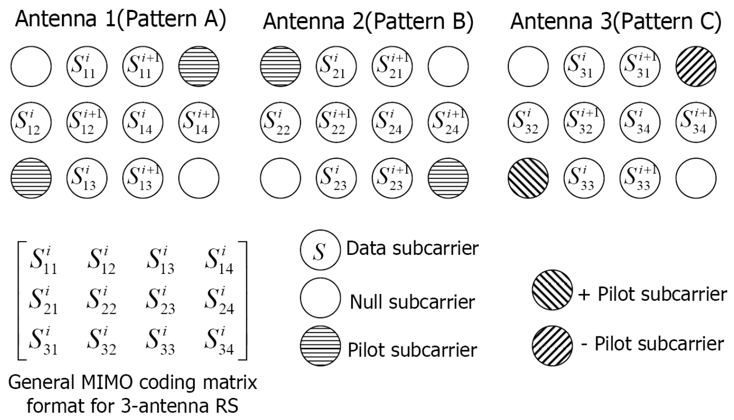

Figure 249b Mapping of data subcarriers for 3-antenna RS

For RS using four antennas, the MIMO coding matrices defined in 8.4.8.3.5 shall be mapped to the tile according to Figure 249c.

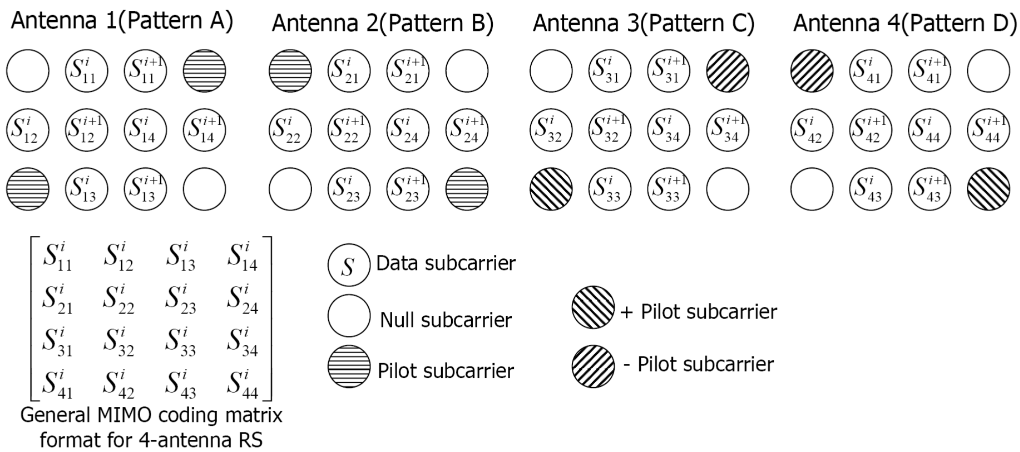

Figure 249c Mapping of data subcarriers for 4-antenna RS

[Insert new subclause 11.8.3.7.25]

11.8.3.7.25 OFDMA RS MIMO uplink support

This field indicates the different MIMO options supported by a RS in the uplink when RS has three or four transmit antennas. A bit value of 0 indicates "not supported" while 1 indicates "supported". The TLV field defined in 11.8.3.7.6 shall be used when RS has one or two transmit antennas. In the following TLV field, all the STFC matrices are reused from downlink. The detailed matrix formats are shown in 8.4.8.3.3, 8.4.8.3.4, 8.4.8.3.5. If bit #11 in the TLV files is set to 1, i.e. Cooperative SM is supported, RS shall support not only pilot pattern A and pilot pattern B but also pilot pattern C and pilot pattern D when single antenna is used for uplink transmission.

Type	Length	Value	Scope
TBD	2	Bit #0: 3-antenna STFC matrix A Bit #1: 3-antenna STFC matrix B, vertical coding Bit #2: 3-antenna STFC matrix C, vertical coding Bit #3: 3-antenna STFC matrix C, horizontal coding Bit #4: 4-antenna STFC matrix A Bit #5: 4-antenna STFC matrix B, vertical coding Bit #6: 4-antenna STFC matrix B, horizontal coding Bit #7: 4-antenna STFC matrix C, vertical coding Bit #8: 4-antenna STFC matrix C, horizontal coding Bit #9: Capable of antenna selection Bit #10: Capable of antenna grouping Bit #11: Cooperative SM Bit #12-15: *Reserved*	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

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6. References

[1] IEEE Standard for Local and Metropolitan area networks, Part 16: Air Interference for Fixed Broadband Wireless Access Systems. Oct. 2004

[2] IEEE Standard for Local and metropolitan area networks 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. Feb. 2006

[3] IEEE 802.16j-06/015, Harmonized Contribution on 802.16j (Mobile Multihop Relay) Usage Models. Sept. 2006

[4] IEEE 802.16j-06/013r3, Multi-hop Relay System Evaluation Methodology (Channel Model and Performance Metric). Feb, 2007.

[5] D. Seethaler, G. Matz and F. Hlawatsch, "An efficient MMSE-based demodulator for MIMO bits-interleaved coded modulation", Global Telecommunications Conference, vol.4, issue. 29 pp: 2455-2459, Nov. 2004.