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Title	**Enhancement of STC/MIMO Pilots**
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Re:	STC/MIMO Pilots Enhancement
Abstract	Proposing new STC/MIMO pilot structure for IEEE P802.16e/D5-2004
Purpose	To enhance STC/MIMO performance
Notice	
Release	
Patent Policy and Procedures	

Enhancement of STC/MIMO Pilots

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1. Problem Statement

Pilots are used for channel estimation and tracking which is critical in mobile channels environment. Without reliable and accurate channel estimation the performance of STC/MIMO will be greatly compromised. Unlike in the standard (non STC/MIMO) mode, the pilot placement in STC/MIMO mode is inadequate in the current adopted IEEE802.16REVd/D5-2004, which greatly limits the effectiveness of the pilots in the moderate to long multi-path delay channels. To overcome this deficiency in the current standard and fully utilize the potential gain provided by STC/MIMO in a wider range of channel environment, an improved set of pilots in STC/MIMO is needed.

2. Proposed solutions

In this contribution, we propose an improved set of pilots in STC/MIMO mode. In STC/MIMO mode, pilots are currently placed every 12 subcarriers apart in both FUSC and PUSC modes. If 1024 FFT is used for BW=10MHz, subcarrier spacing is about 10kHz. In this case, the path delay must be less than about 4us for Nyquist sampling rate, or 2us for 2x oversampling rate[2]. This greatly limits the effectiveness of the pilots for channels with longer path delay, common in cellular deployment. The new pilot set can be adopted to solve this problem and at the same time maintaining low overhead.

To balance the overhead and effectiveness of the pilots, in this design the reference point is set at maximum path delay of 20us, as specified in SUI-6 channel model, which corresponds to 6km path difference, and maximum Doppler frequency of 347Hz, which corresponds to vehicular speed of 150km/hr at carrier frequency of 2.5GHz. The subcarrier is about 11 KHz, assuming scalable OFDMA is being used. We hope this set of parameters will cover most of the application scenarios.

Based on this reference point, we need to place a pilot every 9 and 4.5 sub-carriers in frequency domain, and 20 and 10 symbols in time domain (assuming symbol time 100us and scalable OFDMA is in place), for Nyquist and 2x oversampling rate, respectively. In the sequel, we will adopt the 2x oversampling rate in our reference design.

2.1. Existing STC/MIMO pilots in FUSC mode

In FUSC, the pilots are divided into two major groups, the constant and variable ones, respectively. The constant one is uniformly distributed over the entire BW whereas the variable one is permutated then distributed much denser in frequency domain. Figure 1 and 2 show a segment of the pilot and data allocation over some symbol periods and subcarriers, of a single antenna in a two and four antenna STC/MIMO mode, respectively. The pilots and data are allocated in a similar fashion. Colors in the figure: Black, gray and white represent pilots, data and null allocations (the null allocations are necessary to prevent pilots collision from adjacent antenna). The non-broken pilots are from to the constant pilots set. As we can see from the figure that in time (symbol) domain, there is a pilot for every other symbol and in the frequency domain, there is a pilot for about every 12 sub-carriers.

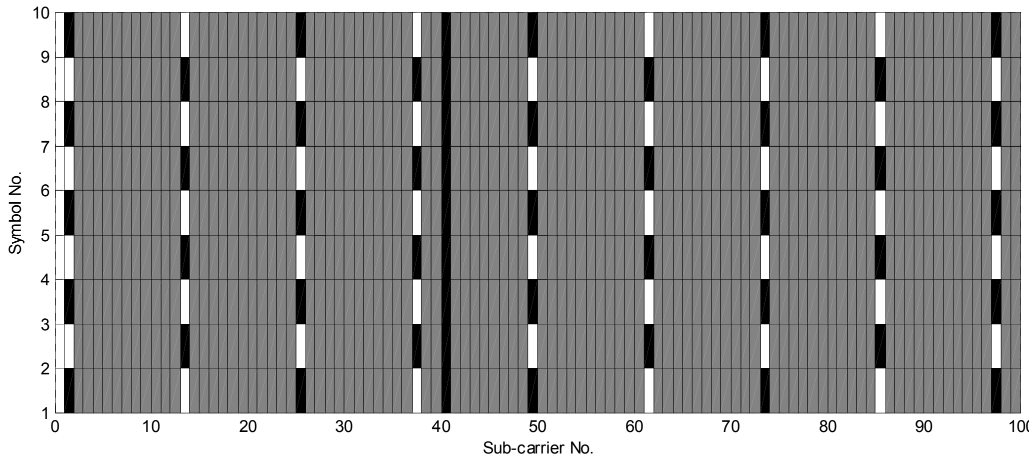

Fig. 1 Pilots placement in DL FUSC for one of the 2 Tx antennas

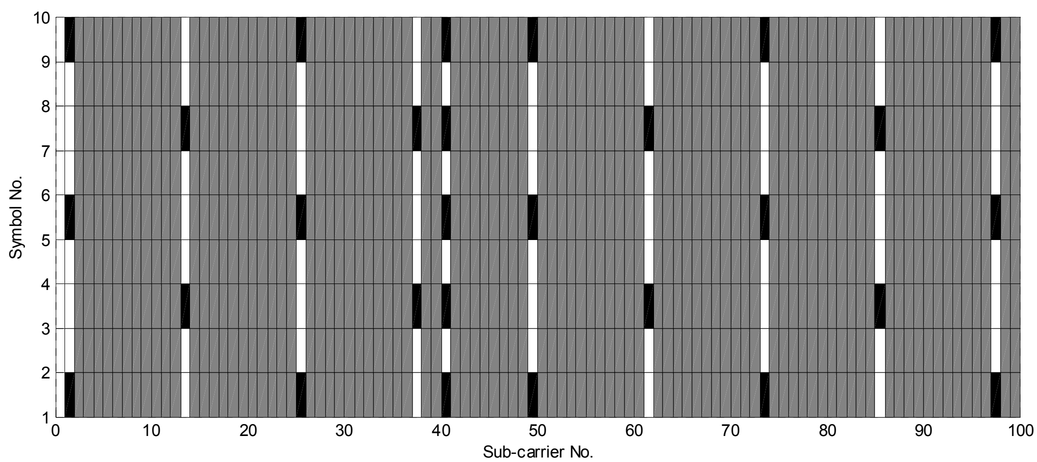

Fig. 2 Pilots placement in DL FUSC for one of the 4 Tx antennas

2.2. Existing STC/MIMO pilots in PUSC mode

In the PUSC mode, pilots are allocated within clusters, as shown in Fig. 3 and 4 for two and four transmit antennas, respectively.

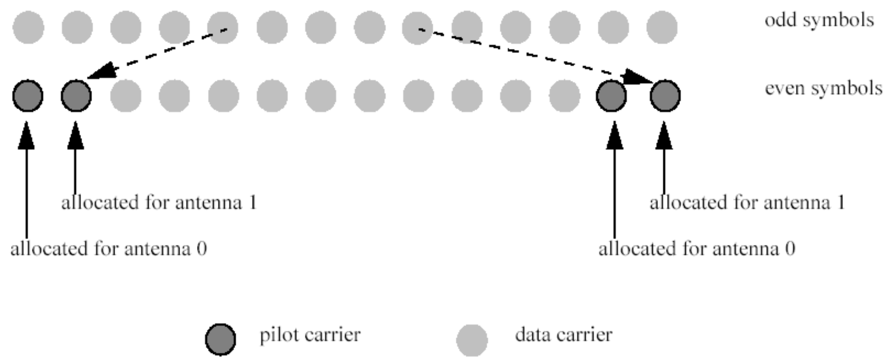

Fig. 3 Clusters and pilots placement in DL PUSC for 2 Tx antennas

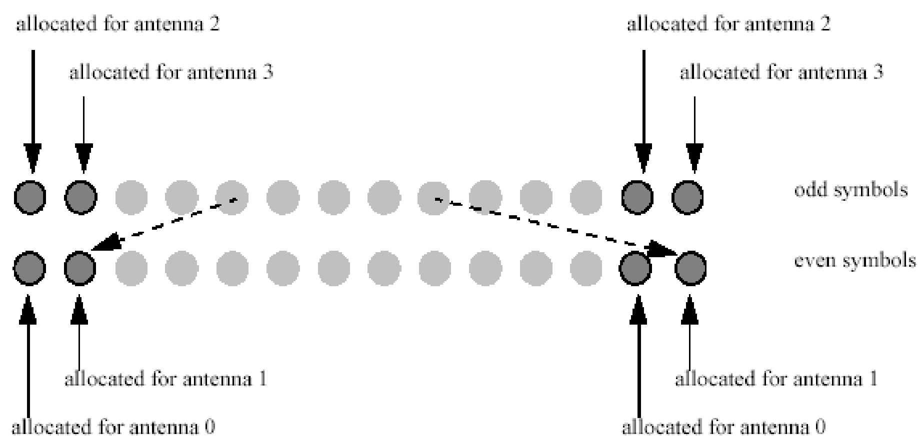

Fig. 4 Clusters and pilots placement in DL PUSC for 4 Tx antennas

3. Improved pilot allocations in STC/MIMO

As we have seen from above discussions, the existing pilot allocation in either FUSC or PUSC is inadequately allocated. In the following we propose improved pilot allocations.

For optimal pilot placement with minimum overhead and satisfying 2x oversampling, a pilot is required for every 4 or 5 sub-carriers in the frequency domain and up to 10 OFDMA symbol periods in the time domain, based on 2x oversampling and for long delay and fast time-varying channel conditions.

3.1. FUSC mode:

To minimize the change, we use the same variable and constant pilot set, as specified in Table-309 of [1]. The proposed solutions are as follows.

The location for the constant pilot sets remain unchanged but the locations for the variable sets are modified as following:

(a) For two antennas

In FUSC all sub-channels shall be used for STC/MIMO transmission, the pilots within the symbols shall be divided between the antennas: antenna 0 uses VariableSet#0 and ConstantSet#0 for even symbols while antenna 1 uses VariableSet#1 and ConstantSet#0 for odd symbols (symbol counting starts at the starting point of the relevant STC/MIMO zone). In addition, the pilot location shall satisfy the following formula:

$$PilotsLocation = VariableSet\#x + 4 \cdot \left[floor(FUSC\_SymbolNumber/2) \bmod 3 \right] \quad (1)$$

where *floor*(x) is the floor function, the largest integer small or equal to x. The following table shows the pilot location for the first few symbol periods:

Table 1. Pilot placement for two antennas

FUSC_SymbolNumber	Pilot location for ant 0	Pilot location for ant 1
0	VariSet#0	VariSet#1
1	VariSet#1	VariSet#0
2	VariSet#0+4	VariSet#1+4
3	VariSet#1+4	VariSet#0+4
4	VariSet#0+8	VariSet#1+8
5	VariSet#1+8	VariSet#0+8
6	VariSet#0	VariSet#1
7	VariSet#1	VariSet#0
8	VariSet#0 +4	VariSet#1+4

(b) For four antennas

Similar to the two-antenna case, pilots shall be transmitted with a structure including 4 times symbol, as follows:

Symbol 0: ant 0 users VariSet#0 and ConstSet#0, ant 1 a users VariSet#1 and ConstSet#1;
Symbol 1: ant 2 users VariSet#0 and ConstSet#0, ant 3 a users VariSet#1 and ConstSet#1;
Symbol 2: ant 0 users VariSet#1 and ConstSet#0, ant 1 a users VariSet#0 and ConstSet#1;
Symbol 3: ant 2 users VariSet#1 and ConstSet#0, ant 3 a users VariSet#0 and ConstSet#1;

In addition, pilots shall also satisfy the following formula:

$$PilotsLocation = VariableSet\#x + 4 \cdot \left[floor(FUSC\_SymbolNumber/4) \bmod 3 \right] \quad (2)$$

The pilot placement for the first few symbol periods is given in the following table:

Table 2. Pilot placement for four antennas

FUSC_SymbolNumber	Ant 0	Ant 1	Ant 2	Ant 3
0	VariSet#0	VariSet#1	null	null
1	null	null	VariSet#0	VariSet#1
2	VariSet#1	VariSet#0	null	null
3	null	null	VariSet#1	VariSet#0

4	VariSet#0+4	VariSet#1+4	null	null
5	null	null	VariSet#0+4	VariSet#1+4
6	VariSet#1+4	VariSet#0+4	null	null
7	null	null	VariSet#1+4	VariSet#0+4
8	VariSet#0+8	VariSet#1+8	null	null

PUSC mode:

In PUSC mode, we propose an improved pilot allocation for two and four antennas, respectively, in Figure 5 and 6. Color definition: white and colored circles represent data and pilots, respectively.

Option 1:

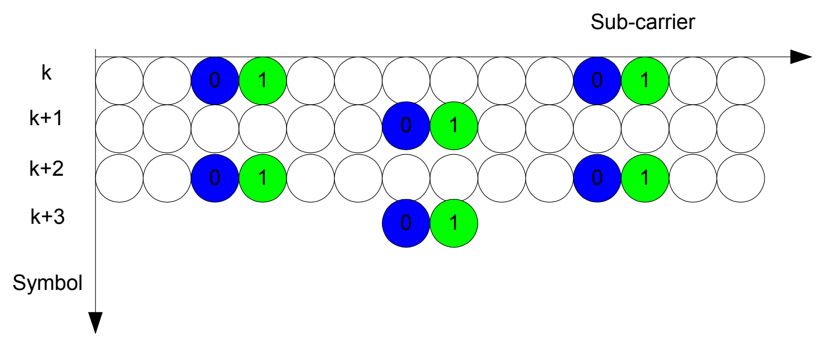

Fig. 5 Proposed pilots scheme for STC/MIMO 2 antenna systems

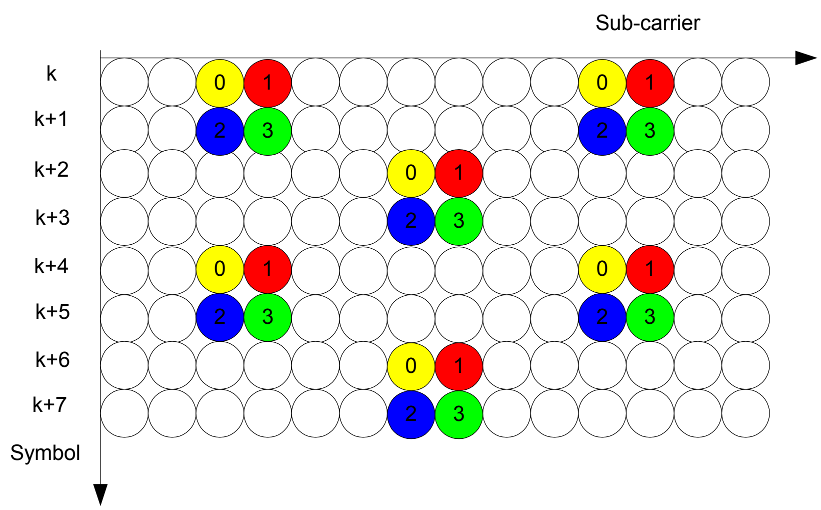

Fig. 6 Proposed pilots scheme for STC/MIMO 4 antenna systems

The overhead for the proposed pilot set is the same for two and four antennas, about 20%. In comparison with the original ones, the overhead is about 14% and 28% for two and four antennas, respectively.

Option 2:

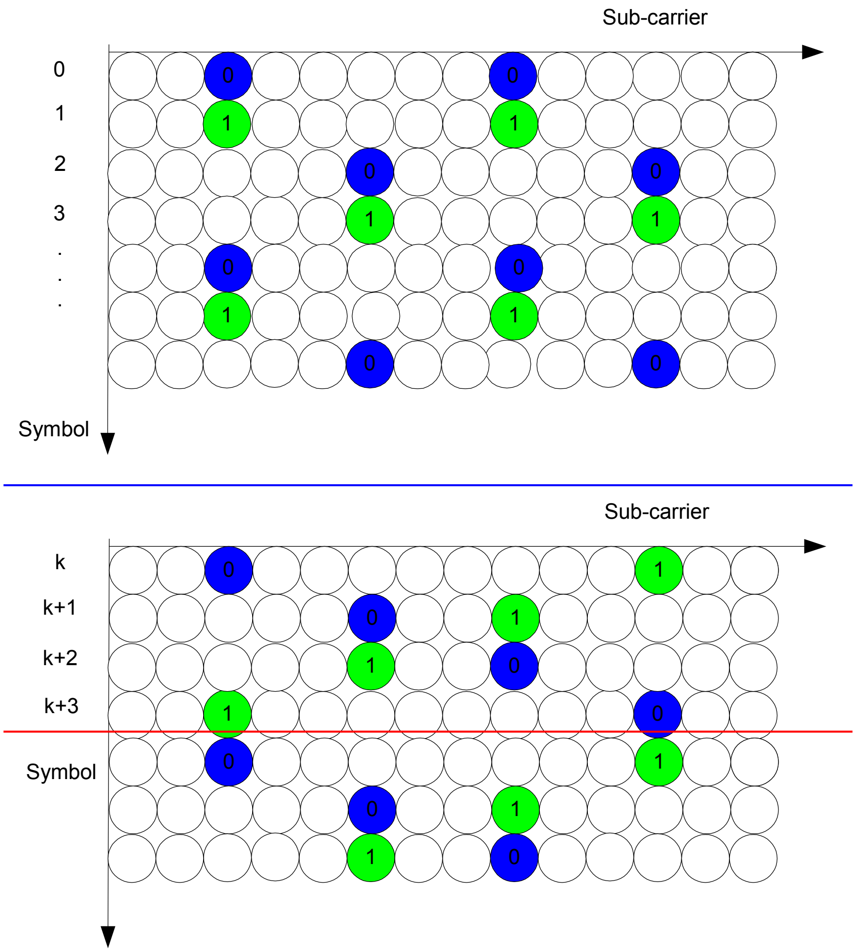

Fig. 7 Proposed pilots scheme for STC/MIMO 2 antenna systems

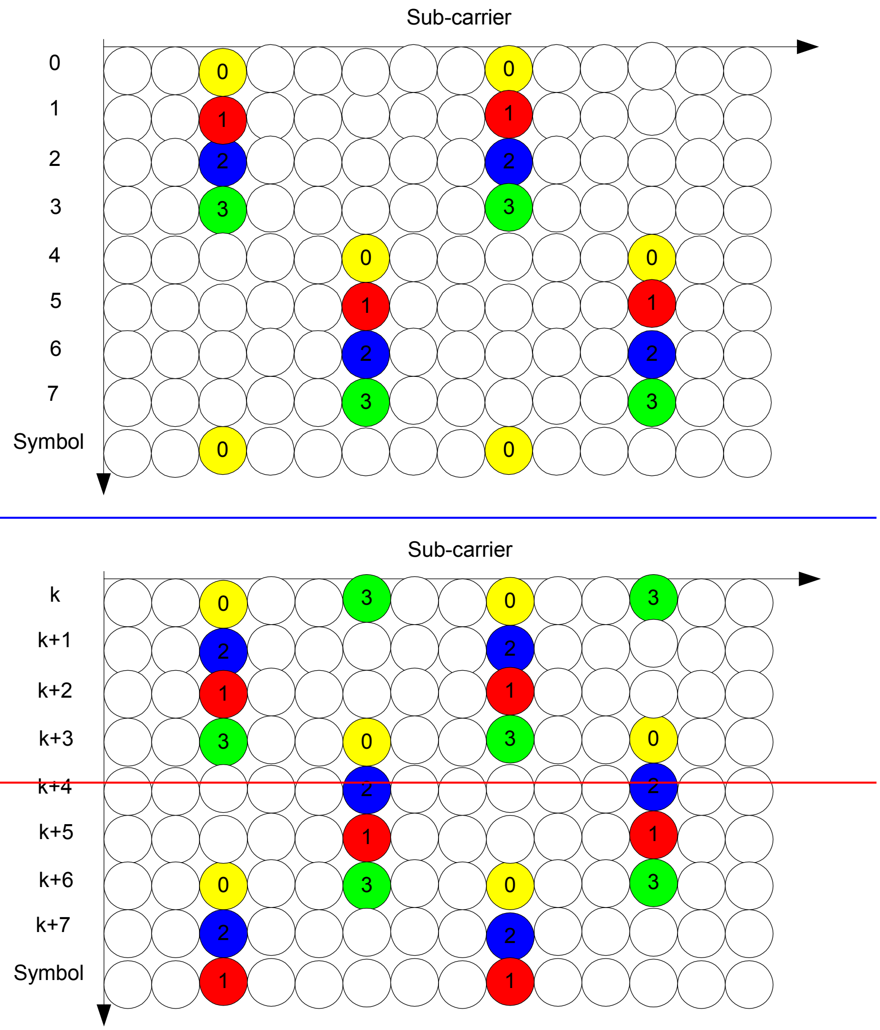

Fig. 8 Proposed pilots scheme for STC/MIMO 4 antenna systems

The overhead for the proposed pilot set is the same for two and four antennas, about 20%. In comparison with the original ones, the overhead is about 14% and 28% for two and four antennas, respectively.

Option 3:
Further overhead reduction is straightforward. One solution is to reduce time domain pilot density, as shown in Figure 9 below.

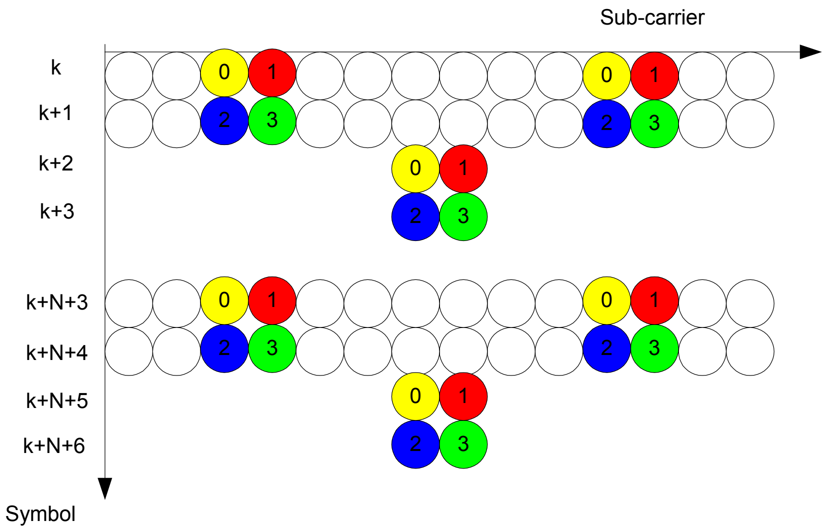

Fig. 9 Alternative proposed pilot scheme for STC/MIMO 4 Tx antenna systems. (It can be easily modified for 2 Tx antennas case).

In Figure 9, the time spacing N (≥ 1) between the pilot sets specifies the overhead; a larger N results in a lower overhead but reduces its effectiveness against time varying channel conditions. Default value of N is set to 1. If N is to set greater than 1, a new STC/MIMO IE can be introduced to specify its value.

4. Specific text changes

[*Add the following text to modify section* ***8.4.8.1.2.1.1 STC using 2 antennas in PUSC***]

=== Start text changes ====

The clusters composing the subchannels used by the STC mode shall be allocated and subcarriers numberd as defined in 8.4.6.2. The cluster structure of the subchannels allocated for STC is slightly modified to fit the STC requirments. The structure shall be modified as depicted in Figure 245 (switching 2 pilot carriers ~~from the odd symbol~~ with 2 data carriers ~~from the even symbols~~at each symbol time, switching of the data carriers and the pilots carriers shall be performed after constellation mapping, therefore maintaining all the encoding scheme and the subchannel allocation scheme). The minimum data burst shall be multiple of 2 symbol periods. In this scheme, transmission on regular subchannels and STC subchannels is possible and is determined by the MAC layer (the allocation is performed by allocating major groups of subchannels for regular or STC transmission). The trasnmission of the data shall be performed in pairs of symbols as illustrated in Figure 246.

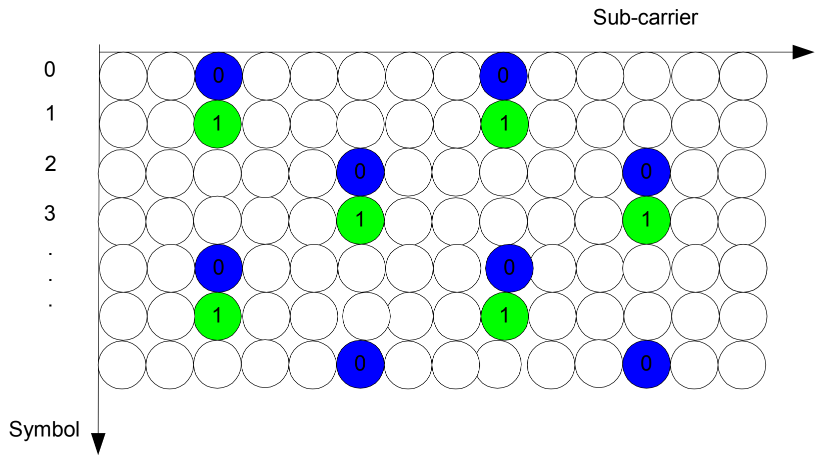

Fig. 245-Cluster structure (colored circles represent pilots with antenna index 0 and 1)

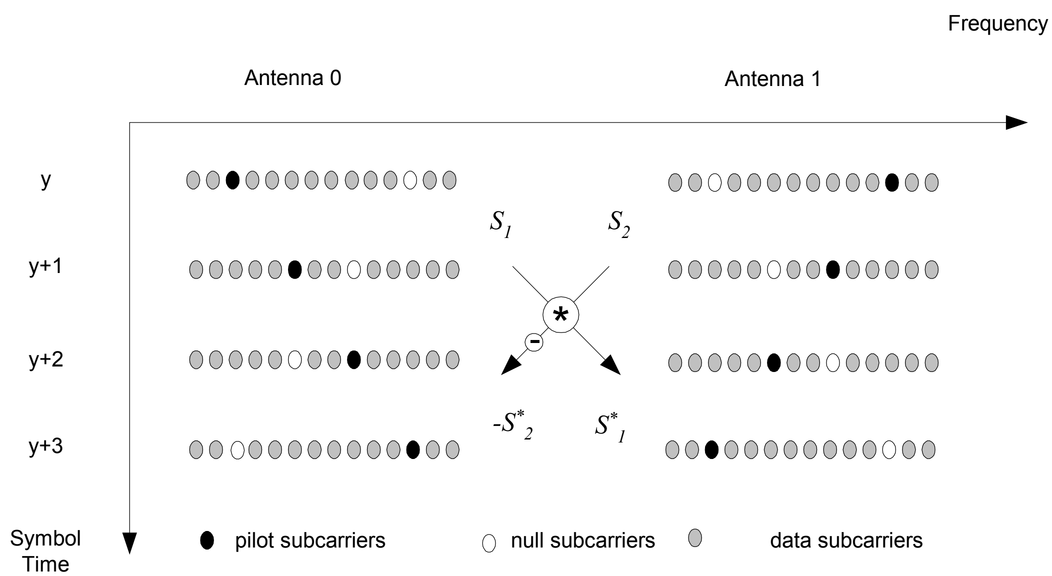

Figure 246-STC usage with PUSC

=== End text changes ====

[*Add the following text to section* ***8.4.8.1.2.1.2 STC using 2 antennas in FUSC***]

=== Start text changes ====

In FUSC all subchannles shall be used for STC transmission, the pilots within the symbols shall be divided between the antennas, antenna 0 uses VariableSet#0 and ConstantSet#0 for even symbols while antenna 1 uses VariableSet#1 and ConstantSet#1 for even symbols, antenna 0 uses VariableSet#1 and ConstantSet#0 for odd symbols while antenna 1 uses VariableSet#0 and ConstantSet#1 for odd symbols (symbol counting starts at the starting point of the relevant STC zone), defined in 8.4.6.1.2.2. In addition, the Variable set of pilots embed in each symbol of each segment shall obey the following rule:

$$PilotsLocation = VariableSet\#x + 4 \cdot \left[floor(FUSC\_SymbolNumber/2) \bmod 3 \right] \quad \text{(aaa)}$$

where *floor*(x) is the floor function, the largest integer small or equal to x.

The trasnmission of the data shall be performed in pairs of symbols as illustrated in Figure 247.

=== End text changes ====

[*Add the following text to section* ***8.4.8.2.1 STC using 4 antennas in PUSC***]

=== Start text changes ====

~~Tor~~ For this configuration the basic cluster structure is changed as indicated in Figure 251 to ~~accumudate~~accommodate the transmission from 4 antennas (pilots ~~for antennas 2/3 override~~switch with data subcarriers at every symbol ~~in the even symbols,,~~ switching ~~and erasing~~ of the data subcarriers shall be performed after constellation mapping, ~~therfore~~therefore maintaining all the encoding scheme and the subchannel allocation scheme). The minimum data burst shall be multiple of 4 symbol periods.

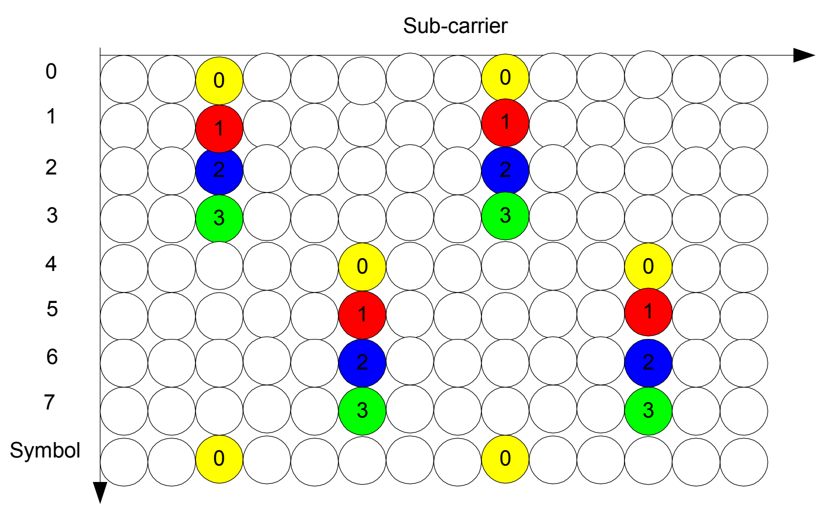

Figure 251 – Cluster structure (colored circles represent pilots with antenna index 0 to 3)

[*Add the following text to section* ***8.4.8.2.2 STC for 4 antennas using PUSC***]

=== Start text changes ====

~~for~~ For the FUSC configuration the pilots embedded within the symbol shall be further divided, the pilots shall be transmitted with a structure including 4 time symbol (repeating itself every 4 symbols) as follows:

Symbol 0: antenna 0 uses VariableSet#0 and ConstantSet#0, antenna 1 uses VariableSet#1 and Constant-Set#1

Symbol 1: antenna 2 uses VariableSet#0 and ConstantSet#0, antenna 3 uses VariableSet#1 and Constant-Set#1

Symbol 2: antenna 0 uses VariableSet#1 and ConstantSet#0, antenna 1 uses VariableSet#0 and Constant-Set#1
Symbol 3: antenna 2 uses VariableSet#1 and ConstantSet#0, antenna 3 uses VariableSet#0 and Constant-Set#1

In addition, pilots shall also satisfy the following formula:

$$PilotsLocation = VariableSet\#x + 4 \cdot \left[floor(FUSC\_SymbolNumber/4) \bmod 3 \right] \quad \text{(bbb)}$$

=== End text changes ====

5. References

[1] IEEE P802.16-REVd/D5-2004
[2] IEEE P802.16d/D3-2004