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Re:	
Abstract	Proposal for modifications to the pilot allocation of the FUSC scheme in OFDMA mode.
Purpose	Reply to comment #433
Notice	
Release	
Patent Policy and Procedures	

Pilot Arrangement in FUSC:
Reply to Comment #433

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1. Problem Statement

In this contribution several limitations of the FUSC scheme are discussed. The first issue relates to the channel estimation loss in mobile conditions, where the channel estimator is updated during reception due to the time-varying nature of the channel. Estimation is based on pilots scattered throughout the symbol(s). It is shown that the pilot spacing in the FUSC scheme with STC does not provide sufficient training information for reliable estimation of the channel, resulting in a significant loss in performance. In effect, estimation loss in highly dispersive channels may not allow data transfer at even the lowest modulation and coding rate.

The second issue relates to the pilot types. The FUSC scheme is comprised of variable as well as constant pilots. The constant pilots interfere with the regularity of the data subcarrier allocations in the symbol while their significance is questionable, especially in mobile conditions.

Lastly, the pilot locations in the current definition are identical for all base-stations transmitting FUSC. It is beneficiary to relate the locations to a configurable parameter, such as *IDCell*.

To combat the above limitations, we propose to adopt (with minor changes for STC support) the pilot allocations of the "additional optional FUSC" (8.4.6.1.2.3) as the pilot allocation of the mandatory FUSC. Note that in our proposal the modification is limited to the allocation of pilots; data subcarrier permutations remain untouched.

In the next section, the channel estimation loss with the FUSC scheme in analyzed. Our solution is presented in section 2 along with a performance comparison. Detailed text changes are deferred to section 3.

2. Channel Estimation Loss

In this section we analyze the channel estimation loss for the FUSC scheme when using the pilot-aided estimation approach. The model and estimator are first briefly described, followed by results showing that the current FUSC STC scheme <u>does not allow reliable channel estimation</u>. Modifications to the current structure are then proposed and a performance comparison is made.

2.1. Model description

A subcarrier spacing of 11.1 KHz is assumed throughout this evaluation.

Let us consider a channel model with a flat power-delay profile and a flat Doppler spectrum, as depicted in Figure 1.

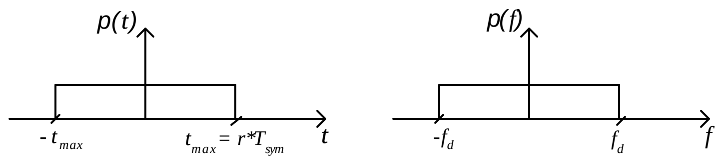


Figure 1 – power-delay and Doppler power profiles

The resulting time-frequency subcarrier correlation function is given by:

$$r(\Delta n, \Delta k) = sinc\left(2 \cdot f_d \cdot (\Delta n \cdot T_{sym})\right) \cdot sinc\left(2 \cdot t_{\max} \cdot (\Delta k \cdot \Delta f)\right) \quad (1)$$

where T_{sym} is the OFDM symbol duration and Df is the subcarrier spacing.

The minimal pilot spacing required according to Nyquist's sampling theorem, *assuming $f_d=0$*, is

$$\Delta f_{\min} = \frac{1}{2t_{\max}} = \frac{1}{2rT_{sym}} = \frac{1}{2r}\Delta f \quad (2)$$

where in the last equality we have neglected the cyclic-prefix for clarity of discussion. As the Doppler frequency increases, this requirement is further tightened. Some level of over-sampling is needed in order to further improve estimation S/N.

2.2. Channel Estimator

The channel estimator used is the well-known 2D MMSE estimator [3]. The model is assumed to be exact (i.e. no model mismatch). A block of 12 symbols was used for evaluation of DL schemes (with all possible variations for the first symbol), and the subcarriers for the 7th symbol were estimated.

2.3. Estimation Loss using Current Definition

2.3.1. 2 Antenna STC

In the 2-antenna STC mode, half of the pilots are available to each transmitting antenna, hence the pilot spacing is in effect doubled to 12 subcarriers over the 2 symbol cycle. Pilots are boosted by 2.5dB[1]. This limits the maximal supported single-sided delay

[1] It is assumed that the data subcarriers have 0dB boost, per the definition of the 'Boosting' field in the DL-MAP_IE (section 8.4.5.3).

spread to $\frac{1}{24} \cdot T_{sym}$ without any over-sampling. Figure 2 shows the estimation S/N and combined S/N[2] for $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

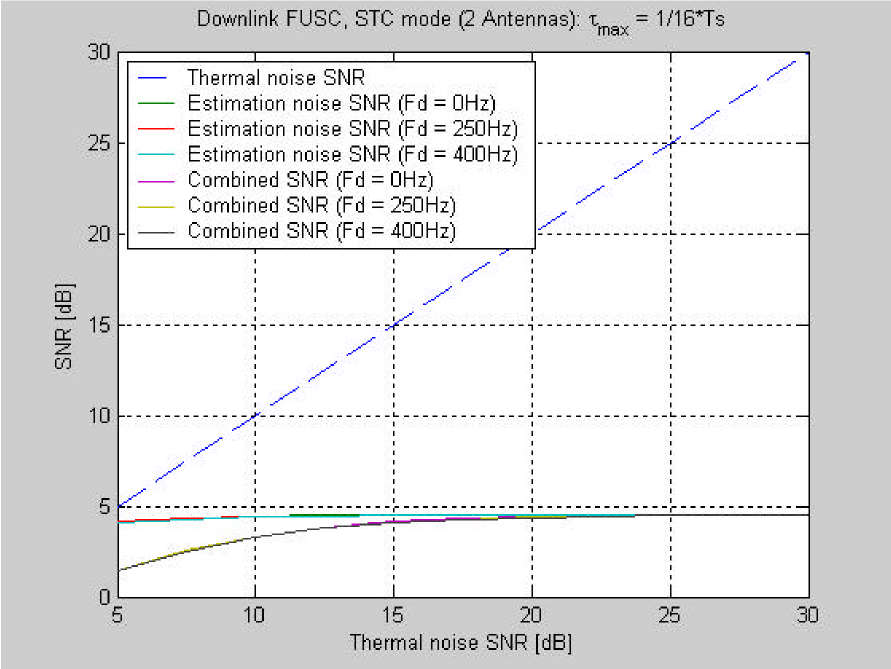


Figure 2 - Downlink FUSC, 2-antenna STC

Clearly at this multi-path level pilot-aided channel estimation is useless.

2.3.2. 4 Antenna STC

In 4-antenna STC mode, every two symbols two antennas share the available pilots. Figure 3 shows how this scheme fails for $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

[2] comprised of estimation noise, thermal noise, and Doppler-induced ICI.

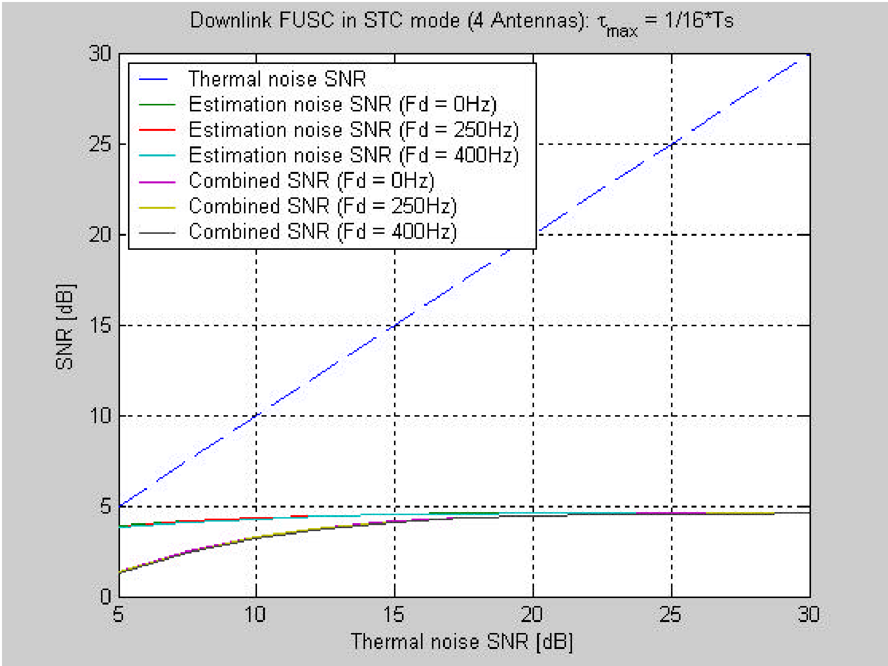


Figure 3 - Downlink FUSC, 4-antenna STC

2.3.3. Regular (Non-STC) mode

The pilot spacing for the non-STC FUSC scheme is 6 subcarriers over a cycle of 2 symbols. For $f_d=0$, the maximal single-sided delay that can be supported is $\frac{1}{12} \cdot T_{sym}$ without over-sampling. Figure 4 shows the estimation S/N and combined S/N[(3)] for $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

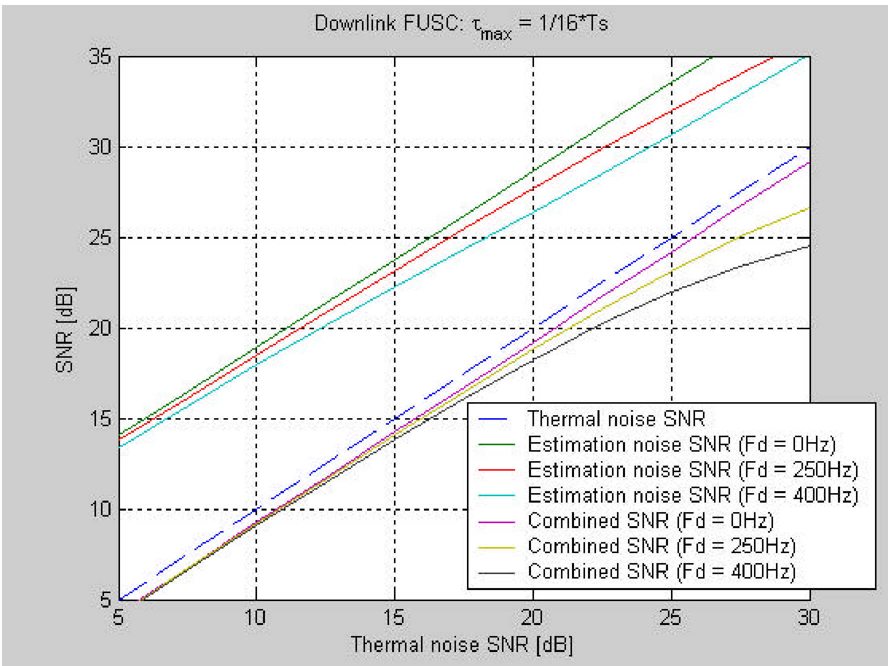


Figure 4 – Downlink FUSC

[3] comprised of estimation noise, thermal noise, and Doppler-induced ICI.

2.4. Proposed solution

The analysis above clearly shows that the FUSC pilot scheme does not work for STC mode in mobile conditions where pilot-based channel estimation is most needed.

A more dense distribution of pilots in the frequency axis (at the expense of a longer symbol cycle) is therefore required for the STC modes.

We propose to adopt the pilot locations of the optional FUSC structure (8.4.6.1.2.3) with minor changes for STC support. We also propose to link the *IDCell* configuration parameter to the pilot locations in order to reduce interference between pilots of nearby cells. The changes are outlined below:

1. Remove constant pilots in order to improve regularity of pilot locations.

2. Change N_{used} to 1729 (2K-FFT) / 865 (1K-FFT) / 433 (512-FFT) / 108 (128-FFT).

3. Define two basic pilot sets (#0 and #1) as follows:

   PilotSet#0 = 18k+3m+1
   PilotSet#1 = 18k+3m+9+1

   where

   k = 0, 1, …, N_{pilots}-1

   and

   m = ((floor(FUSC_SymbolNumber/K_{STC})+IDCell) mod 3)

   K_{STC} = 1 for the non-STC case, 2 for the 2-Antenna STC case, and 4 for the 4-antenna STC case.

4. For the non-STC case:

   Select the pilots at each symbol to be the union of PilotSet#0 and PilotSet#1.

   This is depicted in Figure 5.

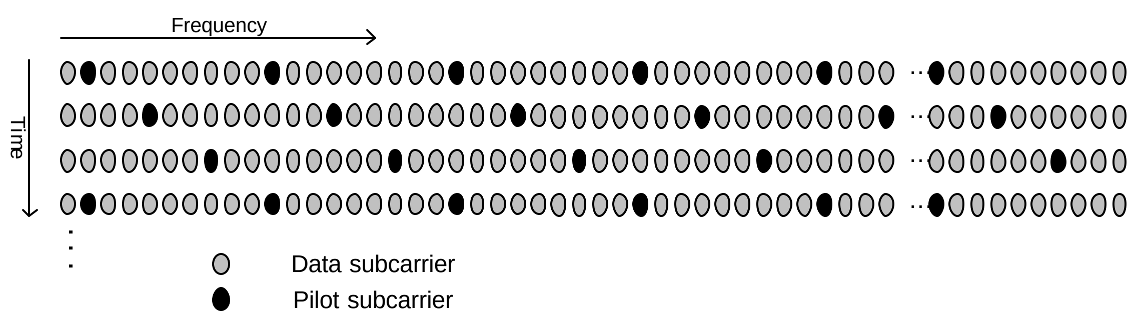


Figure 5 - FUSC structure

5. For the 2-Antenna STC case:

   Select the pilots at each symbol as follows:

   - For even symbols, select PilotSet#0 for antenna #0 and PilotSet#1 for antenna #1.
   - For odd, symbols, select PilotSet#1 for antenna #0 and PilotSet#0 for antenna #1.

   This is depicted in Figure 6.

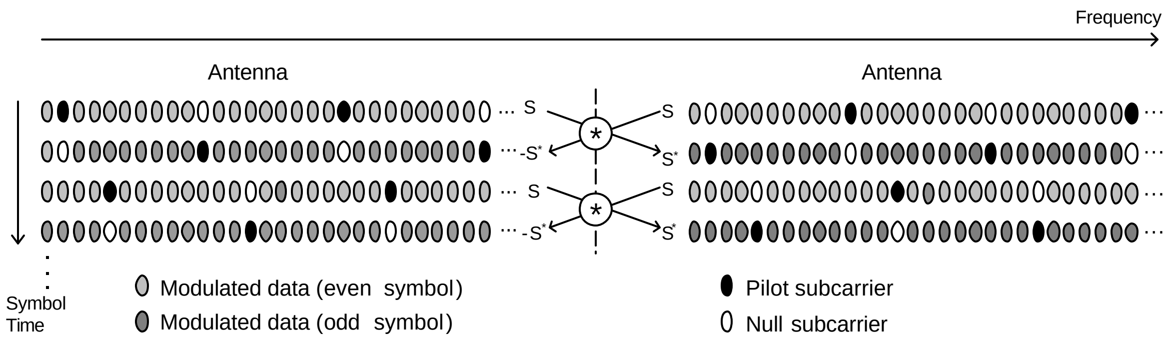


Figure 6 - FUSC structure with STC

6. For the 4-antenna STC mode:

   When 4 antennas are used, transmit pilots from each antenna pair every two symbols. In even symbols, transmit pilots from antennas #0 and #1. In odd symbols, transmit pilots from antennas #2 and #3.

   Select the pilot locations according to FUSC_SymbolNumber:

   - (FUSC_SymbolNumber mod 4) = 0: PilotSet#0 for antenna #0 and PilotSet#1 for antenna #1.
   - (FUSC_SymbolNumber mod 4) = 1: PilotSet#0 for antenna #2 and PilotSet#1 for antenna #3.
   - (FUSC_SymbolNumber mod 4) = 2: PilotSet#1 for antenna #0 and PilotSet#0 for antenna #1.
   - (FUSC_SymbolNumber mod 4) = 3: PilotSet#1 for antenna #2 and PilotSet#0 for antenna #3.

Detailed text changes are given in the last section.

2.5. Performance comparison

The figures below compare the channel estimation performance of the current FUSC structure definitions vs. the definitions proposed in the previous subsection. Results shown are the combined SNR for Doppler spreads of 0Hz and 250Hz with $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

For the STC modes, the proposed modification leads to a very significant improvement. Results are shown in Figure 7 and Figure 8 below.

For the non-STC mode, a slight improvement can be observed at high SNRs.

2.5.1. 2-Antenna STC

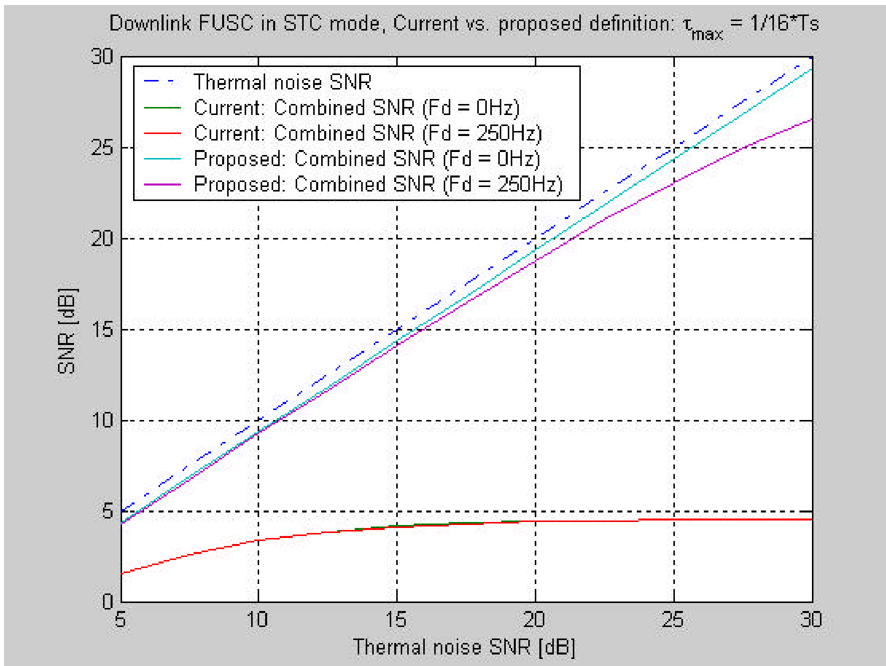


Figure 7 – Comparison between current and proposed FUSC pilot structure, 2-Antenna STC.

2.5.2. 4-Antenna STC

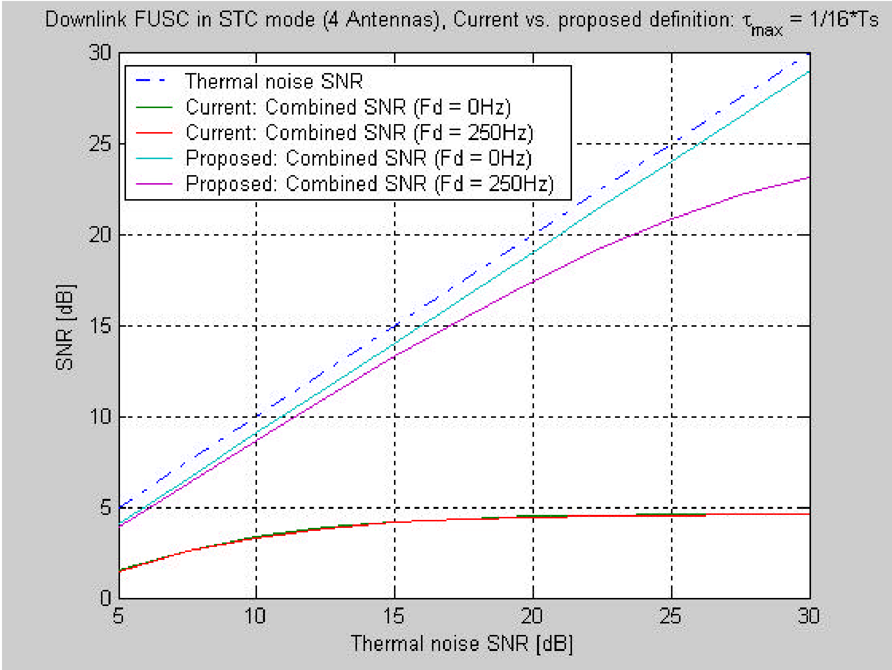
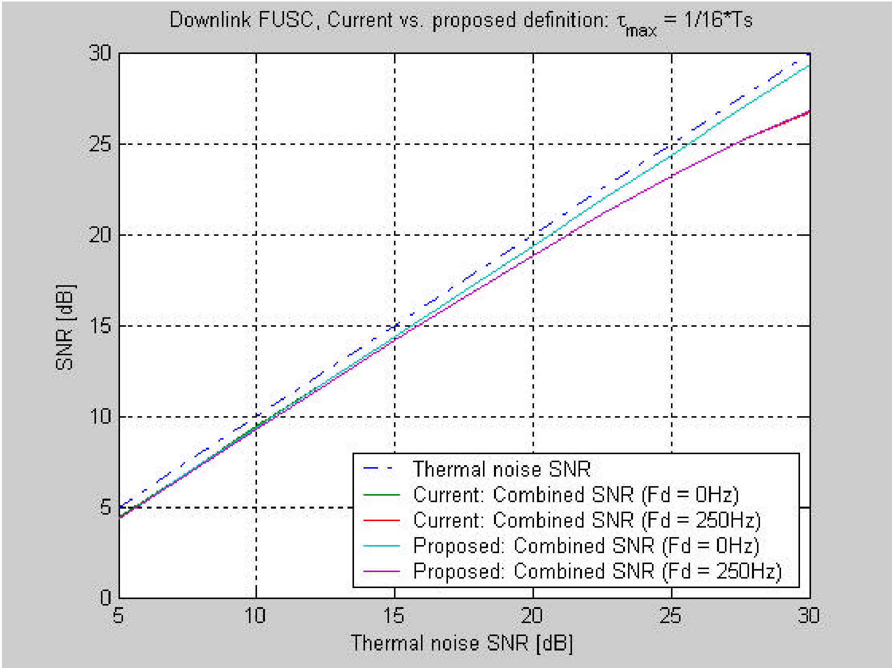


Figure 8 - Comparison between current and proposed FUSC pilot structure, 4-Antenna STC.

2.5.3. Regular (non-STC)



3. Proposed Text Changes

8.4.6.1.2.2, page 567, line 52

[Replace text starting with "There are 2 variable pilot-sets" and ending with "parameters of the symbol:" with the following text:]

There are two pilot-sets, PilotSet#0 and PilotSet#1. These sets are defined by:

PilotSet#0 = 18k + 3m + 1
PilotSet#1 = 18k + 3m + 10 (eq. (X1))

where k = 0, …, (*Npilots*-1) and m = ((floor(*FUSC_SymbolNumber/KSTC)* + *IDCell*) mod 3). *FUSC_SymbolNumber* counts the FUSC symbols used in the transmission starting from 0. K_{STC} is a constant that depends on the STC configuration (see section 8.4), and is equal to 1 for the regular non-STC mode.

When STC is not employed, pilot locations are selected using both pilot sets. When STC mode is employed, the pilots are shared between the different antennas, as described in section 8.4.8. Tables 272a-d summarize the symbol parameters:

[Change text at line 1 of page 569 to the following text:]

Figure 235 depicts as an example of the symbol allocation ~~for segment 0~~ on symbol number ~~1~~ 0:

[Replace figure 235 with the following figure:]

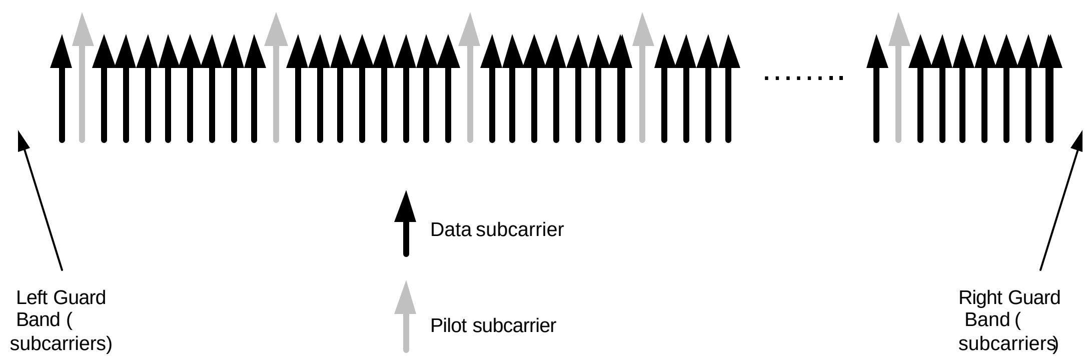


Figure 235 – Downlink symbol structure for symbol number 0 using FUSC

8.4.6.1.2, pages 79-82

[Replace table 272a with the following table:]

Parameter	Value	Comments
Number of DC Subcarriers	1	Index 864
Number of Guard Subcarriers, Left	160	
Number of Guard Subcarriers, Right	159	
Number of Used Subcarriers (Nused)	1729	Number of all subcarriers used within a symbol, including all possible allocated pilots and the DC carrier.
Number of pilot subcarriers (Npilots)	192	
Number of data subcarriers	1536	
Number of data subcarriers per subchannel	48	
Number of Subchannels	32	
PermutationBase	3, 18, 2, 8, 16, 10, 11, 15, 26, 22, 6, 9, 27, 20, 25, 1, 29, 7, 21, 5, 28, 31, 23, 17, 4, 24, 0, 13, 12, 19, 14, 30	

[Replace table 272b with the following table:]

Parameter	Value	Comments
Number of DC Subcarriers	1	Index 432
Number of Guard Subcarriers, Left	80	
Number of Guard Subcarriers, Right	79	
Number of Used Subcarriers (Nused)	865	Number of all subcarriers used within a symbol, including all possible allocated pilots and the DC carrier.
Number of pilot subcarriers (Npilots)	96	
Number of data subcarriers	768	
Number of data subcarriers per subchannel	48	
Number of Subchannels	16	
PermutationBase	6, 14, 2, 3, 10, 8, 11, 15, 9, 1, 13, 12, 5, 7, 4, 0	

[Replace table 272c with the following table:]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 216
Number of Guard Subcarriers, Left	40	
Number of Guard Subcarriers, Right	39	
Number of Used Subcarriers (Nused)	433	Number of all subcarriers used within a symbol, including all possible allocated pilots and the DC carrier.
Number of pilot subcarriers (Npilots)	48	
Number of data subcarriers	384	
Number of data subcarriers per subchannel	48	
Number of Subchannels	8	
PermutationBase	7,4,0,2,1,5,3,6	

[Replace in table 272d the entries below with the following:]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 54
Number of Guard Subcarriers, Left	10	
Number of Guard Subcarriers, Right	9	
Number of Used Subcarriers (Nused)	109	Number of all subcarriers used within a symbol, including all possible allocated pilots and the DC carrier.
Number of pilot subcarriers (Npilots)	12	
Number of data subcarriers	96	
Number of data subcarriers per subchannel	48	
Number of Subchannels	2	
PermutationBase	1, 0	

8.4.6.1.2.2, page 568, line 51

[Delete text starting with "The Variable set of pilots" and ending with "starting from 0"]

8.4.8.1.2.1.2, page 585, line 3

[Replace text starting with "In FUSC all subchannels" and ending with "as illustrated in Figure 247" with the following text:]

In FUSC all subchannels shall be used for STC transmission and the pilots within the symbols shall be divided between the antennas. Pilot sets are defined by equation (X1) with K_{STC}=2. For even symbols, transmitted pilots are PilotSet#0 for antenna #0 and PilotSet#1 for antenna #1, while for odd symbols, transmitted pilots are PilotSet#1 for antenna #0 and PilotSet#0 for antenna #1. The transmission of the data shall be performed in pairs of symbols as illustrated in Figure 247.

[Replace figure 247 with the following figure]

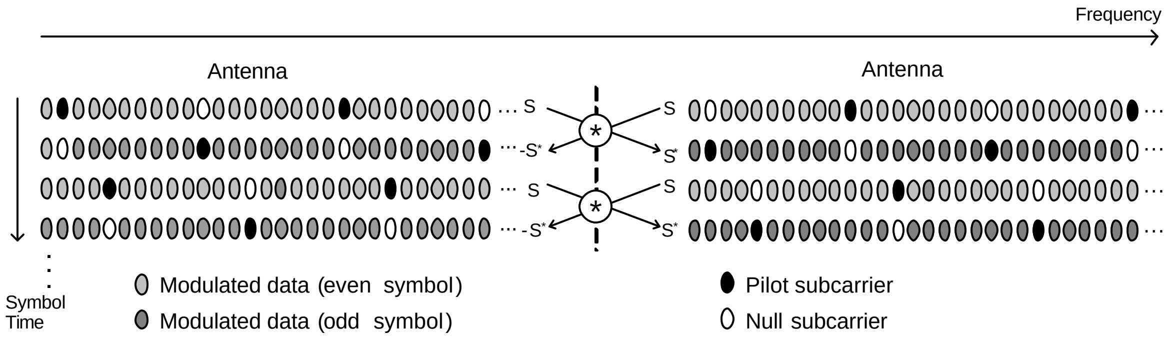


Figure 247 – STC usage with FUSC

8.4.8.2.2, page 589, line 31

[Replace text at lines 31-45 with the following text:]

When 4 antennas are used, each antenna pair transmits pilots every two symbols. In even symbols, pilots are transmitted from antennas #0 and #1, while in odd symbols pilots are transmitted from antennas #2 and #3. Pilot sets are defined by equation (X1) with K_{STC}=4.

Where PilotSet is determined by FUSC_SymbolNumber:

- (FUSC_SymbolNumber mod 4) = 0: PilotSet#0 for antenna #0 and PilotSet#1 for antenna #1.
- (FUSC_SymbolNumber mod 4) = 1: PilotSet#0 for antenna #2 and PilotSe #1 for antenna #3.
- (FUSC_SymbolNumber mod 4) = 2: PilotSet#1 for antenna #0 and PilotSet#0 for antenna #1.
- (FUSC_SymbolNumber mod 4) = 3: PilotSet#1 for antenna #2 and PilotSet#0 for antenna #3.

4. References

[1] IEEE P802.16REVd-D5.

[2] IEEE P802.16e-D3.

[3] P. Hoeher, S. Kaiser, and P. Robertson. "Two-Dimensional Pilot-Symbol-Aided Channel Estimation by Wiener Filtering". Proc. IEEE ICASSP '97, Munich, Germany, pp. 1845-1848, Apr. 1997.