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Source(s)	Ran Yaniv Tal Kaitz Naftali Chayat Vladimir Yanover Marianna Goldhammer All with Alvarion Ltd. 21 A Habarzel St. Ramat - Hahayal Tel - Aviv 69710
	Voice: +972-37674583 mailto: ran.yaniv@alvarion.com Voice: +972-36456273 mailto: tal.kaitz@alvarion.com
Re:	
Abstract	Two fundamental problems exist in the downlink PUSC scheme as it is currently defined. The first is related to the allocation of subchannel data subcarriers into clusters; the second fundamental issue is related to the pilot spacing in STC mode – Pilot-aided channel estimation will fail in a mobile environment with the current spacing. A detailed performance evaluation is presented along with a proposed solution.
Purpose	Proposal for modifications to the structure of the PUSC scheme in OFDMA mode.
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Pilot and Cluster Allocation in Downlink PUSC: Reply to Comments #436, #494, #501, #503

Ran Yaniv, Tal Kaitz, Naftali Chayat, Vladimir Yanover, Marianna Goldhammer
Alvarion

1. Introduction

Two fundamental problems exist in the downlink PUSC scheme as it is currently defined. The first is related to the allocation of subchannel data subcarriers into clusters: current definition states that the subchannel's data subcarriers are spread over all clusters in the major group. Conversely, each cluster contains data subcarriers attributed to several different subchannels, and potentially several different users. As a consequence, beam-forming on specific subchannels is not possible. Furthermore, boosting the data subcarriers of selected subchannels will render the pilots useless since they are not boosted together with the data. This issue is further discussed in section 2, and a solution is proposed.

The second fundamental issue is related to the pilot spacing in STC mode – current definition leads to very significant channel estimation loss when using pilot-aided estimation approaches. In effect, estimation loss in highly dispersive channels may not allow data transfer at even the lowest modulation and coding rate. A detailed performance evaluation along with a proposed solution is presented in section 3.

Detailed text changes are deferred to section 4.

2. Cluster Allocation Problem

As stated in the introduction, the presence of data subcarriers from multiple distinct subchannels in a single cluster leads to several problems:

- Inability to use beam-forming in PUSC mode - a cluster's pilots are shared by all subchannels in the major group, each may be allocated to a different user.
- Boosting of data is independent of pilot power, therefore boosting of data-subcarriers would render pilot-aided channel estimation useless. Note that pilot-aided estimation is crucial in a mobile environment where the channel is time-varying.

One can argue that the current PUSC definition contributes to a high degree of frequency diversity, whereas the use of a clustered approach, in which the clusters are restricted to occupy data from a single subchannel, would limit this diversity. It should be noted however that downlink allocations usually occupy more than a single subchannel, and this naturally increases the frequency diversity order of the user's allocation. Furthermore, the frequency diversity of a single subchannel can be improved, as is proposed in this contribution, by increasing the number of clusters per subchannel from 2 to 4 (i.e. by modifying the cluster size to occupy 12 data subcarriers instead of 24).

Furthermore, there is a redundancy in the existence of both the FUSC and PUSC modes – both modes present the same concepts, with PUSC also supporting multiple segments. From a technical viewpoint, it does not make sense to maintain both.

Proposed solution:

1. Change the cluster structure to the one depicted in Figure 1.

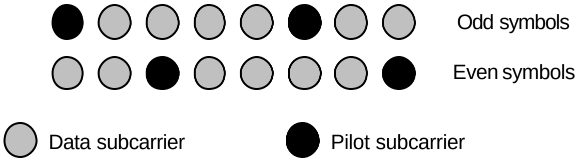

Figure 1 –Basic cluster structure for DL PUSC

Thus, each cluster occupies 12 data subcarriers and 4 pilots. While this modification adds to the training overhead (4 pilots per 16 subcarriers compared to 4 pilots per 28 subcarriers in the current text), it is shown to solve an important performance problem in STC modes (see section 3).

2. Associate a subchannel with 4 physical clusters.

3. Restrict the subchannel's data subcarriers to the subchannel's clusters.

4. Map data subcarriers onto the subchannel's clusters in the following manner: the subchannel's data subcarriers are numbered starting from the subchannel's lowest data subcarrier in the first symbol in an ascending order throughout the subchannel's data subcarriers in the same symbol, then going to next symbol from the subchannel's lowest data subcarrier.

The detailed text changes are presented in section 4.

3. Channel Estimation Loss

In this section we analyze the channel estimation loss for the PUSC scheme when using the pilot-aided estimation approach. The model and estimator are first briefly described, followed by results showing that the current PUSC STC scheme renders pilot-aided channel estimation useless. Modifications to the current PUSC structure are then proposed and a performance comparison is made.

3.1. 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 2.

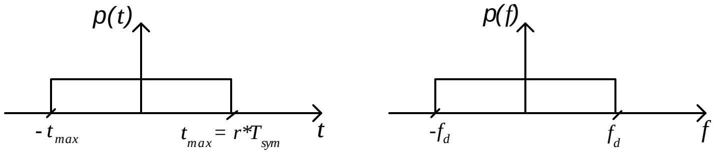

Figure 2 – power-delay and Doppler power profiles

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

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

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

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

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.

3.2. 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 8 symbols was used for evaluation of DL schemes (with all possible variations for the first symbol), and the subcarriers for the 5th symbol were estimated.

3.3. Estimation Loss using Current Definition

3.3.1. DL PUSC – 2/4 Antenna STC

In DL PUSC, clusters are not contiguous in the frequency axis; therefore we are limited to estimating the channel from the pilots that reside inside the cluster (perhaps over several symbol durations). In the 2-antenna STC mode, pilots are only transmitted in the odd symbols. 2 pilots, spaced 12 subcarriers apart, are transmitted by each antenna. When 4 antennas are used, data subcarriers are punctured and pilots take their place – As a consequence, identical channel estimation loss is expected.

This scheme completely fails in high multi-path conditions, as is shown in Figure 3 for $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

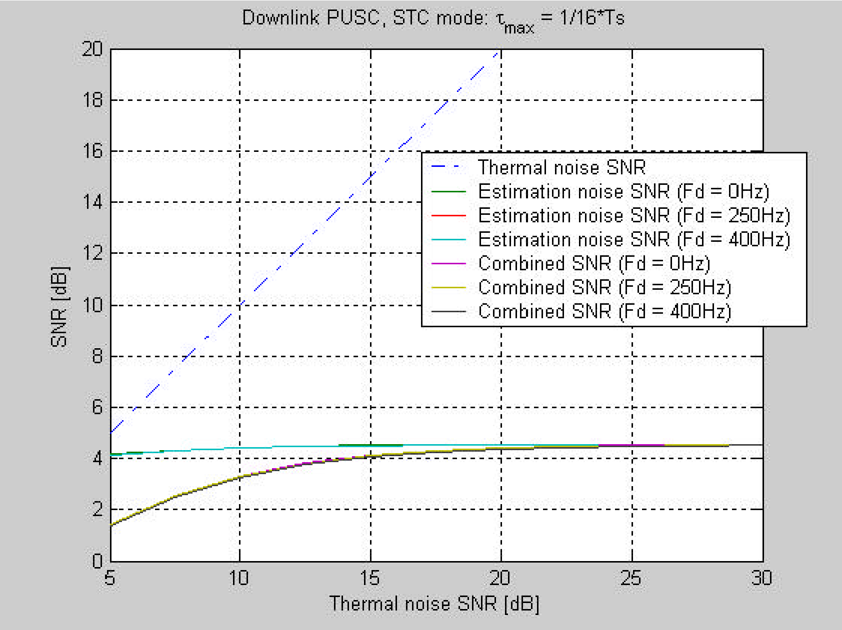

Figure 3 – Downlink PUSC, 2-Antenna STC

3.3.2. Regular Non-STC mode

In the regular mode, pilots are spaced 4 subcarriers apart and are boosted by 2.5dB(1). The degradation in this mode is much more acceptable. Figure 4 below shows the S/N and combined S/N for $t_{\max} = \frac{1}{16} \cdot T_{sym}$.

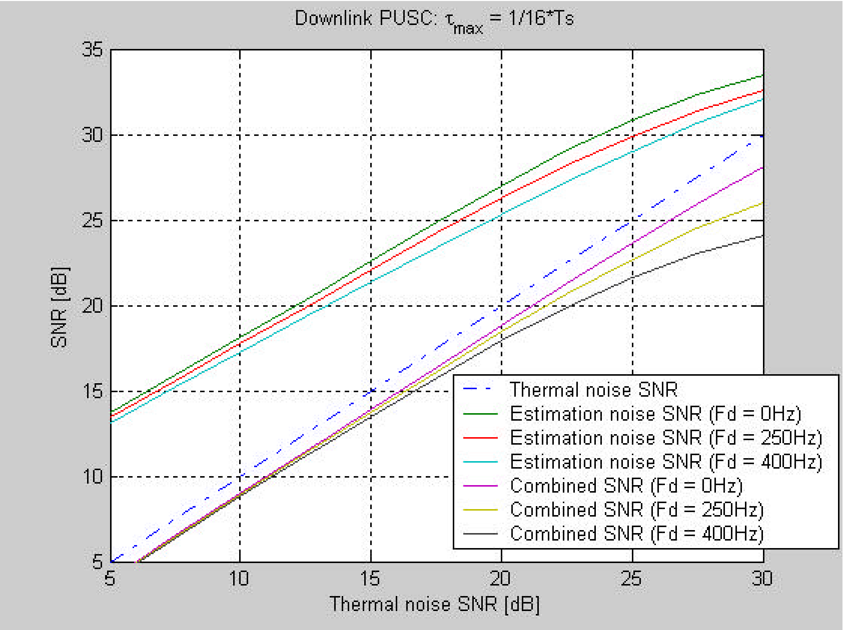

Figure 4 - Downlink PUSC

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[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).

3.4. Proposed solution

The current PUSC pilot scheme does not work in mobile conditions when any form of STC is employed – data transfer can not be achieved with even the lowest modulation and code rate.

We propose the following modifications to the PUSC structure:

1. Current 2x14 cluster replaced with the following 2x8 cluster:

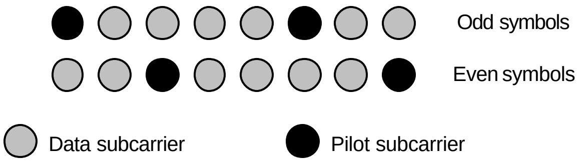

Figure 5 –Basic cluster structure for DL PUSC

The structure has a data-to-total subcarrier ratio of 3/4.

2. Each subchannel is comprised of 4 clusters; the subchannel's data subcarriers are restricted to the subchannel's clusters. Mapping of data subcarriers is performed in the following order: The data subcarriers are numbered starting from the lowest data subcarrier in the first symbol in an ascending order throughout the data subcarriers in the same symbol, then going to next symbol at the lowest data subcarrier.

3. In non-STC mode, all pilots have the same polarity, '+1'.

4. In the 2-Antenna STC mode, all pilots are used by both antennas. This can be achieved by changing the polarity of the pilots used by Antenna #1 in the 2nd STC epoch, as depicted in Figure 6, thus allowing the decoupling of each pilot into two separate measurements, one from each of the antennas (assuming sufficiently slow time-varying channels).

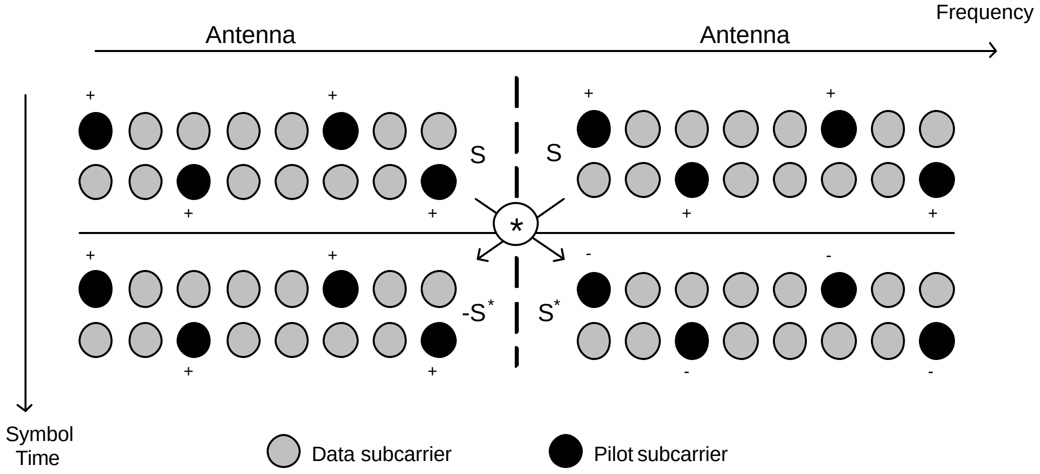

Figure 6 – 2-Antenna STC structure for DL PUSC.

5. In the 4-Antenna STC mode, pilots are split between two antenna pairs, as depicted in Figure 7.

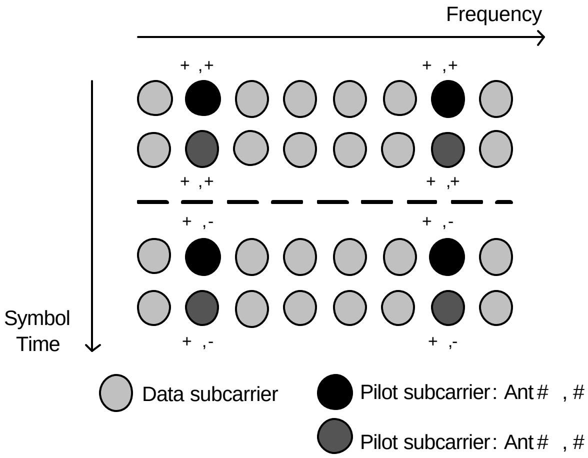

Figure 7 – Two consecutive DL PUSC clusters, 4 Antenna STC mode. The notation "p_x,p_y" specifies that pilot polarity is p_x for Ant #0(#2) and p_y for Ant #1(#3).

3.5. Performance comparison

The figures below compare the channel estimation performance of the current DL PUSC structure definitions vs. the definitions proposed in the previous subsection. Results shown are the combined SNR for Doppler spreads of 0Hz and 250Hz with $t_{\max} = {}^{1}\!/_{16} \cdot T_{sym}$ (unless noted otherwise).

The proposed cluster structure does indeed solve the severe estimation problem for the PUSC STC modes. This is shown in Figure 8 to Figure 10 below.

For the non-STC mode, estimation loss is very similar to the loss with the current definition.

3.5.1. 2-Antenna STC

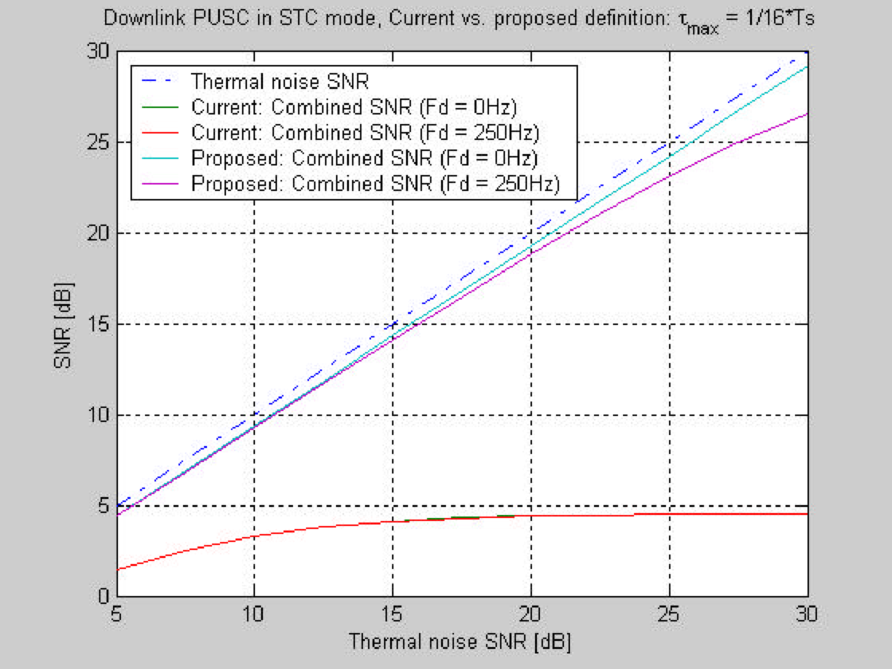

Figure 8 - Comparison between current and proposed DL PUSC structures, 2-Antenna STC.

3.5.2. 4-Antenna STC

$t_{\max} = \frac{1}{16} \cdot T_{sym}$:

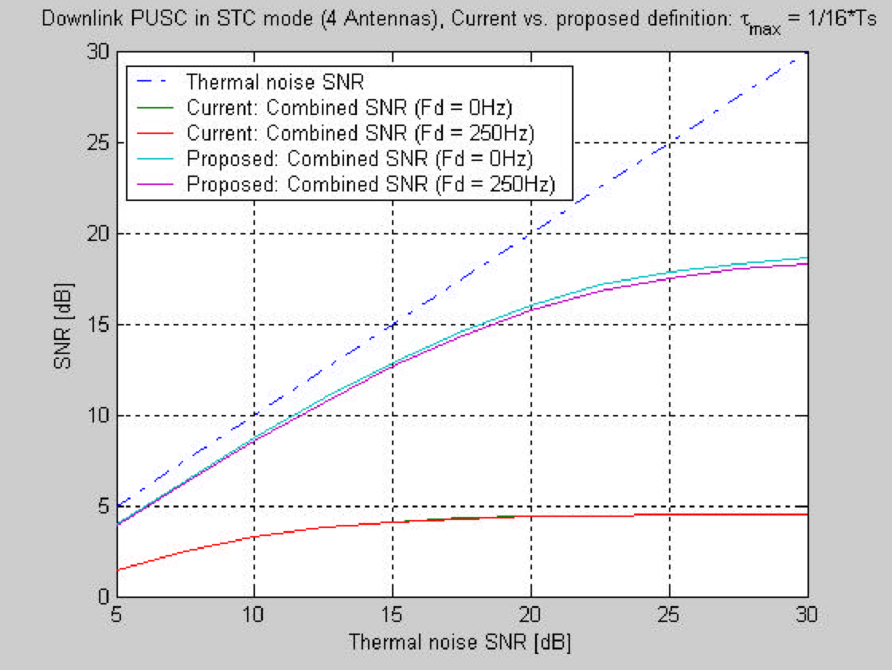

Figure 9 - Comparison between current and proposed DL PUSC structures, 4-Antenna STC.

$t_{\max} = {}^{1}\!/_{32} \cdot T_{sym}:$

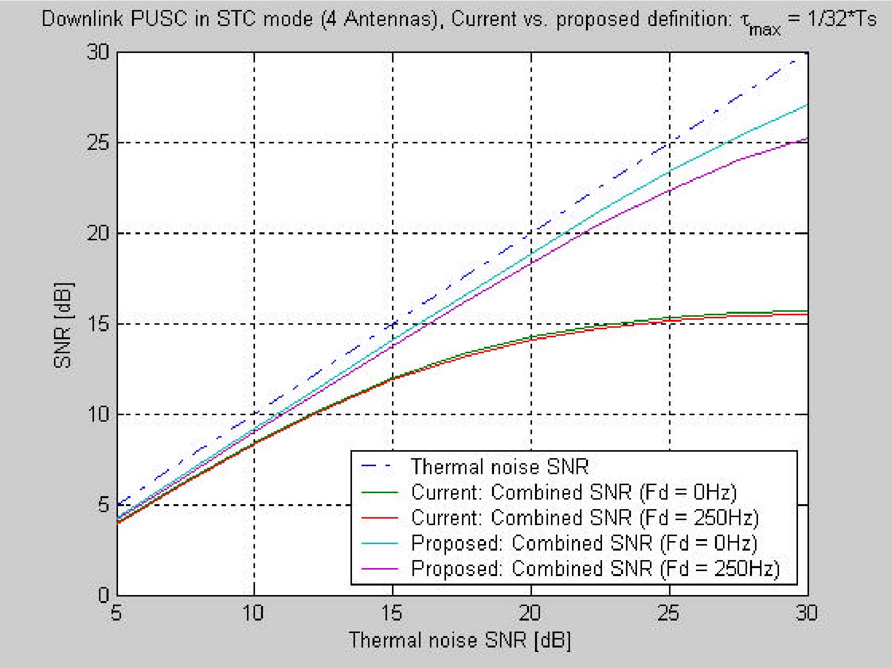

Figure 10 - Comparison between current and proposed DL PUSC structures, 4-Antenna STC.

3.5.3. Regular (Non-STC)

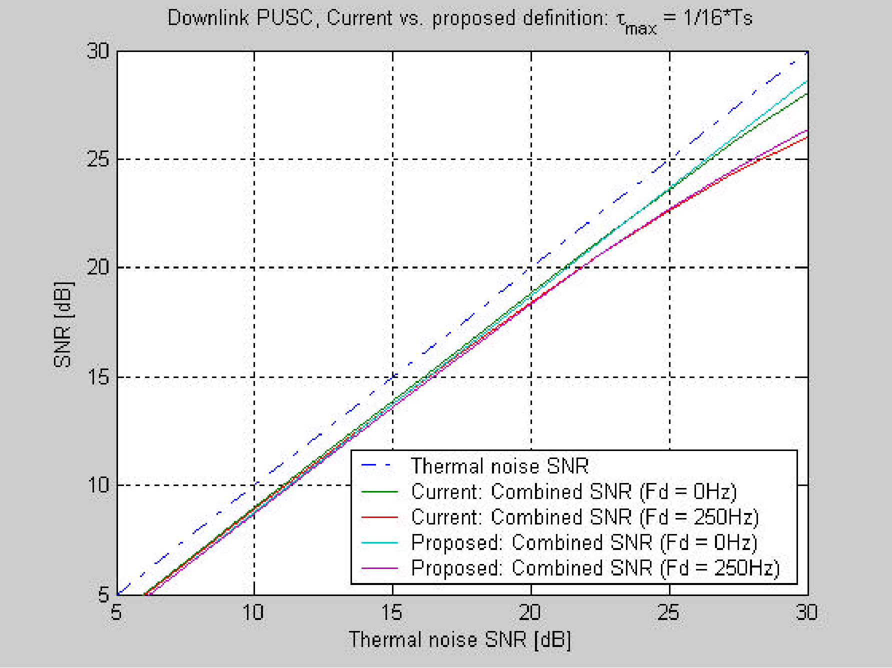

Figure 11 – Comparison between current and proposed DL PUSC structures.

4. Proposed Text Changes

Section 8.4.4.3, page 503:

[Change the entry “Used subchannel bitmap” in table 266 to the following text:]

Used subchannel bitmap	6 bits	Bit #*i* (*i*=0..5): i^{th} major group, as defined in section 8.4.6.1.2.1.1

Section 8.4.4.4, page 504:

[Change text on page 504, lines 40-45 to the following text:]

~~In PUSC, any segment used shall be allocated at least 12 subchannels.~~ The first 4 slots in the downlink part of the segment contain the FCH as defined in 8.4.4.2. These slots contain 48 bits modulated by QPSK with coding rate 1/2 and repetition coding of 4. The basic allocated subchannel sets for Segments 0, 1, and 2 are major groups 0, 2, and 4, respectively, as defined in section 8.4.6.1.2.1.1. ~~Subchannels 0-11, 20-31, and 40-51, respectively~~. Figure 220 depicts this structure.

[Change text on page 505, lines 41-54 to the following text:]

After decoding the DL_Frame_Prefix message within the FCH, the SS has the knowledge of how many and which subchannels are allocated to the PUSC segment. In order to observe the allocation of the subchannels in the downlink as a contiguous allocation block, the subchannels shall be renumbered, the renumbering shall start from the FCH subchannels ~~(renumbered to values 0…11)~~, then continue numbering the subchannels in a cyclic manner to the last allocated subchannel and from the first allocated subchannel to the FCH Subchannels. Figure 221 gives an example of such renumbering for segment 1. For uplink, in order to observe the allocation of the subchannels as a contiguous allocation block, the subchannels shall be renumbered, the renumbering shall start from the lowest numbered allocated subchannel (renumbered to value 0), up to the highest numbered allocated sub-channel, skipping non-allocated sub-channels. Figure 222 gives an example of such renumbering for segment 1 using major groups 2 and 5.

[Change text in figure 221 as follows:]

Physical Enumeration	**Logical Enumeration (Renumbered)**
SC ~~19~~ 17	none
SC ~~20~~ 18	SC 0
SC ~~21~~ 19	SC 1
SC ~~22~~ 20	SC 2
SC ~~23~~ 21	SC 3
SC ~~24~~ 22	SC 4
.	
.	
SC 30	SC 10
SC 31	SC 11
SC 32	none
SC 33	none
.	
..	
SC ~~51~~ 47	none
SC ~~52~~ 48	SC 12
SC 53 49	SC 13
SC 54 50	SC 14
.	
.	
SC ~~59~~ 53	SC ~~19~~ 17

Figure 221 – 2048-FFT example of DL renumbering the allocated subchannels for segment 1 in PUSC

Section 8.4.6.1.2, pages 82-84:

[Replace table 272e with the following table]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 864
Number of Subcarriers, Left	159	
Number of Subcarriers, Right	160	
Number of Used Subcarriers (Nused) including all possible allocated pilots and the DC carrier.	1729	Number of all subcarriers used within a symbol.
Renumbering sequence	0, 54, 108, 162, 27, 81, 135, 189, 14, 68, 122, 176, 41, 95, 149, 203, 5, 59, 113, 167, 32, 86, 140, 194, 23, 77, 131, 185, 50, 104, 158, 212, 9, 63, 117, 171, 36, 90, 144, 198, 18, 72, 126, 180, 45, 99, 153, 207, , 3, 57, 111, 165, 30, 84, 138, 192, 17, 71, 125, 179, 44, 98, 152, 206, 8, 62, 116, 170, 35, 89, 143, 197, , 1, 55, 109, 163, 28, 82, 136, 190, 15, 69, 123, 177, 42, 96, 150, 204, 6, 60, 114, 168, 33, 87, 141, 195, 24, 78, 132, 186, 51, 105, 159, 213, 10, 64, 118, 172, 37, 91, 145, 199, 19, 73, 127, 181, 46, 100, 154, 208, , 26, 80, 134, 188, 53, 107, 161, 215, 12, 66, 120, 174, 39, 93, 147, 201, 21, 75, 129, 183, 48, 102, 156, 210, , 2, 56, 110, 164, 29, 83, 137, 191, 16, 70, 124, 178, 43, 97, 151, 205, 7, 61, 115, 169, 34, 88, 142, 196, 25, 79, 133, 187, 52, 106, 160, 214, 11, 65, 119, 173, 38, 92, 146, 200, 20, 74, 128, 182, 47, 101, 155, 209, , 4, 58, 112, 166, 22, 76, 130, 184, 13, 67, 121, 175, 40, 94, 148, 202, 31, 85, 139, 193, 49, 103, 157, 211 ~~6, 108, 37, 81, 31, 100, 42, 116, 32, 107, 30, 93, 54, 78, 10, 75, 50, 111, 58, 106, 23, 105, 16, 117, 39, 95, 7, 115, 25, 119, 53, 71, 22, 98, 28, 79, 17, 63, 27, 72, 29, 86, 5, 101, 49, 104, 9, 68, 1, 73, 36, 74, 43, 62, 20, 84, 52, 64, 34, 60, 66, 48, 97, 21, 91, 40, 102, 56, 92, 47, 90, 33, 114, 18, 70, 15, 110, 51, 118, 46, 83, 45, 76, 57, 99, 35, 67, 55, 85, 59, 113, 11, 82, 38, 88, 19, 77, 3, 87, 12, 89, 26, 65, 41, 109, 44, 69, 8, 61, 13, 96, 14, 103, 2, 80, 24, 112, 4, 94, 0~~	Used to renumber clusters before allocation to sub-channels
Number of subcarriers per symbol per cluster	8	
Number of clusters	216	
Number of data subcarriers per symbol per subchannel	24	
Number of subchannels	54	

[Replace tables 272f with the following table]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 432
Number of Subcarriers, Left	79	
Number of Subcarriers, Right	80	
Number of Used Subcarriers (Nused) including all possible allocated pilots and the DC carrier.	865	Number of all subcarriers used within a symbol.
renumbering sequence	0, 27, 54, 81, 14, 41, 68, 95, 9, 36, 63, 90, 23, 50, 77, 104, 5, 32, 59, 86, 18, 45, 72, 99, 3, 30, 57, 84, 17, 44, 71, 98, 12, 39, 66, 93, 1, 28, 55, 82, 15, 42, 69, 96, 10, 37, 64, 91, 24, 51, 78, 105, 6, 33, 60, 87, 19, 46, 73, 100, 26, 53, 80, 107, 8, 35, 62, 89, 21, 48, 75, 102, 2, 29, 56, 83, 16, 43, 70, 97, 11, 38, 65, 92, 25, 52, 79, 106, 7, 34, 61, 88, 20, 47, 74, 101, 4, 31, 58, 85, 22, 49, 67, 103, 13, 40, 76, 94 ~~6, 48, 37, 21, 31, 40, 42, 56, 32, 47, 30, 33, 54, 18, 10, 15, 50, 51, 58, 46, 23, 45, 16, 57, 39, 35, 7, 55, 25, 59, 53, 11, 22, 38, 28, 19, 17, 3, 27, 12, 29, 26, 5, 41, 49, 44, 9, 8, 1, 13, 36, 14, 43, 2, 20, 24, 52, 4, 34, 0~~	Used to renumber clusters before allocation to sub-channels
Number of subcarriers per symbol per cluster	8	
Number of clusters	108	
Number of data subcarriers per symbol per subchannel	24	
Number of subchannels	27	

[Replace tables 272g with the following table]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 192
Number of Subcarriers, Left	63	
Number of Subcarriers, Right	64	
Number of Used Subcarriers (Nused) including all possible allocated pilots and the DC carrier.	385	Number of all subcarriers used within a symbol.
renumbering sequence	0, 12, 24, 36, 8, 20, 32, 44, 4, 16, 28, 40, 3, 15, 27, 39, 1, 13, 25, 37, 9, 21, 33, 45, 5, 17, 29, 41, 11, 23, 35, 47, 2, 14, 26, 38, 10, 22, 34, 46, 6, 18, 30, 42, 7, 19, 31, 43 ~~12, 13, 26, 9, 5, 15, 21, 6, 28, 4, 2, 7, 10, 18, 29, 17, 16, 3, 20, 24, 14, 8, 23, 1, 25, 27, 22, 19, 11, 0~~	Used to renumber clusters before allocation to sub-channels
Number of subcarriers per symbol per cluster	8	
Number of clusters	48	
Number of data subcarriers per symbol per subchannel	24	
Number of subchannels	12	

[Replace tables 272h with the following table]

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	Index 48
Number of Subcarriers, Left	15	
Number of Subcarriers, Right	16	
Number of Used Subcarriers (Nused) including all possible allocated pilots and the DC carrier.	97	Number of all subcarriers used within a symbol.
renumbering sequence	0, 3, 6, 9, 1, 4, 7, 10, 2, 5, 8, 11 ~~2, 3, 1, 5, 0, 4~~	Used to renumber clusters before allocation to sub-channels
Number of subcarriers per symbol per cluster	8	
Number of clusters	12	
Number of data subcarriers per symbol per subchannel	24	
Number of subchannels	3	

Section 8.4.6.1.2.1.1, page 567:

[Replace figure 234 with the following figure:]

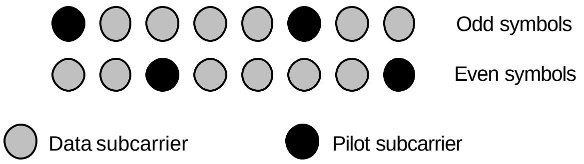

Figure 234 - Basic cluster structure for Downlink PUSC

[Change text on page 567, lines 22 to 43 to the following text:]

The carrier allocation to ~~subchannles~~ subchannels is performed using the following procedure:

1) Dividing the subcarriers into 120 physical clusters, each containing 14 8 adjunct subcarriers per symbol ~~each~~ (starting from carrier 0)
2) Renumbering the physical clusters into logical clusters using the following formula: *LogicalCluster = RenumberingSequence((PhysicalCluster+13*IDcell) mod ~~120~~ Number_of_Clusters)* In the first PUSC zone of the downlink (first downlink zone) the default used IDcell is 0.
3) Dividing the clusters into 6 major groups~~.~~ according to FFT size (see table XYX). ~~Group 0 includes clusters 0-23, group 1 includes clusters 24-39, group 2 includes clusters 40-63, group 3 includes clusters 64-79, group 4 includes clusters 80-103, group 5 includes clusters 104-119.~~ These groups may be allocated to segments, if a segment is being used, then at least one group shall be ~~allocted~~ allocated to it (by default group 0 is allocated to ~~sector~~ segment 0, group 2 is allocated to ~~sector~~ segment 1 and group 4 ~~to~~ is allocated to ~~sector~~ segment 2).
4) ~~Allocating carriers to subchannel in each major group is performed by first allocating the pilot carriers within each cluster, and then taking all remaining data carriers within the symbol and using the same procedure described in 8.4.6.1.2.2.2 (with the parameters from Table 308, using the PermutationBase appropriate for each major group, PermutationBase12 for even numbered major groups and PermutationBase8 for odd numbered major groups) to partition the subcarriers into subchannels containing 24 data subcarriers in each symbol. Note that IDcell used for the first PUSC zone is 0.~~

4) Dividing the clusters into subchannels by allocating 4 consecutive clusters (in logical cluster order) to each subchannel.
5) Allocating the data subcarriers to subchannels: the subchannel's data subcarriers are numbered starting from the subchannel's lowest data subcarrier in the first symbol in an ascending order throughout the subchannel's data subcarriers in the same symbol, then going to next symbol from the subchannel's lowest data subcarrier.

[Add the following table to page 567, before line 44:]

FFT size	Major Group Number	Clusters in major group	Subchannels in major group
2048	**0**	**0-47**	**0-11**
	1	**48-71**	**12-17**
	2	**72-119**	**18-29**
	3	**120-143**	**30-35**
	4	**144-191**	**36-47**
	5	**192-215**	**48-53**
1024	**0**	**0-23**	**0-5**
	1	**24-35**	**6-8**
	2	**36-59**	**9-14**
	3	**60-71**	**15-17**
	4	**72-95**	**18-23**
	5	**96-107**	**24-26**
512	**0**	**0-11**	**0-2**
	1	**12-15**	**3**
	2	**16-27**	**4-6**
	3	**28-31**	**7**
	4	**32-43**	**8-10**
	5	**44-47**	**11**
128	**0**	**0-3**	**0**
	1	**N/A**	**N/A**
	2	**4-7**	**1**
	3	**N/A**	**N/A**
	4	**8-11**	**2**
	5	**N/A**	**N/A**

Table XYX – Allocation of clusters and subchannels into major groups

Section 8.4.8.1.2.1.1, pages 583-584:

[Replace text from line 59 on page 583 up to line 5 of page 584 with following text:]

The clusters composing the subchannels used by the STC mode shall be allocated and subcarriers numbered as defined in 8.4.6.1.2.1. Pilots are transmitted simultaneously from both antennas using the same pilot locations as defined in Figure 234. 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 transmission of the data shall be performed in pairs of symbols as illustrated in Figure 246. Each symbol-pair shall be transmitted twice from each antenna. The pilots transmitted from antenna #1 during every 2nd symbol-pair shall have negative polarity (prior to pilot modulation). All other pilots shall have positive polarity (prior to pilot modulation).

[Remove figure 245]

[Replace Figure 246 with the following figure]

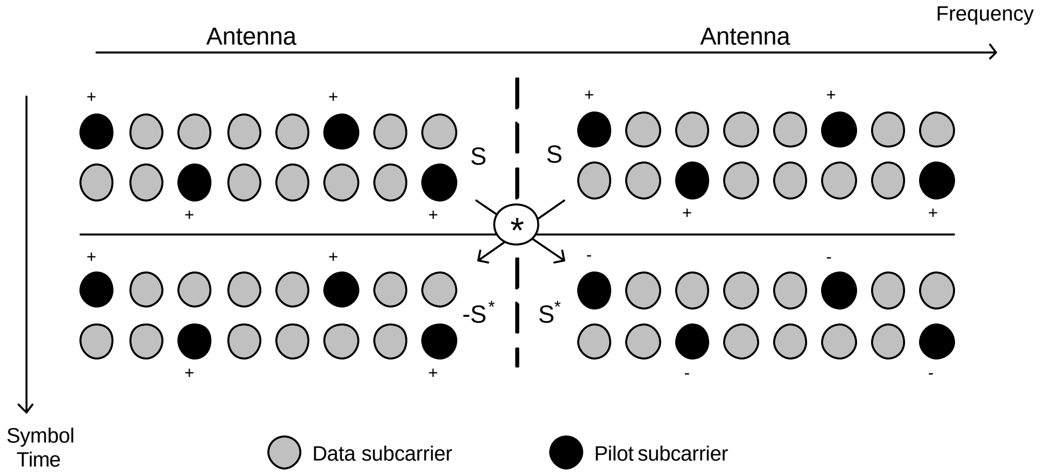

Figure 246 - 2-Antenna STC structure for DL PUSC

Section 8.4.8.2.1, page 588-589:

[Replace lines 39-42 with following text:]

For this configuration the pilot locations in the basic cluster structure are changed as indicated in Figure YYY to accommodate transmission from 4 antennas. Antenna #0 and antenna #1 use the pilots located in the first and third symbols of each two consecutive clusters, while antenna #2 and antenna #3 use the pilots located in the second and fourth symbols of each two consecutive clusters. Antenna #1 and Antenna #3 transmit pilots with negative polarity at the third and fourth symbols, respectively. This is depicted in Figure 251.

[Replace Figure 251 with the following figure]

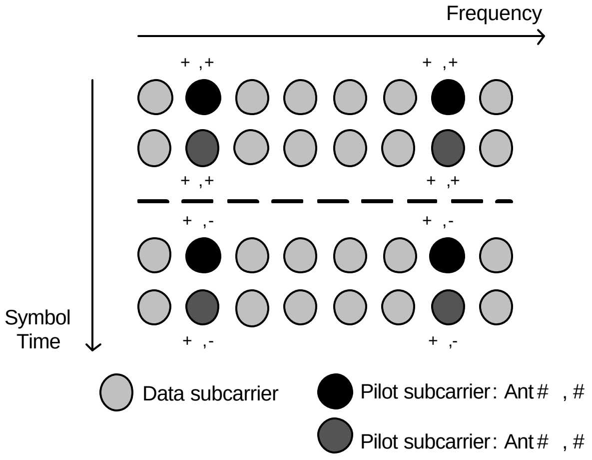

Figure 251 - Two consecutive DL PUSC clusters in 4 Antenna STC mode.

[Change text in page 621 lines 5-9, to the following text:]

$$\mathrm{Re}\{c_k\} = \frac{8}{3}\left(\frac{1}{2} - w_k\right)\cdot p_k \qquad (131)$$
$$\mathrm{Im}\{c_k\} = 0$$

where $p_k = 1$ for all modes other than STC mode of downlink PUSC, in which case p_k is the pilot's polarity as defined in section 8.4.8.

5. 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.