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Title	**Uplink OFDMA for 802.16a Physical Layer**
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Re:	256-FFT OFDMA mode
Abstract	Changes needed to support OFDMA (subchannelization) in 256-FFT node are presented.
Purpose	Enhancement of the 256-FFT mode.
Notice	
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Patent Policy and Procedures	

Uplink OFDMA for the 256 FFT mode

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1. Introduction

This submission discusses the changes to the D2 draft required to support up-link OFDMA in the 256 point FFT mode.

The submission is in response to discussions held in meeting #17, and follows the lines proposed by D. Beyer, K. Eklund, M. Kasslin and N. van Waes in document c802.16a-02/30. *While in many parameters our submission agrees with c802.16a-02/30, there are still some differences in approach that will need to be resolved at the March 2002 Plenary meeting*. The main differences apply to subcarrier allocation method, number of pilot subcarriers and the preferred FEC approach. We do accept Nokia's proposal to use 4 subchannels and to allow only certain combinations thereof (1, 2 or 4 subchannels).

The proposal is also addresses the comments #1062 by Nico van Waes, (and the related document c802.16a-02/30) and the comment #443 by Jori Arrakoski.

The motivation to support UL OFDMA in this mode is three fold:

A. To gain advantage from the OFDMA benefits, where they are most pronounced, namely the up-link.
B. To maintain a simple robust system.
C. To implement OFDMA as a natural extension to the OFDM mode, in which the UL OFDM is a special case of the UL OFDMA.

The OFDMA advantages in the UL are

A. The increase in link budget. The power concentration with the UL OFDMA can compensate for the low-transmit power of the SU.
B. Reduction of overheads due to preamble. For short bursts, the overhead associated with the preamble is significant. OFDMA can reduce this overhead by transmitting in smaller bandwidth, thus the burst length is increased while the system throughput remains the same. The preamble overhead (a fixed number of OFDM symbols) per burst is reduced.
C. In a like manner the overheads associated with data granularity are reduced.

2. Technical discussion

The proposed change allows the division of the uplink channel into 4 sub-channels. An SU can transmit utilizing one, two or four sub-channels. In the latter case, the entire uplink bandwidth is used by a single SU, and the system degenerates to the OFDM case. Thus the proposed change can be regarded as a natural extension to the OFDM scheme.

In the following the term *slot* shall be used to describe a rectangular allocation, which consists of one OFDM symbol in time and one sub-channel in frequency.

A typical uplink channel is shown in Figure 1, where a frequency-time map is shown. The frequency axis is shown in logical sub-channel units. Each rectangle is signifies an OFDMA slot. The physical partitioning into sub-channels is discussed in the following subsections.

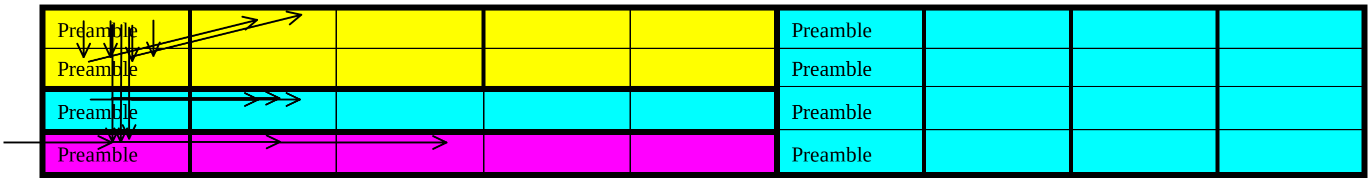

Figure 1 An example of time-frequency map in 256 OFDM, CC+RS coding

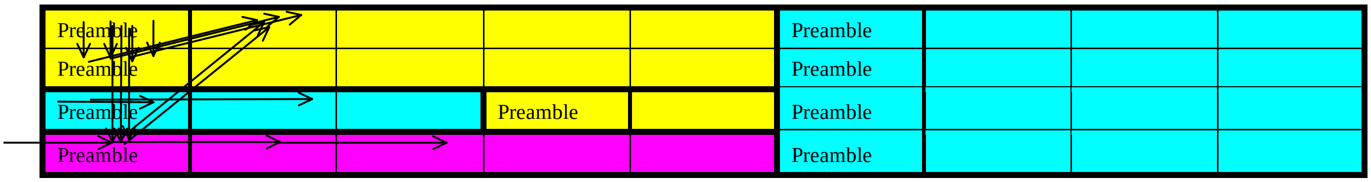

Figure 2 An example of time-frequency map in 256 OFDM, optional CC only mode

In Figure 1, four different up-link bursts are shown. The first occupies two sub-channels, and 8 OFDMA slots. The second and third occupies one sub-channel and 4 slots each, while the fourth occupies four sub-channels (i.e. the entire band) and 12 slots. This uplink burst is in fact an OFDM burst.

In Figure 2 we demonstrate the gain due to improved granularity when the optional Convolutional Coding mode is used. In this case we fit 5 bursts in same airtime, since two stations have very short payloads.

The mapping approach is frequency first. That is, symbols coming form the symbol mapper are mapped first in frequency, until the entire frequency allocation is exhausted, then in time. This has two advantages:

A. Simplification in the Base-station implementation, and more importantly,
B. Consistency with the OFDM mode, so that OFDM is a special case of the proposed uplink OFDMA.

2.1 Sub-channelization strategies

Different subchannelization schemes can be considered. We will compare in more detail three schemes.

A. Lumped sub-channels scheme.

This is the scheme proposed in Nokia's 802.16-02/30 submission. In this scheme the band is divided into four contiguous regions, as shown in Figure 3. This scheme is most simple to implement in the sense that the adjacent sub-channel interference, due to frequency errors and phase noise in minimized. A major drawback of this scheme, is the low level of frequency diversity that is achieved, making the system susceptible to low-delay spread multipath.

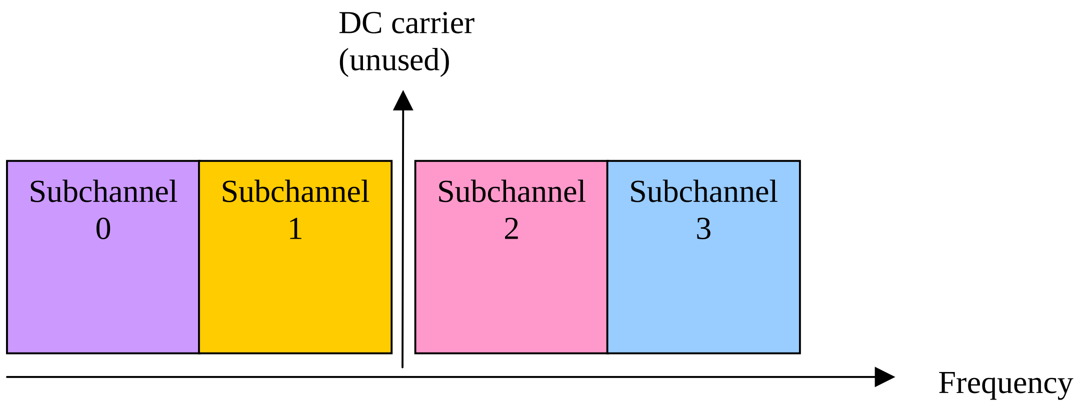

Figure 3 Lumped Approach

B. Interleaved scheme

In this scheme the sub-channels are interleaved across the entire band in a regular manner, where the subchannel k , occupies the subcarriers $k,k+4,k+8\ldots$. The scheme is schematically depicted in Figure 4. This scheme offers the most frequency diversity. On the other hand, the system is sensitive to interference from other sub-channels.

An alternative to the regular interleaving is to use permuted interleaving, in the same manner used in the 2K OFDMA mode. This has the potential of reducing interference from other base-stations, by using different permutation codes. However, it is judged that due to the small number of subchannels, the improvement of permuted interleaving will be very small.

A difficulty with regular interleaving is related to the pilot allocation. For simplicity of implementation we would like to have the same pilot allocation for all the subchannels, regardless of the subchannel index. As a result, when the four subchannels are used, (i.e. OFDM mode is used) the pilots will be lumped together, and the frequency diversity of the pilots will be degraded.

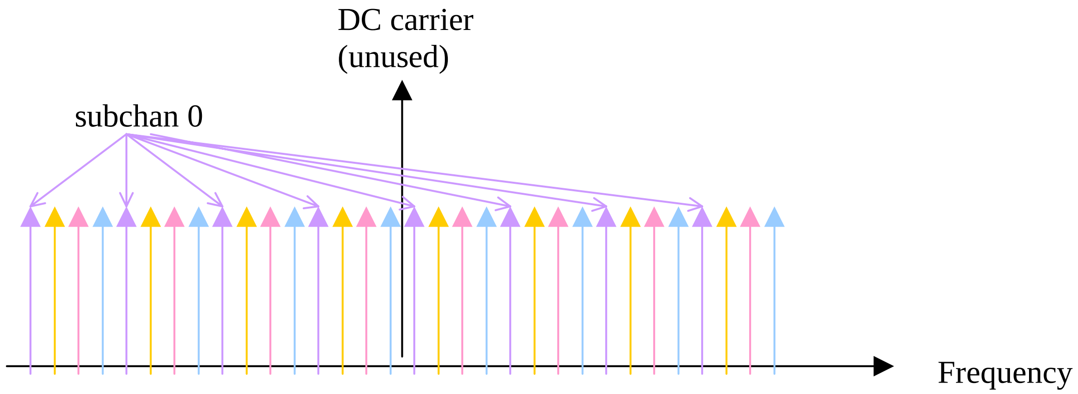

Figure 4 Interleaved approach

C. Clustered scheme

In the clustering schemes, the subcarriers are divided into small groups of contiguous subcarriers, termed *clusters*. This approach was proposed by Cimini, Daneshrad, and Sollenberger in [1].

In this scheme, each subchannel is composed of several clusters. This is depicted in Figure 5. This approach has the advantage of providing frequency diversity, while maintaining the immunity against interference from adjacent subchannels.

Clustering also overcomes the difficulty of pilot assignment, since adding a pilot within each cluster causes the pilots to spread evenly over the band.

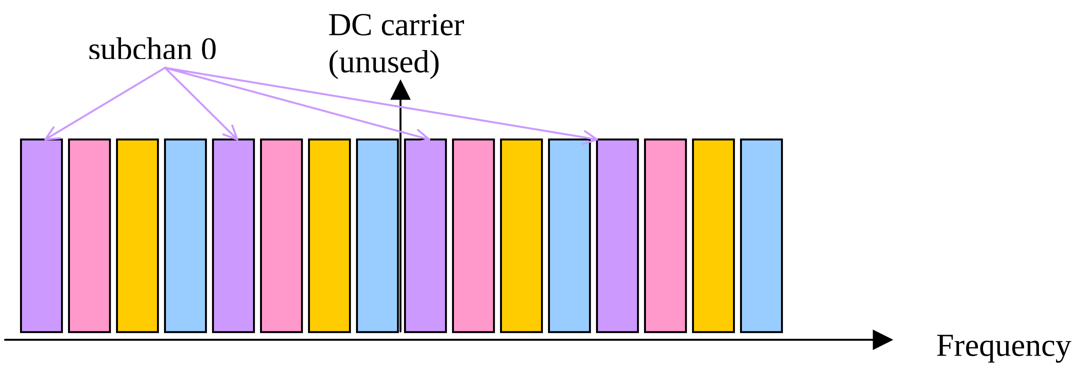

Figure 5 Clustered approach

In the text proposal below we have taken the clustered approach, as in our opinion it gives the best tradeoff between sensitivity to frequency errors and between the multipath induced diversity.

2.2 Number of Subcarriers

An important issue that needs to be addressed is the number of pilots. Draft D2 defines 8 pilots for 256 FFT OFDM mode. For OFDMA purpose this will give 2 pilots per subchannel, which is clearly not enough, especially in multipath situations, where both pilots may fade. The approach considered here is to increase the number of pilots to 16, giving 4 pilots per subchannel. As a result, the overall number of subcarriers is increased to 208. In a separate submission (802.16a-02/35) we address the issue of spectral masks and show that this increase is still well within the allowed limits.

2.3 Error correcting codes.

The OFDMA UL channels use the same mandatory coding scheme as the 256 OFDM , namely the concatenated RS and CC. The mandatory RS+CC uses blocks which are the equivalent of one OFDM symbols, or 4 OFDMA slots. Thus all allocations using the mandatory mode, are in multiples of 4 slots. This the case of the example given in Figure 1.

Additionally the optional TPC codes, for which the block size is also 4 slots, can be used. In this case also the allocations are in multiples of 4 slots. This means that for one subchannel allocation the data duration is a multiple of 4 OFDM symbols, and in allocation of 2 subchannels the allocation is a multiple of 2 subchannels.

One of the niceties of the OFDMA approach, however, is the reduction in allocation granularity. Clearly, this is in contradiction with the requirements of having allocations which are multiples of 4 slots. To overcome this limitation, an optional coding scheme is proposed. *The scheme is convolutional code with zero tail termination*.

Please note:

A. This is an optional mode for the UL only.
B. The mandatory RS+CC has the reputation of being more robust at low bit error rate than the CC only. However, the decision whether to use RS+CC, or the CC code is entirely at discretion of the scheduler of the base-station. So the scheduler can trade-off between reliability (when required) and data overhead.
C. For a system to operate the UL OFDMA system, the implementation of CC is not mandatory. This is true for both SU and Base-station. The base station will not invoke this mode in stations not supporting it, and in the case BST does not support the CC mode it will always ask stations to transmit in the mandatory CC+RS mode.

3. References

[1] L.J Cimini, B. Daneshrad, and N.R Sollenberger, "*Clustered OFDM with transmit diversity and coding", in Proc. IEEE Global Telecom Conf*"." London U.K., Nov 1996 pp 703-707.

4. Recommended changes

4.1 Changes to Clause 8.3.5.5.1

Page 154, line 55, insert:

An UL PHY burst may be sent in an optional subchannelization mode. In such case the assignments to different stations may overlap in time. In this mode the subcarriers are divided into 4 groups (subchannels). A station may be assigned either 1, 2 or all 4 subchannels. When all 4 subchannels are assigned, the subchannelized mode becomes equivalent to the OFDM mode. The implementation of the subchannelized mode is optional and shall apply only to a P-MP networks.

4.2 Changes to Clause 8.3.5.5.2.2.1

page 163, 5, replace table 216 with:

Table 208— OFDM UL-MAP information element

Syntax	**Size, bits**	**Notes**
UL-MAP_Information_Element() {		
CID	16	
UIUC	4	
Time Offset	12	
Subchannelization code	4	0000-default, OFDM 0001 subchannels 0+1+2+3 0010 subchannels 0+1 0011 subchannels 2+3 0100 subchannel 0 0101 subchannel 1 0110 subchannel 2 0111 subchannel 3 1xxx – reserved
Length in OFDM Symbols	8	
}		

page 163, after 59, add:

Sub-channelization code
The subchannelization code indicated which of the subchannels are assigned to the transmission. Note that OFDM mode corresponds to assigning all the subchannels to same station.

Number of OFDM Symbols
The number of OFDM symbols assigned to carry the UL Burst.

4.3 Changes To Clause 8.3.5.5.3

The following table replaces table 212 on page 159:

Parameter	Value
N_FFT	256
N_used	208
Guard Carriers	Left: -128 .. –105 Right: 105 .. 127
BasicConstantLocationPilots	-98, -46, 7, 59, (within subchannel 0) -85, -33, 29, 72, (within subchannel 2) -72, -20, 33, 85, (within subchannel 1) -59, -7, 46, 98 (within wubchannel 3)
Allocated carriers	Subchannel 0: {-104 .. –92, -52 .. -40, 1 .. 13, 53 .. 65} Subchannel 2: {-91 .. –79, -39 .. -27, 14 .. 27, 66 .. 78} Subchannel 1: {-78 .. –66, -26 .. -14, 27 .. 39, 79 .. 91} Subchannel 3: {-65 .. –53, -13 .. -1, 40 .. 52, 92 .. 104}

4.4 Changes to Clause 8.3.5.5.4.2.1

On pg. 160, 46, after table 213, add:

When the concatenated convolutional – Reed-Solomon encoding is invoked on uplink in conjunction with subchannelization, the number of OFDM symbols allocated shall contain an integral number of FEC blobks.

4.5 New Clause 8.3.5.5.4.2.2

On pg. 160-161, Insert the following new clause after 8.3.5.5.4.2.1, renumbering the existing Turbo Product Codes section to 8.3.5.5.4.2.3

8.3.5.5.4.2.2 Convolutional Coding Only (optional)

This is an optional mode which is allowed only on the UL, and only in conjunction with subchannelization. Reed-Solomon encoding shall not be used. Prior to encoding the encoder shall be reset to an all-zero state. The last byte of the allocation (region) shall be set to all zeros and shall not be scrambled.

Modulation	Bytes Per Subchannel in One OFDM Symbol		Code Rate
	Uncoded	Coded	
QPSK	6	12	1/2
QPSK	9	12	3/4
16 QAM	12	24	1/2
16 QAM	18	24	3/4
64 QAM	24	36	2/3
64 QAM	27	36	3/4

When the convolutional coding mode is invoked, an arbitrary number of OFDM symbols may be allocated.

4.6 Changes To Clause 8.3.5.5.4.3

page 161, 32, replace first sentence with:

All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of coded bits allocated per OFDM symbol, N_CBPS. N_CBPS varies depending on modulation and the number of subchannels allocated in the OFDM symbol.

4.7 Changes to Clause 8.3.5.5.5.2

page 163, 5, replace table 216 with:

Contention Channel Index	bit 0	bit 1	bit 2	bit 3
0	-104	-52	+1	+53
1	-99	-51	+2	+54
2	-98	-50	+3	+55
...	...	...	...	...
k	k-104	k-52	k+1	k+53
...	...	...	...	...
50	-54	-2	+51	+103
51	-53	-1	+52	+104

4.8 Changes to Clause 11.1

Make the changes proposed in contribution C80216a-02_30.pdf by Beyer, Eklund, Kasslin and von Waes, page 44, lines 1-44.