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Re:	Call for proposals IEEE 802.16e-03/02: Mobility Enhancements to IEEE Standard 802.16/802.16a
Abstract	Proposed 802.16e PHY and MAC changes for OFDM FFT-256 mode
Purpose	To be used as baseline for OFDM FFT-256 modifications for mobile operation
Notice	
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Modifications to OFDM FFT-256 mode for supporting mobile operation

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1. Introduction

The scope of this submission is to propose and discuss the modifications to the OFDM FFT-256 Physical Layer of the 802.16a in order to support mobile subscriber stations. The emphasis in the proposal is both on improving the link budget, which is relevant to low power, obstructed and battery operated equipment in general, and on withstanding channel variations, which is relevant to mobility.

A goal that we have put to ourselves is a strong compatibility to 802.16a, and in particular to its optional subchannelized mode. On uplink the transmissions corresponding to the proposed 802.16e-subchannelized scheme can be performed simultaneously with the 802.16a subchannelized traffic.

On downlink we maintain the structure of 200 subcarriers of which 8 are pilots. The MAC frame is partitioned into the part intended for fixed stations, followed by the part intended for the mobile stations. The mobile part is augmented with training information allowing tracking of a time-varying channel. We propose to include two forms of augmentation – one by hopping pilots and one by midamble insertion.

The description below was written to allow easy conversion into a normative text.

2. Uplink

Discussion of tradeoffs

Number of subchannels

The most fundamental parameter is the subchannelization ratio, N. Crudely speaking it determines the:

- Bit rate per subchannel = (Full BW bit rate)/N
- Power concentration = 10* log10(N)
- # subcarriers per subchannel = (total #subcarriers)/N
- Allocation quantum duration = (allocation quantum [bits])/(data rate per subchannel)

The most important tradeoff is what is more important – the link budget or the minimum data rate? If the data rate is too low, is it still "broadband"?

Another dilemma is related to allocation quantum duration. If it is short, we have more flexibility in fitting allocation quanta in the MAC frame interval and in partition between the bandwidth allocated to 802.16e stations and to 802.16a stations.

The table below compares several subchannelization options.

# subchannels	48	32	24	16	12
# carriers/subchannels	4	6	8	12	16
#data OFDM symbols/block 48 sc/block, except ** 96sc/block	12	8	6	4	6**
#training OFDM symbols/block	3	2	1	1	1
#total OFDM symbols/block	15	10	7	5	7
Time efficiency	80%	80%	86%	80%	86%
Power concentration re. OFDM	17 dB	15 dB	14 dB	12 dB	11 dB
Data Rate per subchannel, 3.5M	44 kb/s	66 kb/s	95 kb/s	133 kb/s	190 kb/s
Block duration [usec], 3.5M	1080	720	504	360	504
Block duration [usec], 5M, 1/8	756	504	352.8	252	352.8

For the sake of brevity, we shall not discuss the training details for each option.

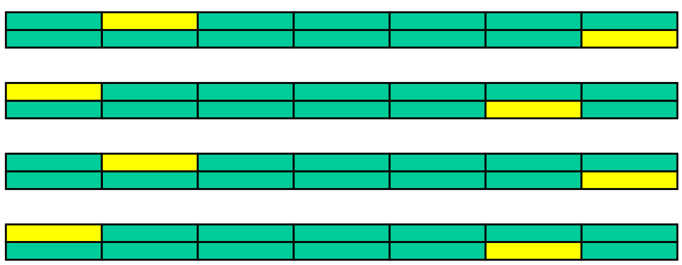
We have decided to base our proposal on subchannelization factor of **24**, as for the preferred bandwidths of 3.5 MHz and 5 MHz it exhibits a good tradeoff of power concentration, data rate per subchannel, and allocation block granularity

Subcarrier allocation strategy

In previous submission two options were presented – hopping narrowband clusters, and scattered nonhopping subcarriers. In this proposal we have decided to focus on nonhopping solution. The main reason is that this form of allocation does not demand extensive buffering in the transmitter to achieve frequency diversity effect, simplifying thus the CPE side.

The allocations are done in blocks of 56 subcarriers, of which 48 are data subcarriers and 8 are pilot (=training) subcarriers. With 8 subcarriers per subchannel in each OFDM symbol, the duration of each allocation block is 7 OFDM symbols.

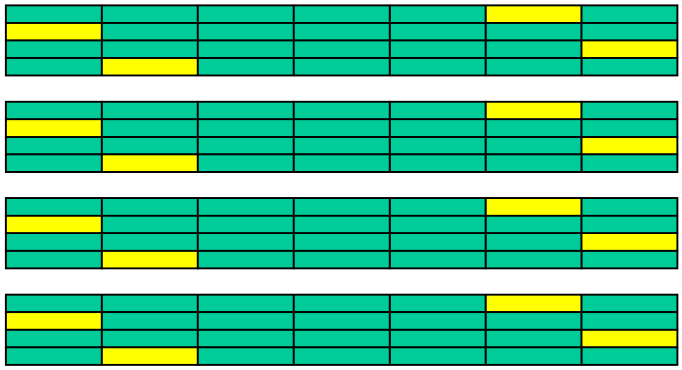
Each subchannel is composed of 8 subcarriers. Those are split into 4 pairs. This is illustrated graphically in the figure below.



The correlation of channel coefficients within each pair allows saving in training overhead. Two training subcarriers are paid for each group of 12 data subcarriers. The training subcarriers are spread in time, to allow tracking of channel variations.

By splitting the 8 subcarriers into 4 clusters, frequency diversity is maintained within each subchannel. Subcarrier pairs are spaced approximately ¼ BW apart, however the spacing is slightly irregular, as it is in 802.16a. By this a frequency diversity order of 4 is retained, inheriting the advantages of irregularity attained as well.

Additional feature of the proposed allocation is that when consecutive pairs of subchannels are assigned, forming effectively “12 subchannel” structure, they form clusters 4-subcarrier wide, which allow further improved channel estimation by utilizing the pilots jointly.



Harmonization with 802.16a subchannelization

The proposed subchannelization scheme has 24 subchannels. The 24 subchannels are divided into groups of 6, so that each six 802.16e subchannels use same carrier set as one 802.16a subchannel. This feature allows simultaneous use of both 802.16e-subchannelized stations and 802.16a-subchannelized stations.

Table 1: Allocation of subcarriers to subchannels in 802.16e

Sub-channel #	Sub-carrier 0	Sub-carrier 1	Sub-carrier 2	Sub-carrier 3	Sub-carrier 4	Sub-carrier 5	Sub-carrier 6	Sub-carrier 7
0	-87	-86	-49	-50	1	2	64	65
1	-85	-84	-47	-48	3	4	66	67
2	-83	-82	-45	-46	5	6	68	69
3	-81	-80	-43	-44	7	8	70	71
4	-79	-78	-41	-42	9	10	72	73
5	-77	-76	-39	-40	11	12	74	75
6	-100	-99	-36	-37	14	15	51	52
7	-98	-97	-34	-35	16	17	53	54
8	-96	-95	-32	-33	18	19	55	56
9	-94	-93	-30	-31	20	21	57	58
10	-92	-91	-28	-29	22	23	59	60
11	-90	-89	-26	-27	24	25	61	62
12	-62	-61	-24	-25	26	27	89	90
13	-60	-59	-22	-23	28	29	91	92
14	-58	-57	-20	-21	30	31	93	94
15	-56	-55	-18	-19	32	33	95	96
16	-54	-53	-16	-17	34	35	97	98
17	-52	-51	-14	-15	36	37	99	100
18	-75	-74	-11	-12	39	40	76	77
19	-73	-72	-9	-10	41	42	78	79
20	-71	-70	-7	-8	43	44	80	81
21	-69	-68	-5	-6	45	46	82	83
22	-67	-66	-3	-4	47	48	84	85
23	-65	-64	-1	-2	49	50	86	87
24	-63	-88	-38	-13	38	13	88	63

The frequency domain structure of the subchannelization is summarized in the Table 1. In each row the subcarriers used by the subchannel are listed. The coloring is used to emphasize which subcarriers belong to the four original 802.16a subchannels.

Simultaneous operation of 802.16a- and 802.16e-subchannelized stations

The table bellow lists the possible partitions of 802.16a and 802.16e subchannels for simultaneous operation. For example, whenever subchannel 1 of 802.16a is unused, subchannels 0-5 of 802.16e can be utilized.

802.16a subchannels unused	Corresponding 802.16e subchannels
1	0-5
2	6-11
3	12-17
4	18-23
1+2	0-11
3+4	12-23
1+2+3+4 **	0-24

** In the case that all the bandwidth is allocated to mobile stations, 25th subchannel can be formed from the remaining 8 subcarriers.

The proposal described above is designed for strong backwards compatibility with 802.16a, and in particular with the subchannelization mode of 802.16a. By removing or weakening this requirement, e.g. dividing the bandwidth only half-half, and not with granularity of a quarter, the subcarrier allocation can be changed to achieve higher diversity order.

Training subcarriers

The allocation is done in blocks of 56 subcarriers, of which 48 are data subcarriers and 8 are pilot (=training) subcarriers. With 8 subcarriers per subchannel in each OFDM symbol, the duration of each allocation block is 7 OFDM symbols. Table 2 shows, within the time-subcarrier structure, which subcarriers are data and which are pilots.

Table 2: Time-subcarrier table indicating which subcarriers are pilots

subcarrier / time	0	1	2	3	4	5	6	7
0	D	P	D	D	D	P	D	D
1	D	D	D	P	D	D	D	P
2	D	D	D	D	D	D	D	D
3	D	D	D	D	D	D	D	D
4	D	D	D	D	D	D	D	D
5	P	D	D	D	P	D	D	D
6	D	D	P	D	D	D	P	D

Whenever a subcarrier is used for a pilot, its value is determined by a lookup into the vector:

Pilot_value(-100..100) = {… TBD …};

Note: The amount of possible allocations is large, and it is difficult to design a sequence that will have low PAPR for all allocation combinations. This consideration, however, is of reduced importance, since the accompanying data subcarriers in any case outnumber the pilot subcarriers.

Interleaving

The interleaving uses a 48-subcarrier interleaver dependent on constellation, same way as 802.16a uses in 1/4BW allocation.

Modulation process

The subcarrier filling goes according to the following pseudocode:

```
// OFDM symbol loop
For (t=tstart; t<=tstop; t++) {
  // subchannel loop
  For (scnl= scnl_start; scnl<=sc_stop; scnl++) {
    // subcarrier within subchannel loop
    For (scrr=0; scrr<8; scrr++) {
      // whether subcarrier is data or pilot depends on location
      // of subcarrier in time and frequency within block
      If is_pilot((t-tstart) mod #symbols_per_block, scrr)
        Subcarrier(t,LUT(scnl,scrr))=pilot_value(LUT(scnl,scrr))
      Else
        Subcarrier(t,LUT(scnl,scrr))=data_from_interleaver
             }
        }
   Zero the rest of the subcarriers;
   IFFT the symbol and transmit
   }
```

The ordering of the carriers in the LUT (as shown in Table 1) takes care to spread the coded bits in frequency. The allocation is always a multiple of 48 subcarriers, so at the end of the process always a whole amount of interleaving blocks is used.

The data is read sequentially from the interleaver and used to fill the OFDM symbols one by one. Therefore, the buffering requirements in the transmitter are low.

3. Downlink

The support of mobility demands, among other things, operation of the receiver in a time varying channel. The receiver needs to update its channel estimate in order to demodulate correctly the QAM modulated subcarriers. We propose to implement in the standard two mechanisms – the hopping pilot mechanism and the midamble insertion mechanism.

Scattered pilot solution

The accepted practice, for this purpose, is to vary the pilot locations from symbol to symbol, and by that to reach, within certain time effective pilot density which allows channel estimation. This solution is well studied, for example, in the context of DVB-T standard and is used in the OFDMA portion of 802.16a standard.

In this proposal we retain from 802.16a the structure of 8 pilots in each OFDM symbol (1 pilot out of 25 subcarriers, on average). By varying the pilot locations with a periodicity of 8 OFDM symbols, an effective pilot density of 1-out-of-3 is achieved. This combination of parameters is a reasonable tradeoff between Doppler tolerance and delay spread tolerance.

The pilot locations, for each of the 8 OFDM symbols in a period, are listed in the table below:

Symbol number	Pilot locations							
Symbol #1	-98	-73	-48	-23	2	27	52	77
Symbol #2	-89	-64	-39	-14	11	36	61	86
Symbol #3	-80	-55	-30	-5	20	45	70	95
Symbol #4	-95	-70	-45	-20	5	30	55	80
Symbol #5	-86	-61	-36	-11	14	39	64	89
Symbol #6	-77	-52	-27	-2	23	48	73	98
Symbol #7	-92	-67	-42	-17	8	33	58	83
Symbol #8	-83	-58	-33	-8	17	42	67	92

The switchover to “mobile” downlink traffic occurs after the downlink traffic to fixed stations was transmitted. At this stage, the channel estimate at the mobile stations can be significantly corrupted. In order to restore channel estimate and enter a tracking mode we recommend to transmit a midamble (preamble in the middle), one OFDM symbol long, at the transition. This is similar to the switchover to STC mode in current 802.16a standard. We recommend this preamble to differ from the regular preamble, to avoid false detection during frame start search.

Simplified solution based on midamble insertion

Some may claim that retraining the channel estimate by periodically inserting a midamble, and then continuing with the regular DL format. While in our view this approach is unsatisfactory for vehicular speeds, we are willing to accept that for certain low-speed applications it might be satisfactory. In order to accommodate this solution we propose to define an IE which will indicate an insertion of a midamble.

4. Map elements for mobile operation

UL_mobile_IE

This IE indicates the region used for mobile uplink transmission allocation. The parameters are same as for UL_subchannelization_IE. In the case that UL_mobile_IE is after an UL_subchannelization_IE and the map elements following it, the Duration field may accept value 0, in which case the mobile map elements will start allocation from same OFDM symbol as indicated by the preceding UL_subchannelization_IE. Stations not supporting mobile UL extensions will skip the UL mobile map according to the Length_of_Allocations field value.

Syntax	Size	Notes
UL_mobile_Information_element() {		
extended UIUC	4 bits	Mobile_UL = 0x04
Duration	12 bits	Cumulative duration of the allocations
Length_of_allocations	12 bits	Number of bytes consumed by mobile UL allocations following this IE
}		

UL map element modifications

Syntax	Size	Notes
UL-MAP_information_element() {		
CID	16 bits	
UIUC	4bits	
if (UIUC == 4)		
Focused_contention_IE()	28 bits	
else if (UIUC == 15)		
Extended UIUC dependent IE	variable	Power_Control_IE() or AAS_UL_IE() or Subchannelization_IE() or UL_Mobile_IE()
else {		
if (subchannelization){		
Subchannel Index	3 bits	0x0 = Reserved 0x1 = use subchannel 1 0x2 = use subchannel 2 0x3 = use subchannel 3 0x4 = use subchannel 4 0x5 = use subchannel 1 and 3 0x6 = use subchannel 2 and 4 0x7 = Reserved
Duration	5 bits	in OFDM symbols
Reserved	4 bits	
}		
if (Mobile_UL){		
Start Subchannel Index	**5 bits**	**0 .. 24**
Start time offset	**5 bits**	**in multiples of 7 OFDM symbols**
Number of Subchannels	**5 bits**	**0 .. 24**
Duration	**5 bits**	**in multiples of 7 OFDM symbols**
}		
}		
Else		
Duration	12 bits	
}		
}		

The allocation is performed in rectangles, the length of which is a multiple of 7 OFDM symbols, and the width is an integral number of subchannels.

Mobile_DL_IE

In the DL-MAP, an Mobile_DL enabled BS may transmit DIUC=15 with the Mobile_DL_IE() shown in Table xx to indicate that the subsequent allocations shall be encoded with variable location pilots. No preceding DL allocations shall be Mobile_DL encoded and all subsequent DL allocations until the end of the frame shall be Mobile_DL encoded.

Table xx: OFDM Mobile_DL Information Element format

Syntax	Size	Notes
Mobile_DL_Information_element() {		
extended DIUC	4 bits	Mobile_DL = 0x03
}		

The duration of the DIUC=15 Mobile_IE() allocation is always exactly one OFDM symbol. During this allocation, the midamble shall be transmitted. After this allocation, the BS shall transmit with variable pilot locations until the end of the frame.

Midamble_DL_IE

In the DL-MAP, a Midamble_DL enabled BS may transmit DIUC=15 with the Midamble_DL_IE() shown in Table xx to indicate that a midamble shall be inserted.

Table xx: OFDM Mobile_DL Information Element format

Syntax	Size	Notes
Midamble_DL_Information_element() {		
extended DIUC	4 bits	Midamble_DL = 0x04
}		

The duration of the DIUC=15 Midamble_DL_IE() allocation is always exactly one OFDM symbol. During this allocation, the midamble shall be transmitted. After this allocation, the BS shall transmit regular DL with fixed pilot locations. The Midamble_DL_IE may be repeated during a MAC frame more than once, at BST discretion.

Bibliography

[1] C802.16e-03/07, “OFDM (FFT 256) Fixed & Mobile System Considerations”

[2] C802.16e-03/03, “Initial PHY proposal for 802.16e”

[3] 802.16e-03/02, “Call for Proposals on IEEE Project 802.16e: Mobility Enhancements to IEEE Standard 802.16/802.16a”