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Title	Corrections for UL channel Sounding
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Re:	IEEE P802.16e-2005 and IEEE P802.16-2004 In response to call for maintenance change request (IEEE 802.16maint-06/018) issued on 2006-06-16.
Abstract	Corrections and clarifications to UL channel sounding.
Purpose	Adopt changes.
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Corrections For UL Channel Sounding

Intel, Motorola, Samsung, Arraycomm, Beceem, Alcatel, Fujitsu

1. Motivation

Analysis of currently defined UL channel sounding mechanism in the standard found several problems that render the feature unusable. The problems, identified by several companies, are listed below:

1. Overlapping sounding allocations of different lengths using cyclic shift separability do not retain intra-cell orthogonality due to an erroneous requirement defining the sequence to be length dependent thereby assigning different Golay values to identical OFDM subcarriers.
2. Inter-cell interference mechanisms as defined do not actually prevent high interference and correlation between cells and are very difficult to predict or plan.
3. Sounding transmission PAPR as defined today has very large variance and can reach 11dB as opposed to having 5-6dB PAPR as stated in standard. This PAPR problem is due to several mistakes in signal definition (including corrupted sequence table and incorrect definition of sequence rotation).
4. MS maximum power capability for sounding signal is not explicitly defined.
5. Sounding zone region definition with respect to number of symbols and relationship with underlying permutation zone requires clarification to prevent ambiguity.

These problems require correction of channel sounding section in the standard and some related clarifications. The following contribution makes the relevant corrections to solve the problems identified.

2. Details

2.1. Solution of intra-cell orthogonality and inter-cell interference

Maintaining intra-cell orthogonality and low cross-correlation between sounding signals generated by MS-s in adjacent cells is enabled by fixing the transmitted sub-carrier coefficients to their respective sub-carrier index and defining a specific rotation scheme that enables planning of the cross correlation between adjacent cells.
The solution requires a fixed assignment of sequence values to subcarriers according to the following equations. First we define b_k to be the modulation coefficients (similar to c_k in equation 100 of 802.16-2004 but with shifted k index) of all the used tones in the sounding symbol, k between 0 and (N_{used} -1). b_k always equal 0 for k= (N_{used} -1)/2 which is the DC sub-carrier (N_{used} is defined according to AMC permutation, i.e. 1729 for 2K FFT, 865 for 1K, 433 for 512 etc.).

2.1.1. Cyclic shift separability

For CSIT type A with cyclic shift separability we define

$$b_k = \begin{cases} \left[2\cdot\left(\frac{1}{2} - G\left(\left[k+u+offset_D(fft)\right] \bmod 2048\right)\right)\right]\cdot e^{-j\frac{2\pi kn}{P}} & k \in B, k \neq \frac{N_{used}-1}{2} \\ 0 & \text{otherwise} \end{cases}$$

where

k is the subcarrier index ($0 \le k \le N_{used} - 1$, N_{used} is the number of usable subcarriers in the sounding symbol),

G(x) is the low PAPR Golay sequence as defined in table 315e ($0 \le x \le 2047$),
P is the max cyclic shift index (from the sounding instructions),
n is the assigned cyclic time shift index (also from the sounding instructions), which ranges from 0 to *P*-1,
B is the group of allocated subcarriers/bands according to the sounding instructions.
u is a shift value defined in the PAPR reduction, and safety zone, and sounding zone allocation IE (0 <= u <= 127),
fft is the FFT size used,
$offset_D(fft)$ is an FFT size specific offset into the Golay sequence, which is defined in table 315g.

2.1.2. Decimation separability

For CSIT type A with decimation separability we define

$$b_k = \begin{cases} 2 \cdot \left(\frac{1}{2} - G([k + u + offset_D(fft)] \bmod 2048) \right), & k \in B, k \neq \frac{N_{used} - 1}{2}, k \bmod D = g \\ 0, & otherwise \end{cases}$$

where
D is the decimation value (from the sounding command) (2,4,8,16,32,64,128,5)
g is the actual decimation offset (= d + antenna + optional_randomization)
k is the subcarrier index ($0 \le k \le N_{used} - 1$, N_{used} is the number of usable subcarriers in the sounding symbol),
G(x) is the low PAPR Golay sequence as defined in table 315e ($0 \le x \le 2047$),
B is the group of allocated subcarriers/bands according to the sounding instructions.
u is a shift value defined in the PAPR reduction, and safety zone, and sounding zone allocation IE (0 <= u <= 127),
fft is the FFT size used,
$offset_D(fft)$ is an FFT size specific offset into the Golay sequence, which is defined in table 315g.

2.2. Golay sequence correction

Existing Golay sequence in 802.16e-2005 has been corrupted when converted from binary to hexadecimal sequence. The sequence should be corrected to a true Golay sequence which can enable the low PAPR as originally intended. The existing sequence has high PAPR of up to 11dB compared to 5-6dB PAPR achievable with the original sequence.
See Figure 1 for PAPR comparison between the existing corrupted sequence and the correct Golay sequence.

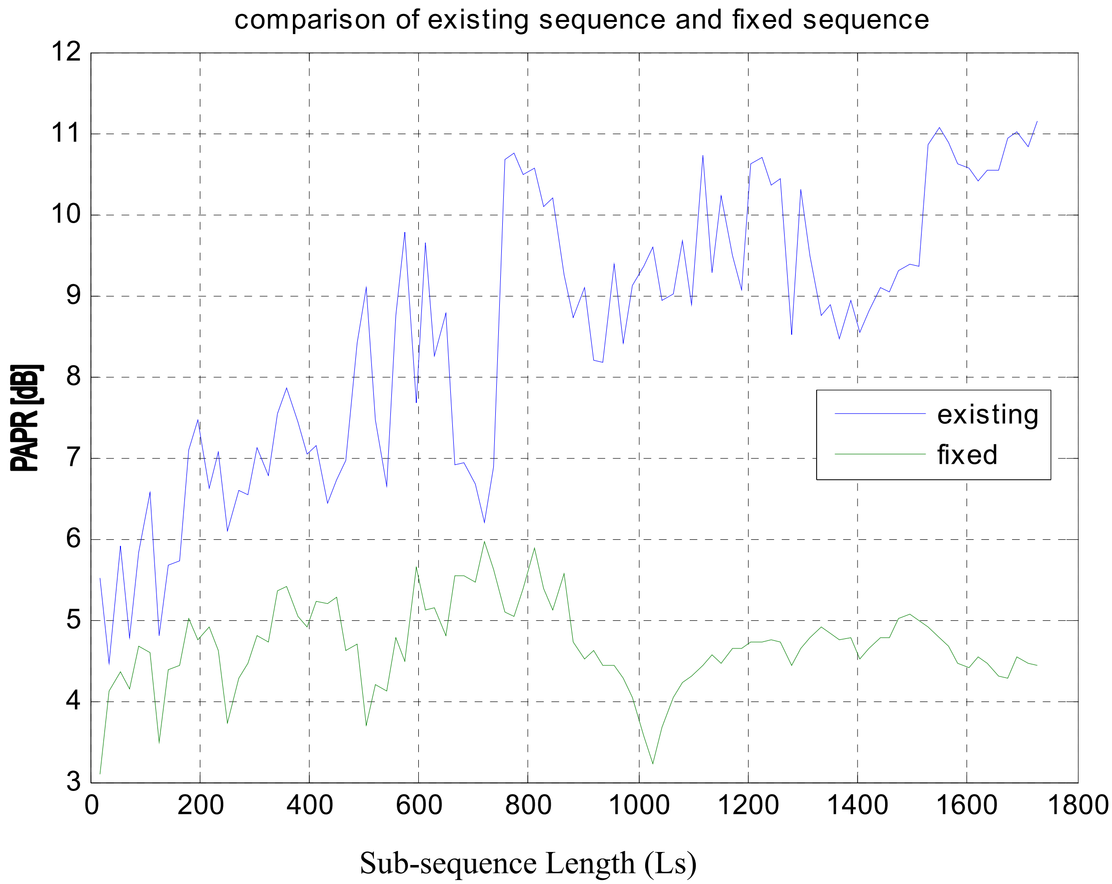
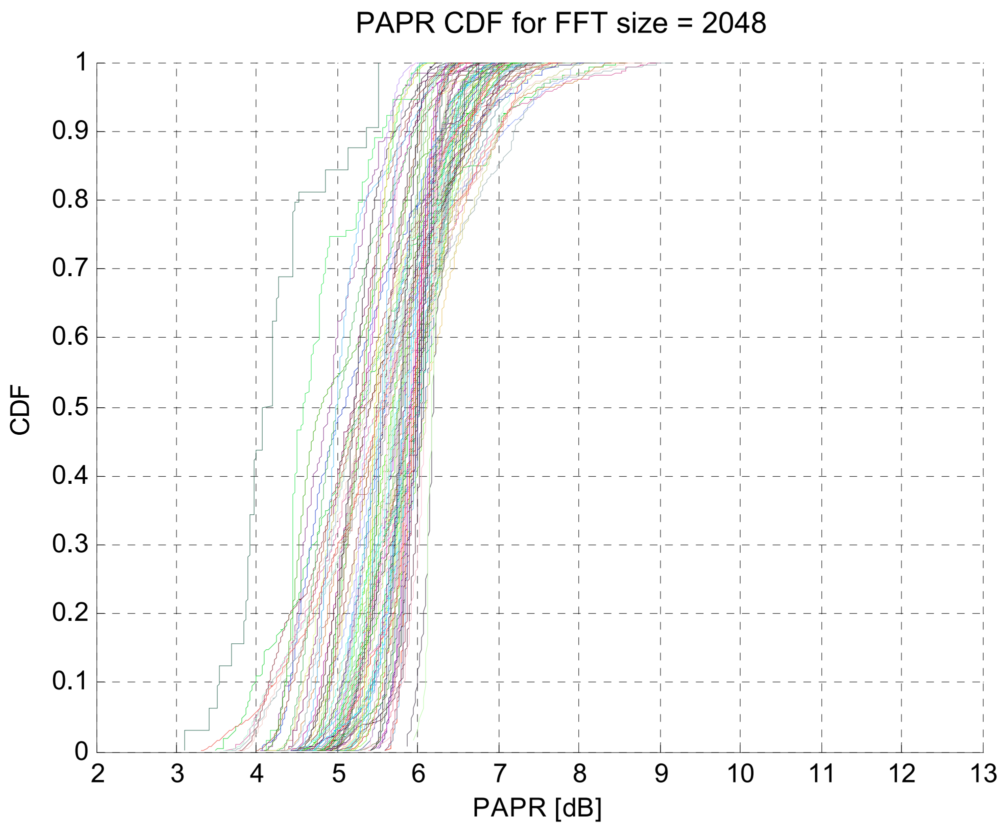


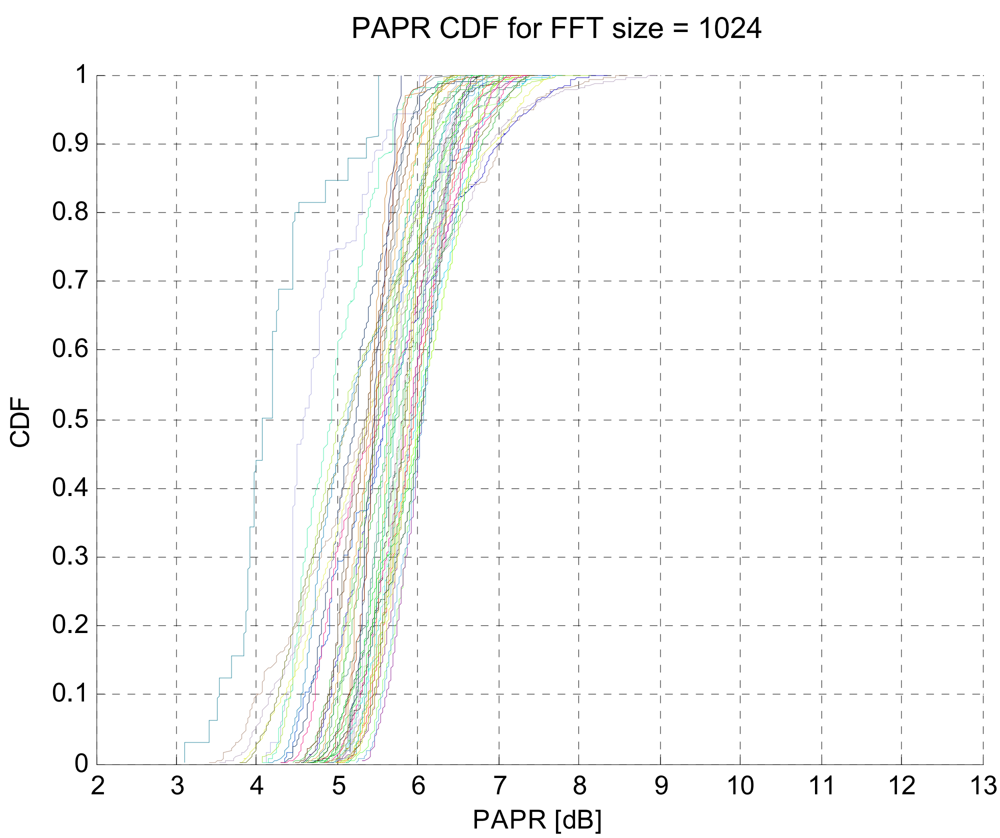
Figure 1 - PAPR comparison between the existing corrupted sequence (existing) and the correct Golay sequence (fixed). Note that this graph does not reflect effects of rotation.

2.3. Dealing with the DC tone

When the allocated sub-carriers/bands of the sounding signal contain the DC tone it is important to prevent discontinuity of the Golay sequence which increases the PAPR by approximately 2 dB. Therefore it is required to puncture the Golay sequence at the DC tone (i.e. skip over the sequence value that would have been assigned to the DC tone).

In a similar manner it is important to prevent discontinuity of the decimation interval when crossing the DC, therefore the DC tone should be counted in the calculation of the decimation, and if the decimation offset selected leads to selection of the DC tone as one of the active tones it should be punctured as well resulting in almost double the decimation interval without a transmitted tone.


PAPR CDF for FFT size = 2048
CDF
PAPR [dB]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
10
11
12
13


PAPR CDF for FFT size = 1024
CDF
PAPR [dB]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
10
11
12
13

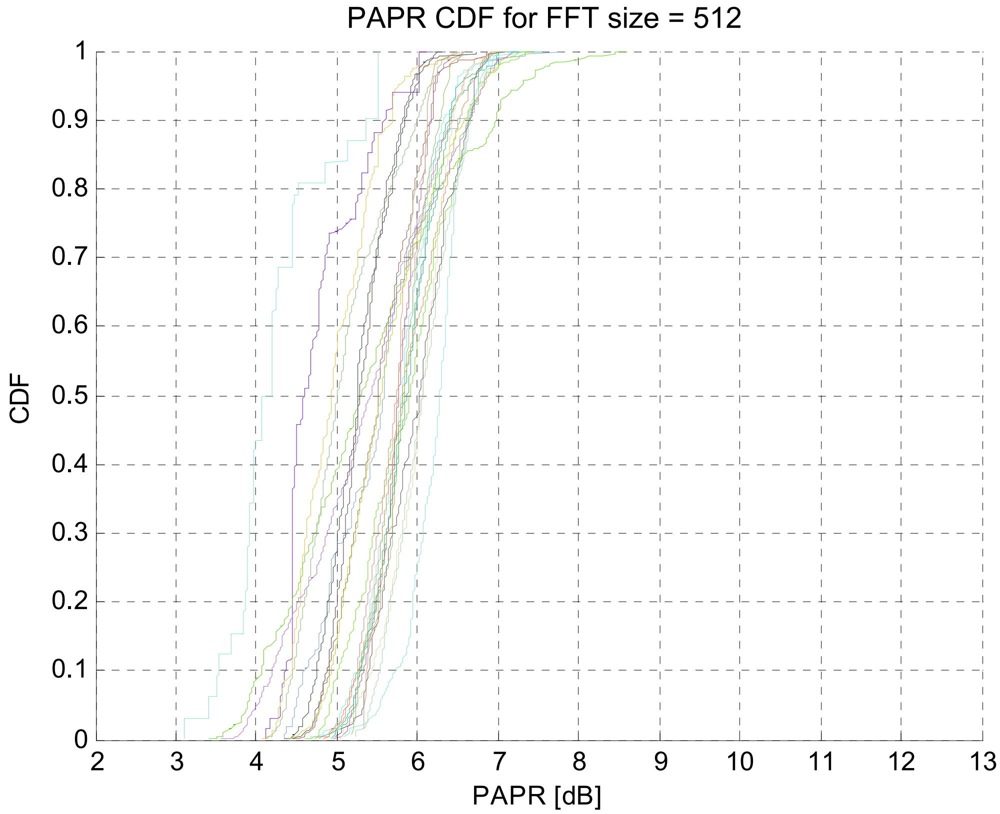
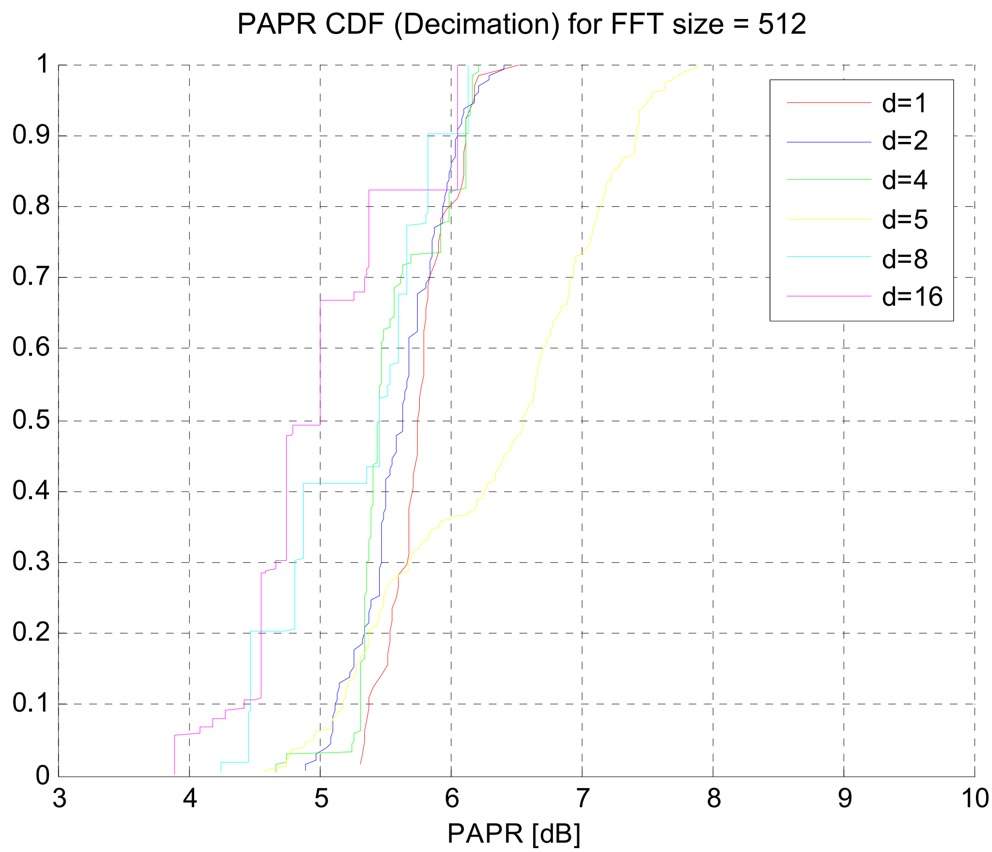
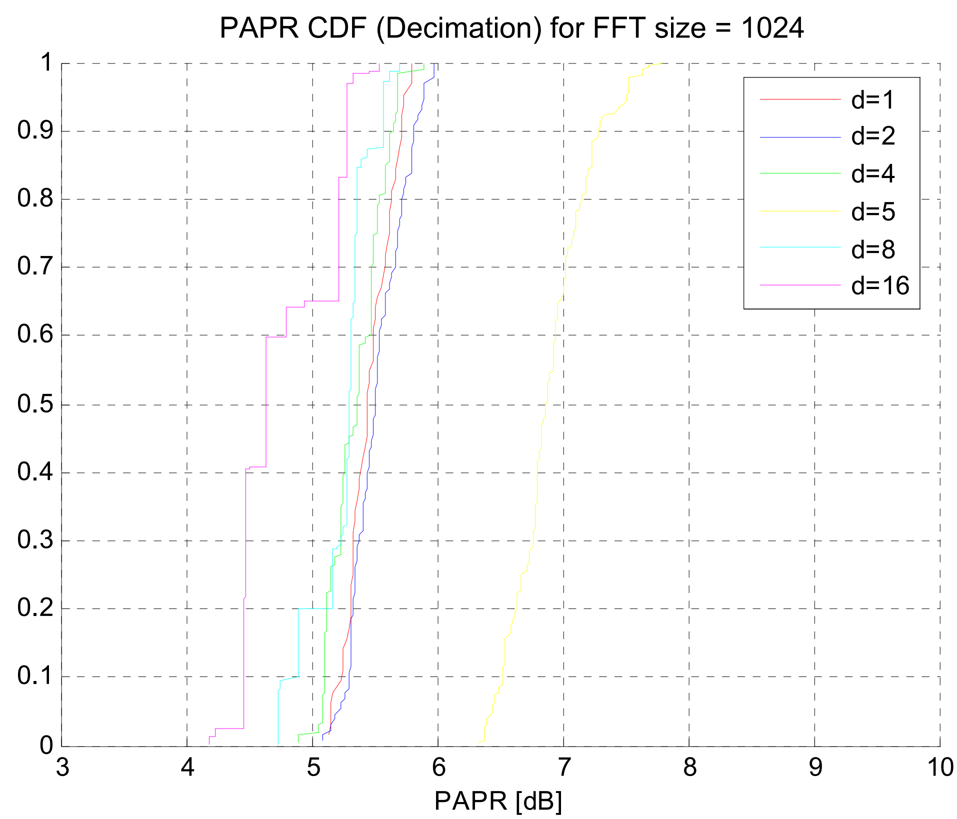


Figure 2 – CDF of PAPR for various **cyclic shift allocation lengths** over all possible inter-cell variation values


PAPR CDF (Decimation) for FFT size = 512
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
4
5
6
7
8
9
10
PAPR [dB]
d=1
d=2
d=4
d=5
d=8
d=16


PAPR CDF (Decimation) for FFT size = 1024
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
4
5
6
7
8
9
10
PAPR [dB]
d=1
d=2
d=4
d=5
d=8
d=16

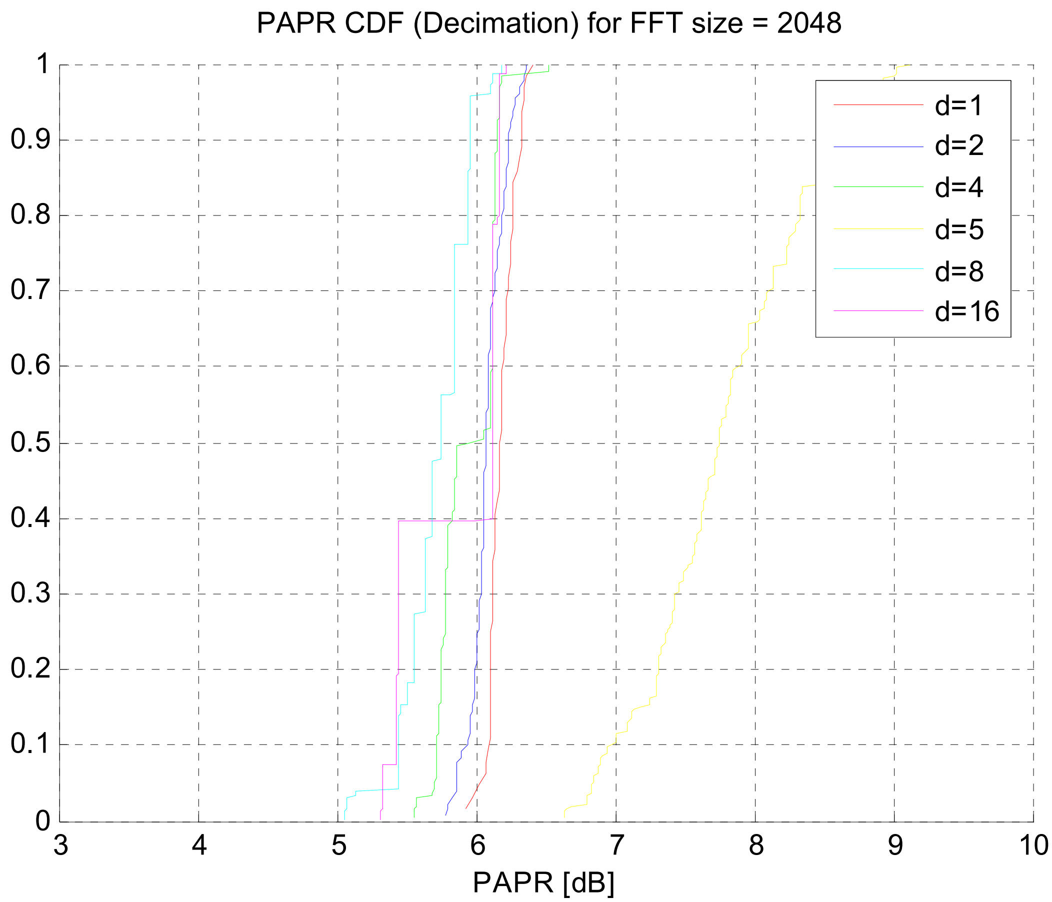


Figure 3 – CDF of PAPR for various **decimation separability options** over all possible inter-cell variation values

3. Changes summary

*[**Modify** following paragraph in Section 8.4.6.2.7.1 Page 552]*

Define b_k as the complex coefficients modulating all subcarriers in the sounding symbol, $0 \le k \le N_{used} - 1$ (N_{used} is the value assigned to Band AMC permutation for the respective FFT size), such that the signal transmitted by the MS is defined by:

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi f_c t} \cdot \sum_{\substack{k=0 \\ k \ne \frac{N_{used}-1}{2}}}^{(N_{used}-1)} b_k \cdot e^{j2\pi (k - \frac{N_{used}-1}{2}) \Delta f (t - T_g)} \right\}$$

For CSIT capability A, if the separability type is zero, then the sequence b_k used by a transmit device (MS or MS antenna) associated with the n-th index is determined according to the following equation:

$$\cancel{s_{un}(k) = s_u(k) e^{-j\frac{2\pi k n}{P}}}$$

$$b_k = \begin{cases} \left[2 \cdot \left(\frac{1}{2} - G([k + u + offset_D(fft)] \bmod 2048) \right) \right] \cdot e^{-j\frac{2\pi k n}{P}} & k \in B, k \ne \frac{N_{used}-1}{2} \\ 0 & \text{otherwise} \end{cases},$$

where

k is the subcarrier index ~~of the occupied subcarrier~~ (~~$0 \le k \le L_s - 1$~~ $0 \le k \le N_{used} - 1$, ~~L_s~~ N_{used} is the number of usable ~~occupied~~ subcarriers in the sounding symbol),
$G(x)$ is the low PAPR Golay sequence as defined in table 315e ($0 \le x \le 2047$),
P is the max cyclic shift index (from the sounding instructions),
n is the assigned cyclic time shift index (also from the sounding instructions), which ranges from 0 to P-1,~~.~~
B is the group of allocated subcarriers/bands according to the sounding instructions.
u is a shift value defined in the PAPR reduction, and safety zone, and sounding zone allocation IE (0 <= u <= 127),
fft is the FFT size used,
$offset_D(fft)$ is an FFT size specific offset as defined in table 315g.

~~The sequence $s_u(k)$ whose length is equal to L_s (a multiple of 18), is obtained as a cyclic shift of the sequence $S(k)$ by an offset equal to u such that the variable u stands for the decimal value of the number represented by the binary digits b5…b0 and~~

~~b5..b3 = three least significant bits of UL_Permbase,~~
~~b2..b0 = three least significant bits of the frame number.~~

~~The sequence $s(k)$ is the binary subsequence of the Golay sequence given in Table 316b, starting from location $Offset(Ls)$, the latter given by Table 316c. The PAPR for any of these subsequences is approximately 5 dB.~~

*[**Modify** following paragraph in Section 8.4.6.2.7.1 Page 553, below table 315f]*

For CSIT type A, if the separability type is one, then the occupied ~~a spacing of D~~ subcarriers are decimated (where D is the Decimation value) starting with offset d relative to the first used subcarrier (k=0). ~~is maintained between every two occupied subcarriers associated with the same transmit device.~~ The occupied subcarriers for each transmit device shall be modulated by BPSK symbols extracted from the Golay sequence according to the following equation:

$$b_k = \begin{cases} 2\cdot\left(\frac{1}{2} - G([k+u+offset_D(fft)]\bmod 2048)\right), & k \in B, k \neq \frac{N_{used}-1}{2}, k \bmod D = g \\ 0, & otherwise \end{cases}$$

where

- *k* is the subcarrier index ($0 \le k \le N_{used} - 1$, N_{used} is the number of usable subcarriers in the sounding symbol),
- *G(x)* is the low PAPR Golay ~~sequence as~~ defined in table 315e ($0 \le x \le 2047$),
- *fft* is the FFT size used,
- *u* is a shift value defined in the PAPR reduction, and safety zone, and sounding zone allocation IE (0 <= u <= 127),
- *$offset_D(fft)$* is an FFT size specific offset as defined in table 315g.
- *B* is the group of all allocated subcarriers/bands according to the sounding instructions,
- *D* is the decimation value (from the sounding command),
- *g* is the actual decimation offset (as defined below)

~~in the same manner as done in 8.4.9.4.3, Equation (130). The relevant value of *wk* is taken from the Golay sequence in Table 316b with offset given according to Table 316d.~~ Let $\hat{d}$ be the value of the decimation offset *d* plus the relative offset according to the MS antenna number (when Multi-Antenna Flag equals 0, then only the first antenna does sounding). If Decimation Offset Randomization equals 0, then $g=\hat{d}$, otherwise *g=((p((~~baseID~~ IDcell+Frame Number)* mod32*) +* $\hat{d}$ *)*mod*D*, where *p(x)* is the value in PermutationBase as defined by Table 311 ("OFDMA downlink carrier allocations for FUSC in 2048 FFT mode") at the location *x*. The first subcarrier to be occupied is located at the g^{th} subcarrier. The pseudo-random cyclic shift of the decimation offset may be used to combat inter-cell interference. On the other hand, when this pseudo-random cyclic shift is not used, then an alternative strategy for combating inter-cell interference involves assigning each neighboring cell/sector a set of decimation offsets that is different from those used by neighboring cells/sectors.

*[**Replace** Table 315e in Section 8.4.6.2.7.1 Page 552 with]*

Table 315e—Golay sequence of length 2048 bits

```
0xEDE2,0xED1D,0xEDE2,0x12E2,0xEDE2,0xED1D,0x121D,0xED1D,0xEDE2,0xED1D,0xEDE2,0x12E2,
0x121D,0x12E2,0xEDE2,0x12E2,0xEDE2,0xED1D,0xEDE2,0x12E2,0xEDE2,0xED1D,0x121D,0xED1D,
0x121D,0x12E2,0x121D,0xED1D,0xEDE2,0xED1D,0x121D,0xED1D,0xEDE2,0xED1D,0xEDE2,0x12E2,
0xEDE2,0xED1D,0x121D,0xED1D,0xEDE2,0xED1D,0xEDE2,0x12E2,0x121D,0x12E2,0xEDE2,0x12E2,
0x121D,0x12E2,0x121D,0xED1D,0x121D,0x12E2,0xEDE2,0x12E2,0xEDE2,0xED1D,0xEDE2,0x12E2,
0x121D,0x12E2,0xEDE2,0x12E2,0xEDE2,0xED1D,0xEDE2,0x12E2,0xEDE2,0xED1D,0x121D,0xED1D,
0xEDE2,0xED1D,0xEDE2,0x12E2,0x121D,0x12E2,0xEDE2,0x12E2,0xEDE2,0xED1D,0xEDE2,0x12E2,
0xEDE2,0xED1D,0x121D,0xED1D,0x121D,0x12E2,0x121D,0xED1D,0xEDE2,0xED1D,0x121D,0xED1D,
0x121D,0x12E2,0x121D,0xED1D,0x121D,0x12E2,0xEDE2,0x12E2,0x121D,0x12E2,0x121D,0xED1D,
0xEDE2,0xED1D,0x121D,0xED1D,0xEDE2,0xED1D,0xEDE2,0x12E2,0xEDE2,0xED1D,0x121D,0xED1D,
0x121D,0x12E2,0x121D,0xED1D,0xEDE2,0xED1D,0x121D,0xED1D
```

*[**Add** following text below table 315e]*

Comment to table 315e: hexadecimal series should be read as a sequence of bits where each 16bit word is started at the MSB and ends at the LSB where the second word MSB follows. First bit of sequence is referenced as offset 0.

*[**Remove** Table 315f in Section 8.4.6.2.7.1 Page 553]*

*[**Replace** Table 315g in Section 8.4.6.2.7.1 Page 554 with]*

Table 315g—Offsets in the Golay sequence

FFT Size	Offset
128	859
512	542
1024	60
2048	30

*[**Add** following text below the table in section 11.8.3.2 page 672 of **802.16-2004**]*

OFDMA MS that support Uplink Channel Sounding shall use the BSPK value to report the maximum transmit power for the Uplink Channel Sounding Transmission.