Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Interpolation effects for OFDM preamble**
Date Submitted	**2001-11-09**
Source(s)	Tal Kaitz BreezeCOM Ltd. Atidim Technology Park Bldg. 1 P.O.B 13139 Tel Aviv 61131 Israel Voice: + 972 3 6456273/262 Fax: + 972 3 6456222/290 mailto: talk@breezecom.co.il
Re:	OFDM Preamble Ad-Hoc discussions
Abstract	The effects of interpolation on channel estimation accuracy for OFDM preamble are discussed.
Purpose	
Notice	
Release	
Patent Policy and Procedures	

Effects of Interpolation on Channel Estimation Accuracy for OFDM Preamble

Tal Kaitz, Alvarion

(Formerly BreezeCOM)

1. Introduction

The proposed preamble for 802.16.3 OFDM PHY layer, is composed of two identical sequences, and a cyclic prefix. Each sequence is composed of 128 points. This structure is shown in Figure 1.

Cyclic prefix	128 point sequence	128 point sequence

Figure 1 Proposed preamble structure

The periodic structure of the preamble allows for accurate timing and frequency offset recovery, in the presence of unknown channel response. However a difficulty associated with the periodicity, is that the preamble contains energy only in the *even* subcarriers, and no energy in the *odd* subcarriers. As a result, the channel response can be directly evaluated only at the even subcarriers. The channel response at the odd carriers needs be evaluated by some form of interpolation.

The objective of this document is to study the effects of interpolation on the channel estimation accuracy, thereby to establish the validity of the proposed approach.

In the following, three preamble schemes are compared. Among the three schemes, only the first requires the use of interpolation techniques.

2. The considered approach

We consider here the problem of interpolation/smoothing in the frequency domain. For each subcarrier, several neighboring subcarriers are combined to estimate the response of the subcarrier under study.
For odd subcarriers, the neighboring even subcarriers are used to estimate the response at that frequency. Thus interpolation is performed.
For even subcarriers, the neighboring subcarriers and the subcarrier under study are used to improve the channel estimation. Thus smoothing is performed.
In both cases, special care must be taken at the band edges, and also near the non-energizing DC carriers, where some if the neighboring subcarriers are missing.

Here, linear interpolation/filtering is used. The interpolation coefficients are derived by following an Minimum Mean Square Error approach.

Before applying the interpolation and filtering, fine timing estimation is applied. Thus was shown to be detrimental to the accuracy of the interpolation.

3. Definition of terms

Let us consider the 802.16.3 OFDM scheme. We need to estimate 200 spectral lines, half of which are located on either sides of the unused DC sub-carrier. The channel response is estimated from the preamble. We shall compare three approaches

a. The proposed scheme, discussed above, namely one OFDM symbol composed of two identical sequences of 128 points each. As discussed only 100 subcarriers are energized.

b. Non-periodic FFT symbol, where all the 200 subcarriers are energized.

c. Same as (b) but with two repetitions of the same OFDM symbol. This estimation overhead for this scheme is twice as much as for the other schemes.

For all cases, we shall assume that the power of the preamble is boosted by 3dB relative to the power of the data. This is made possible due to the fact the subcarrier phase loading is judiciously chosen to yield extremely low peak to average power ratio.

Here we shall use the following notations:

E_s – the average symbol power at FFT output. The average is over subcarriers and channel instances.
N_0 – thermal noise power at the FFT output.

_ = E_s/N_0 – signal to noise at the FFT output.

_$_e$ - Channel estimation signal to noise before smoothing interpolating.

_$_f$ - Channel estimation signal to noise after smoothing and interpolating.

Ns - Number of symbols used for estimation. (1 for option a and b. 2 for option c).

G - Preamble power boosting.

D- Degradation due to channel estimation error.

For all cases, the estimation error, before smoothing is related to the signal to noise by:

$$\_{e} = \_ \cdot Ns \cdot G. \qquad (1)$$

Additionally, the degradation due to channel estimation is

$$D = 10\,?\log_{10}\frac{\gamma_f^{-1}+\gamma^{-1}}{\gamma^{-1}} \quad \text{(dB)} \qquad (2)$$

4. Results and Performance Comparison.

In this section we shall consider the case of 3.5 MHz channels, sampled at 4Ms/s.
The channel model considered was similar to SUI #4 with directional antennas. The length of the impulse response of scaled to 8uS (instead of 4uS) in order to test the system at extreme conditions.

Accurate knowledge of SNR value was assumed. Additionally, no ISI effects and no residual frequency error were considered.

4.1 Effects of interpolation

First the interpolating scheme (a) was considered. The resulting estimation error per subcarrier, for various SNR is shown in Figure 2.

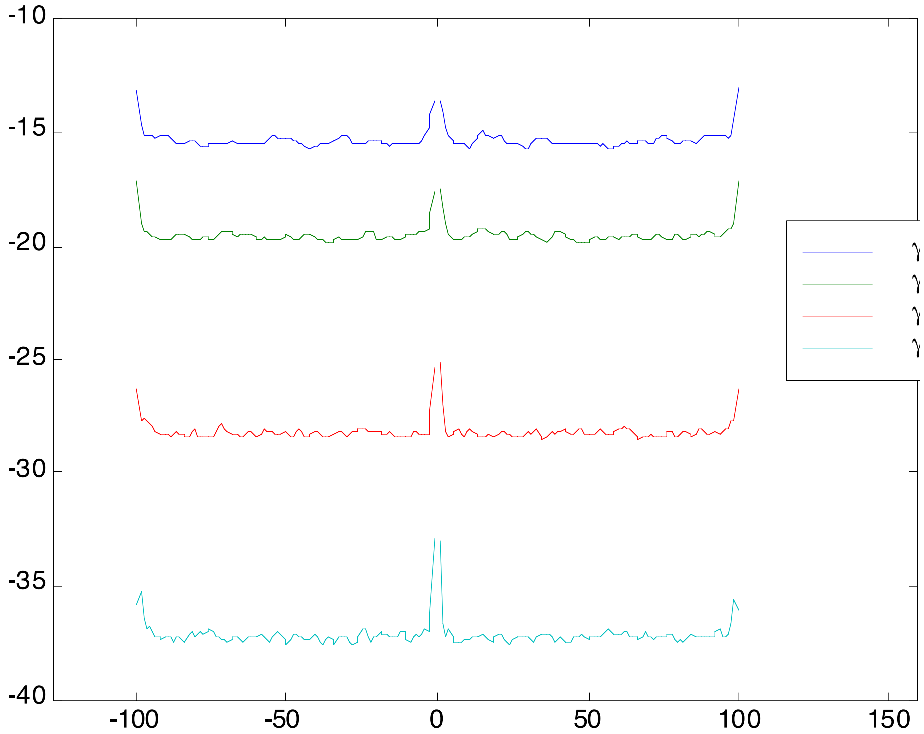

Figure 2 Estimation error vs. Subcarrier location

From Figure 2, several observations can be made:

- The estimation error are more severe at the band edges and near the DC carrier. In these cases, there are fewer neighboring subcarriers.
- The difference between decoding SNR _ and estimation SNR depends upon the former.
- The SNR improvement for the _=5dB case is about 10 dB. This is partly related to the power boosting of 3 dB and partly to the interpolation/smoothing effect.
- For _=30dB the improvement is only 7dB.

4.1 Comparison

In this section the three discussed schemes are compared.

First, they were compared in terms of Estimation SNR after filtering ($_f$) . For all schemes, smoothing (and interpolation were appropriate) was performed. The results are shown in Figure 3.

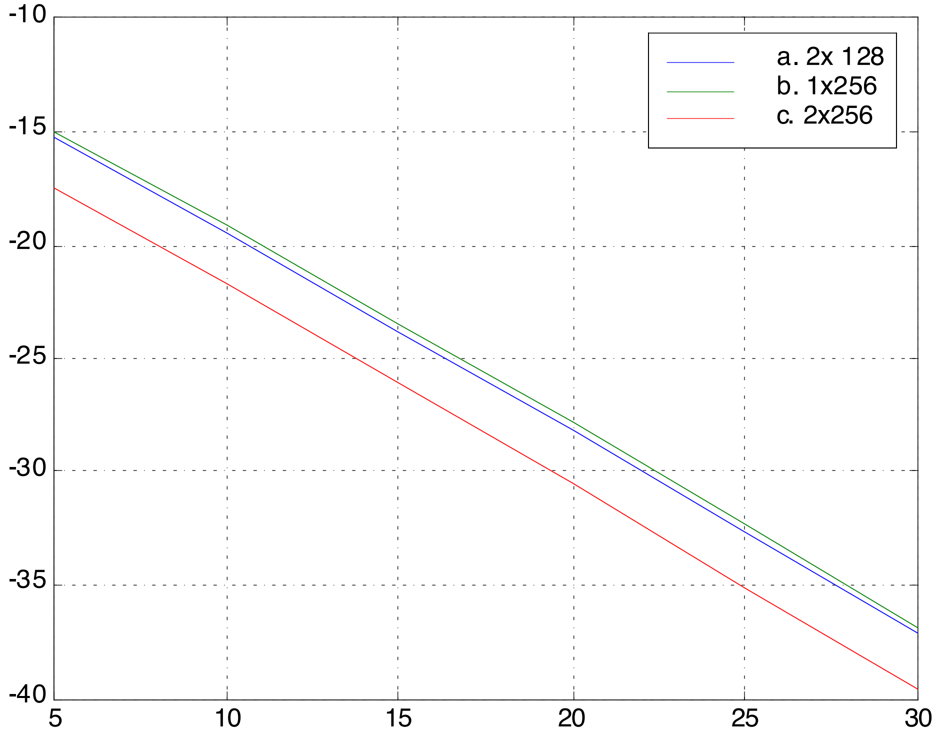

Figure 3 Estimation error vs. SNR

As can be seen the first two schemes are almost identical. Scheme (c) is 3 dB better. This is not surprising given that it uses twice as many points.

Next, the degradation due to estimation error was computed per equation (2). This is shown in Figure 4. The differences between the schemes are fractions of a dB.

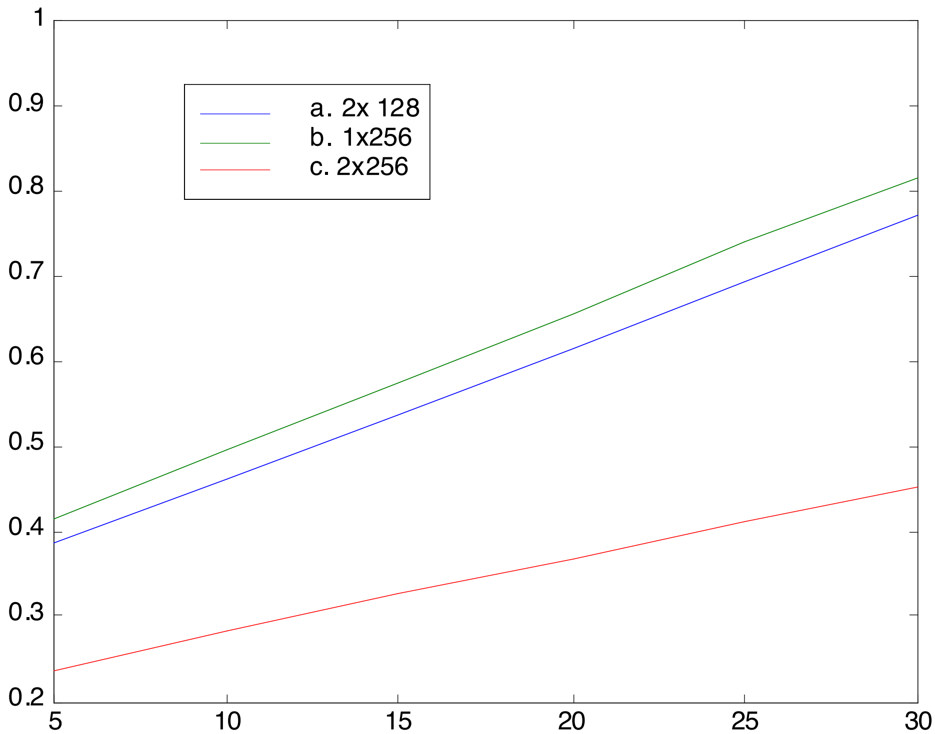

Figure 4 Degradation to Estimation Errors

5. Extension to higher Bandwidths.

So far only the 4MHz bandwidth case. We shall now extend the results to other rates. We shall use the following assumptions:

- SUI 4 model with maximum impulse response length of 4uS delay.
- SNR is _=20dB.
- Bandwidth in the range of 4…20MHz.
- Cyclic prefix is 1/8 of an OFDM symbol.
- 256 points FFT.

As a result of last 3 assumptions, the cyclic prefix is in the range of 1.6uS…8uS.

The degradation is plotted as of function of the ratio between the impulse length (4uS) and the cyclic prefix length.
The rationale for this is as follows: As the bandwidth increases the interpolation techniques begins to fail. However, as the bandwidth is increased and the delay spread is kept the same, degradation may also occur due to inter-symbol-interference, and this may be the dominating factor. Thus the relevant parameter is the ratio between the cyclic prefix and the delay spread.

The results are shown in Figure 5. It can be seen that (b) and (c) are pretty robust. However (a) begins to fail when the impulse response is longer then about twice the guard interval.

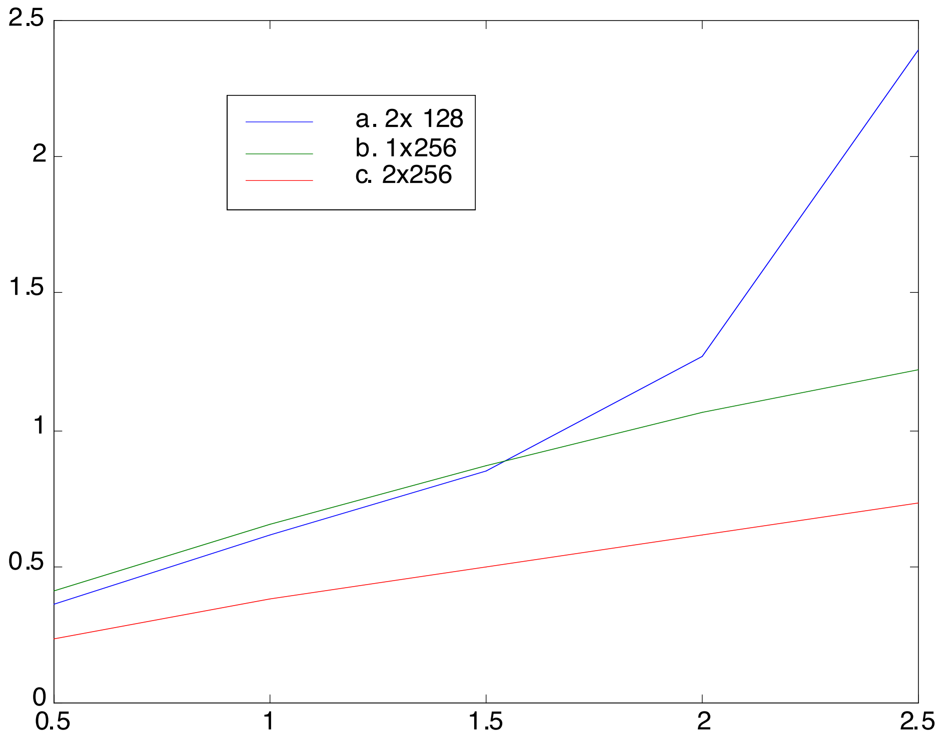

Figure 5 Degradation vs. normalized delay spread

6. Conclusions

It was shown that the proposed schemes incurs little degradation when the delay spread is shorter then twice the cyclic prefix. (For the case of cyclic prefix of 1/8 and SUI 4 model).
For higher delay spreads some degradation is caused and other schemes, which require no interpolation, perform better.