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Title	**OFDMA Downlink - Evaluation of channel estimation performance under mobile conditions**	
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Abstract	In the Downlink of the OFDMA mode the pilots are spaced 6 subcarriers apart over a 2 symbol cycle in FUSC mode, and 4 subcarriers apart over a 2 symbol cycle in PUSC mode. This spacing is not adequate for highly dispersive multi-path channels, as will be shown in this performance evaluation.	
Purpose		
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OFDMA Downlink - Evaluation of channel estimation performance under mobile conditions

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1. Problem Statement

In the Downlink of the OFDMA mode, as specified in [1] and [2], the pilots are spaced 6 subcarriers apart over a 2 symbol cycle in FUSC mode, and 4 subcarriers apart over a 2 symbol cycle in PUSC mode. This spacing is not adequate for highly dispersive multi-path channels, as will be shown in the performance evaluation that follows.

2. Performance Evaluation

2.1. Model description

A 2K FFT over a 20MHz bandwidth is assumed, leading to a 11.1 KHz subcarrier spacing.

Let us consider a channel model with a flat power-delay profile and a flat Doppler spectrum, as depicted in Figure 1.

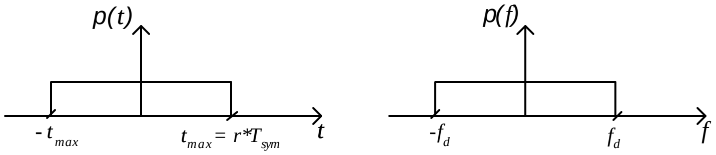

Figure 1

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

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

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

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

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 Furthermore, some level of over-sampling is needed in order to improve estimation S/N even further.

2.2. Channel Estimator

The channel estimator used for this performance evaluation is the well-known 2D MMSE estimator [3]. The channel was estimated for the third symbol of a four symbol group (i.e. with a look-ahead of one symbol) using all available pilots.

2.3. Results (current text)

2.3.1. DL FUSC

Let us first consider the DL FUSC scheme. The pilot spacing is 6 subcarriers over a cycle of 2 symbols. Pilots are boosted by 2.5dB over data subcarriers. For $f_d=0$, the maximal single-sided delay that can be supported is $\frac{1}{12}\cdot T_{sym}$ without over-sampling. Figure 2 and Figure 3 below show the estimation S/N and combined S/N[1] for $t_{\max}=\frac{1}{16}\cdot T_{sym}$ and $\frac{1}{12}\cdot T_{sym}$. As can be seen from these figures, this scheme leads to non-negligible degradation in both scenarios, and completely fails for channels with $t_{\max}\geq\frac{1}{12}\cdot T_{sym}$.

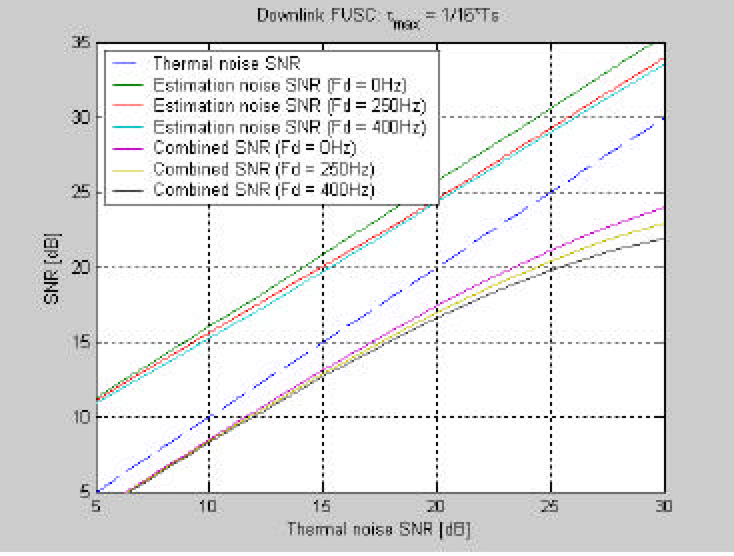

Figure 2

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[1] comprised of estimation noise, thermal noise, and Doppler-induced ICI.

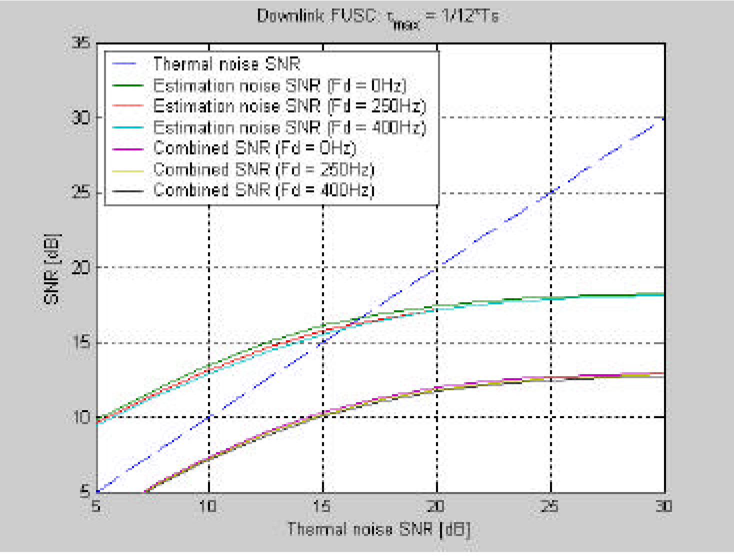

Figure 3

2.3.2. DL FUSC - STC

In STC mode, only half of the pilots are available to each transmitter, hence the pilot spacing is in effect doubled to 12 subcarriers over the 2 symbol cycle. This limits the maximal supported single-sided delay spread to ${}^{1}\!/_{24}\cdot T_{sym}$. Figure 4 shows how this scheme fails for $t_{\max} = {}^{1}\!/_{16}\cdot T_{sym}$.

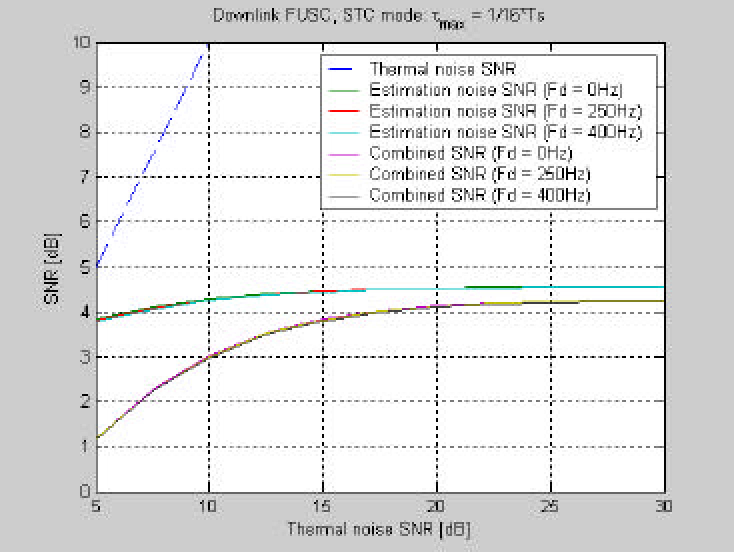

Figure 4

2.3.3. DL PUSC

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). Pilots are spaced 4 subcarriers apart and are boosted by 2.5dB over data subcarriers.

Figure 5 and Figure 6 below show the S/N and combined S/N for $t_{\max} = {}^{1}\!/_{16} \cdot T_{sym}$ and ${}^{1}\!/_{12} \cdot T_{sym}$. As can be seen from these figures, this pilot spacing leads to non-negligible degradation in both scenarios.

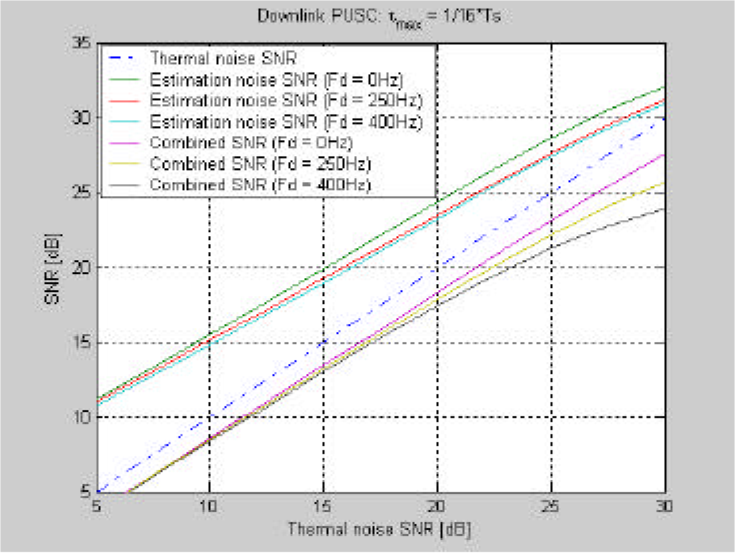

Figure 5

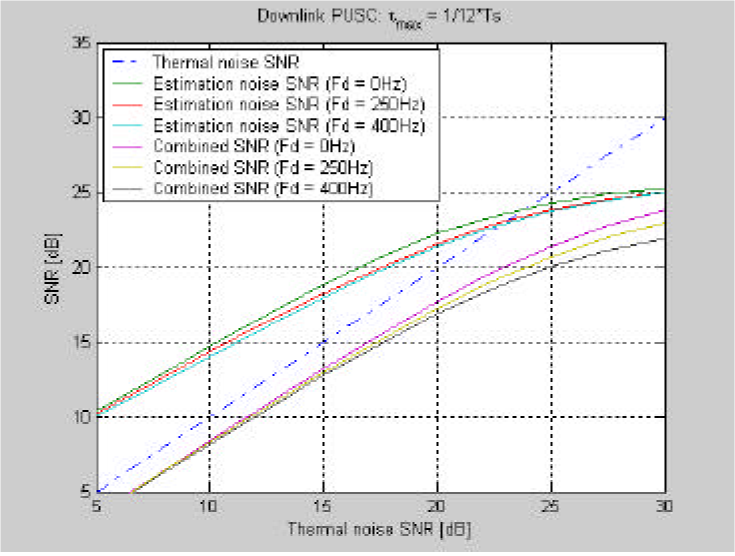

Figure 6

3. Conclusions

The scattered pilot spacing in the OFDMA downlink mandatory modes is not sufficient for highly dispersive multi-path channels in fixed as well as in mobile environments. A scheme that covers more subcarrier locations over a longer cycle of symbols should be sought.

4. Reference

[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.