Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Comparison between the midamble and the hopping-pilots schemes for estimation of the downlink mobile channel.**
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Re:	The document is submitted in response to “Call for Proposals on IEEE Project 802.16e: Mobility Enhancements to IEEE Standard 802.16/802.16a” (IEEE 802.16e-03/02).
Abstract	Two possible modifications to the downlink IEEE 802.16a OFDM FFT-256 PHY have been proposed to tackle the issue of estimating the time-varying mobile channel – one is to insert midamble symbols every several ‘regular’ symbols, the other is to use the already existing pilots by varying their location from symbol to symbol. The document compares the performance, in terms of signal-to-noise ratio, of the two schemes. It is shown that the hopping-pilots scheme outperforms the midamble scheme while requiring no additional overhead.
Purpose	The document is submitted for consideration in the 802.16e WG.
Notice	
Release	
Patent Policy and Procedures	

Comparison between the midamble and the hopping-pilots schemes for estimation of the downlink mobile channel

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Introduction

This document compares two proposed modifications to the Downlink IEEE 802.16a PHY (OFDM FFT-256 mode) needed for estimating the time-varying mobile channel. The two schemes – the midamble scheme and the hopping-pilots scheme – are first detailed, followed by a brief description of the MMSE estimation approach. The performance obtained with the two schemes is compared, and conclusions are drawn.

Notations

E_s	Average signal power / subcarrier
E_d	Average signal power / data subcarrier
N_0	Thermal noise power / subcarrier
N_{ICI}	ICI power / subcarrier (due to Doppler spreading)
N_{est}	Estimation noise power / subcarrier
N_{tot}	Total noise power / subcarrier
p_i	Received (and demodulated) pilot

Midamble scheme

One possible modification to the 802.16a PHY (OFDM mode) is to transmit a midamble symbol once every L symbol durations. We hereby assume that these midambles have the same basic structure as the 802.16a preamble, i.e. FFT-256 symbol with only even subcarriers occupied and a 3dB boost in overall symbol energy. It is clear that as L grows larger, the required transmission overhead ($\sim 1/L$) is reduced and the estimation performance is degraded.

We later analyze the performance of this scheme in two modes:

1. Channel estimation is performed at each symbol time, by using the two midambles adjacent to the current symbol time (one past, one future). This scenario entails latency of up to L symbols.

2. Channel estimation is performed when a midamble is received, and based on that midamble alone. This estimation is held constant until the next midamble is received. In this scenario there is no added latency.

Hopping-pilots scheme

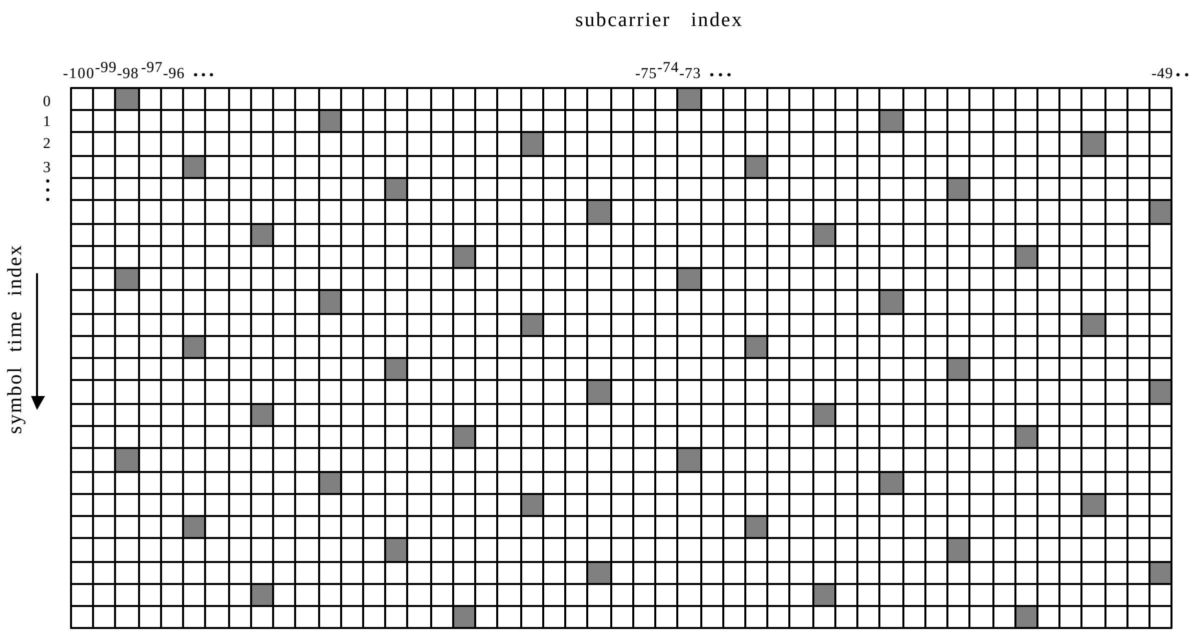
This scheme is proposed in [1]. The following is a brief summary.

The downlink IEEE 802.16a OFDM mode implements an FFT-256 OFDM symbol with 200 active subcarriers, out of which 8 are pilot subcarriers at fixed locations and 192 are data subcarriers. The modification requires that the location of these 8 pilot subcarriers will vary from symbol to symbol cyclically with a period of 8 symbols. Hence, no additional overhead is required to accommodate this scheme.

Let $k=0\ldots Ns\text{-}1$ be the time index of the current symbol relative to the beginning of a packet, and let the active subcarriers be indexed from –100 to +100. The symbol's pilots will be spaced every 25 subcarriers at the following subcarrier indices:

$$P_k = \{-98,-73,-48,-23,+2,+27,+52,+77\} + \mathrm{mod}(9k,24)$$

The diagram below illustrates this scheme.



It is further proposed to boost the power at the pilot locations by 3dB relative to the power at the data subcarriers. This boost reduces estimation noise at the expense of reducing the average data subcarrier power.

Channel Estimator

The channel can be estimated with either of the schemes by MMSE interpolation [2][3] (with the midamble scheme all midamble subcarriers are regarded as pilots). In the following, the method is briefly summarized.

The channel estimator at each subcarrier of a symbol is a linear combination of the received (and demodulated) pilots in the subcarrier's vicinity, i.e.

$$c_n^{(k)}=sum_i\ w_i^{(n,k)}p_i$$

where n is the subcarrier index and k is the symbol time index. The coefficients $\{w_i^{(n,k)}\}$ are determined via linear MMSE interpolation using a 2-D Weiner filter. Assuming worst-case channel statistics, i.e. a flat Doppler power spectrum with maximum Doppler frequency of $f_{d,max}$ and a uniform delay power spectrum with maximum delay spread of t_{max}, the 2-D channel correlation function, $r(\ ,\ )$, is given by:

$$r(n_1-n_2,k_1-k_2)= sinc\,(2f_{d,max}\,(n_1-n_2)T_s)\cdot sinc(2\,t_{max}(k_1-k_2)F_{sc})$$

where T_s is the symbol duration and F_{sc} is the subcarrier spacing. The Wiener filter solution is

$$\underline{w}^{(n,k)}= \underline{D}^{(n,k)\,T}\cdot \underline{\underline{R}}^{-1}$$

where

$$R_{i,j}= E_p\, r\,(n_i-n_j\,,\,k_i-k_j) +N_0\ \ d(n_i-n_j\,,\,k_i-k_j)$$

is the correlation between the received pilots p_i and p_j, E_p is the power in which the pilots are transmitted, and

$$D_i^{(n,k)} = E_p^{\,½}\, r(n-n_i\,,\,k-k_i)$$

is the cross-correlation between the channel at (n,k) and received pilot p_i.

Performance Analysis

The performance of estimation based on the above two schemes was analyzed. Performance is measured as the total SNR at the data subcarriers, E_d/N_{tot}, where N_{tot} is the combined power of estimation noise, thermal noise, and ICI (due to Doppler spreading).

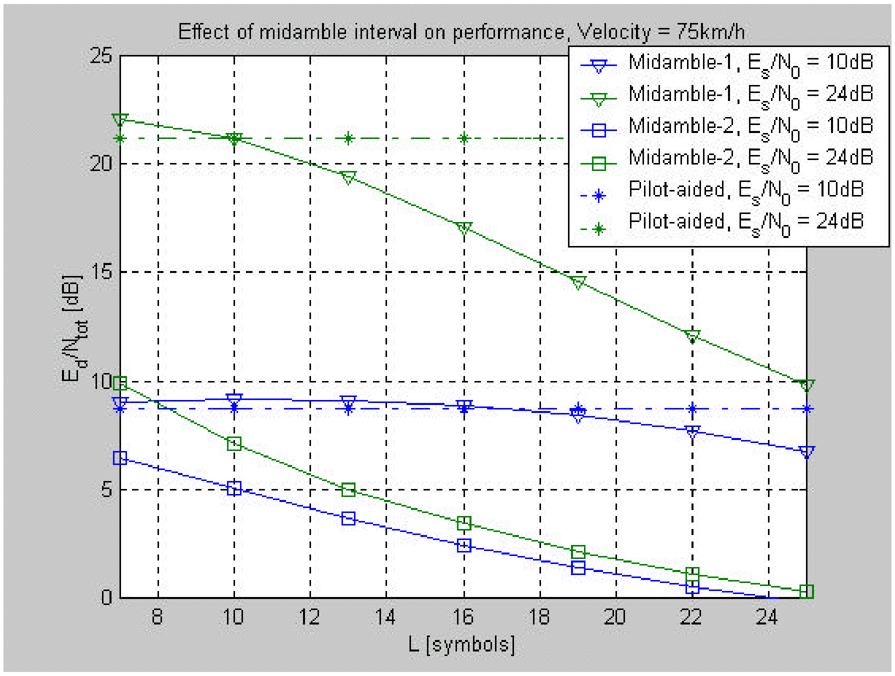
The following assumptions were made:

- OFDM Symbol: FFT-256, full bandwidth, FFT rate is 4 Msamples/sec.
- Carrier frequency: 3.5 GHz.
- MMSE estimator is matched to a maximum delay spread of 4µsec and to true Doppler frequency.
- For the midamble scheme: the two estimation modes described earlier were examined.
- Velocities: 75km/h ($f_{d,max}$ = 250Hz), 150km/h ($f_{d,max}$ = 490Hz).
- Channel profile: Vehicular Test A [3].

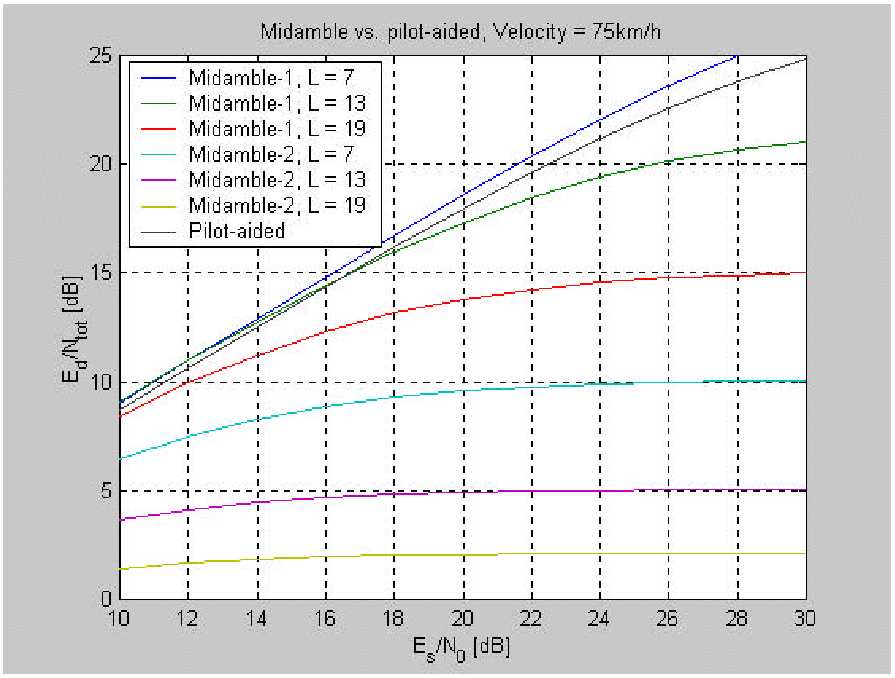
For the midambles scheme, in all figures below, 'Midamble-1' refers to symbol-by-symbol estimation based on two adjacent midambles, while 'Midamble-2' refers to estimation once every L symbols based on a single midamble.

Velocity: 75km/h

In the figure below, the total SNR is shown for the midamble scheme as a function of the midamble spacing, *L*, for several values of E_s/N_0. For comparison, the total SNR for the hopping-pilots scheme is also drawn.

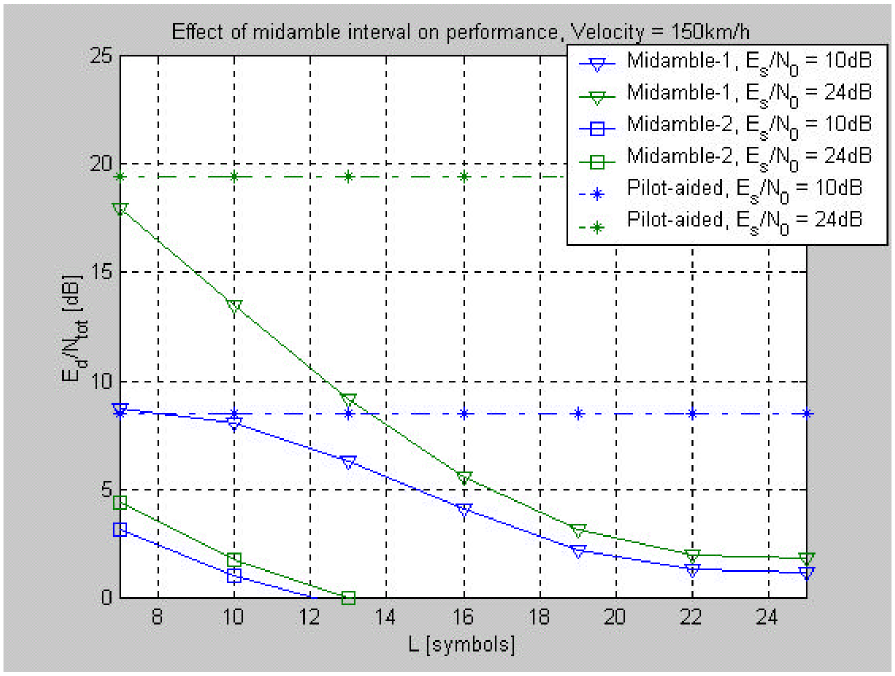


In the next figure, the total SNR as a function of E_s/N_0 is shown for the two schemes:

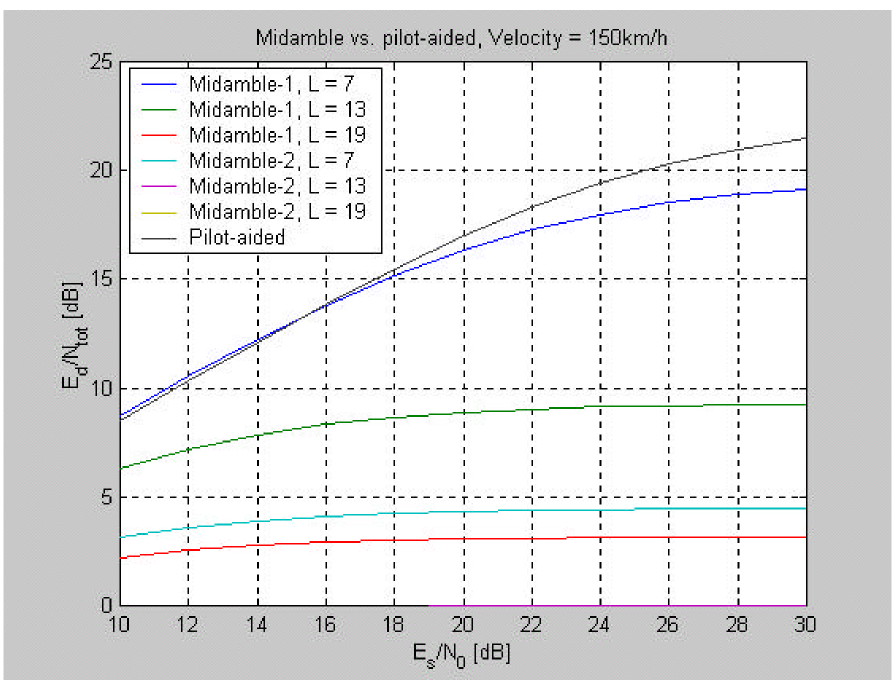


Velocity: 150km/h

In the figure below, the total SNR is shown for the midamble scheme as a function of *L*. For comparison, the total SNR for the hopping-pilots scheme is also drawn.



In the next figure, the total SNR as a function of E_s/N_0 is shown for the two schemes:



Conclusions

1. At the velocities examined, 75km/h and 150km/h, the midamble scheme with estimation update every L symbols ('midamble-2' mode) fails completely.

2. For channel estimation from adjacent midambles at each symbol ('midamble-1' mode) a significant overhead is required to achieve the hopping-pilots scheme performance. For example, a midamble spacing of 10 symbols is required at E_s/N_0 of 24dB. This translates to a 10% overhead. For lower E_s/N_0 (~10dB), a larger spacing will suffice since thermal noise is anyway dominant.

3. At velocity of 150km/h, the 'midamble-1' mode requires a spacing of 6 symbols (which translates to 17% overhead) to achieve the hopping-pilots scheme's performance at SNR of 24dB.

4. All in all, the hopping-pilots scheme performs considerably better and with no additional overhead.

References

[1] J. Liebetreu, J. Tellado, T. Kaitz, N. Chayat, M. Goldhammer, A. Efron, A. Wang, A. Middleton, O. Kelman. "Modifications to OFDM FFT-256 mode for supporting mobile operation". Submitted to the IEEE 802.16e task group (IEEE C802.16x-03/12).

[2] 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.

[3] ITU Recommendation ITU-R M.1225 – Guidelines for evaluation of radio transmission technologies for IMT-2000 (Question ITU-R 39/8).