Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Specific Recommended Channel Multipath Models for 802.16.1– with Some Implications for PHY Design**
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Re:	Response to IEEE 802.16 PHY Task Group request for specific multipath channel models in PHY minutes of Session #6, March 6-9, 2000.
Abstract	We propose models, with appropriate parameters, of multipath channel impulse responses, against which PHY layer solutions may be tested. Implications for PHY design – notably design of preamble sequences for equalizer training – are also suggested.
Purpose	Aid in the PHY Task Group's preparation of a detailed evaluation table for performance of PHY layer air interface proposals.
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Specific Recommended Channel Multipath Models for 802.16.1

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1. Introduction

Based on available broadband wireless propagation data and previous literature, several classes of multipath propagation models were presented at the previous 802.16 Working Group meeting [Fal00], [Xu00], [[Zha00]. The present contribution attempts to fulfill a request that simpler models for evaluation of PHY solutions be recommended *with as few variable parameters as possible*. Implications for PHY design – notably design of preamble sequences for equalizer training – are also suggested.

2. Recommended Multipath Models

2a. Background

Broadband wireless systems of the type envisaged in the 802.16.1 functional requirements document will likely tend to be deployed with highly directive subscriber antennas in environments offering line of sight transmission. Nevertheless, an intersymbol interference impairment may occur as a result of multipath – reflections, scattering or diffraction caused by objects near the line of sight path, which are illuminated by an antenna beam. These multipath components may change with environmental conditions; for example wet leaves and flat roofs covered with water have different scattering and reflection properties from their dry counterparts [Xu99], [Xu00].

The use of highly directive antennas (e.g. ±1° beamwidth), at least at the subscriber's end, as well as careful placement of subscriber and base antennas to achieve LOS paths, should limit the maximum delay spread to moderate values; e.g. below 60 ns. Measurement data and theoretical models using directive antennas at millimeter wave frequencies supporting this hypothesis include: [ETSI99], [Fal99b], [Fal00], [Pap97a], [Tho94], [Vio88], [Xu99], [Xu00] and [Zha00]. Much longer delay spreads, with relatively dense impulse response patterns, are typically observed in environments where wide base and subscriber antenna beams and NLOS paths are the norm [Erc99].

2b The Recommended Multipath Models

Four recommended multipath response models, numbered 0 through 3, are shown in **Table 1**, corresponding respectively to a channel with no multipath, one with "good" multipath, one with "medium" multipath, and one with "bad" multipath. They are all normalized to have unit energy. These models are intended to be useful for evaluation of PHY solutions with bandwidths from a few MHz up to about 50 MHz. They are adapted from responses shown in [ETSI99], [Fal99b], [Fal00], [Pap97a], [Vio88], [Xu99], [Xu00] and [Zha00]. They are not necessarily typical responses, although their echo delays and amplitudes are similar to those of some responses that have been reported in the above references. Instead, they are intended to provide varying degrees of "stress" for evaluation of PHY solutions. Model 1 has a small (-20 dB) echo at a 20 ns. delay. Model 2 has -10.5 dB and –20 dB echoes at 0 ns. and 30 ns., respectively. This model exhibits a "non-causal" characteristic (the first pulse is a precursor, less than the maximum echo, which is at 20 ns.). Precursors were observed in measurements reported in [Fal99b], and can represent situations where the shortest radio path is attenuated relative to some slightly longer paths – for example due to partial attenuation or blocking of the LOS path by heavy localized rain, or to misalignment of the subscriber's antenna. This model can test the ability of a moderately complex adaptive equalizer to overcome multipath-induced intersymbol interference. Furthermore, its non-causal characteristic would provide a more severe test of a decision feedback equalizer than would an equivalent causal response. Model 3 is a normalized version of a measured channel reported in [Pap97a]. Because its second echo, at –2.8 dB, is negative and only 3.6 ns. from the main pulse, this channel will cause severe attenuation (a manifestation of a multipath fade) of signals whose bandwidth is much less than 250 MHz. The last echo, at –16.2 dB, is at a delay of 15.3 ns.

It is worth noting that good, medium and bad channel models were measured and reported in [Pap97a] and [Zha00]. The good channel model in those references is the same as our Model 0; i.e. no multipath echo. The bad channel model is the same as our Model 3, and is also the same as Model “L7” in [ETSI99]. The medium channel model in [Pap97a] and [Zha00] has a smaller delay spread than our Models 1 and 2, and a smaller multipath echo than our Model 2. However, the multipath response measurements on which the 3 channel models of [Pap97a] were based were all done for path lengths of under 0.5 km. Longer paths could admit somewhat larger delay spreads (see for example [Xu99] and [X00]).

	Tap Number	**Tap Delay (ns.)**	**Tap Amplitude**
Model 0	1	0	1.0
Model 1	1	0	0.995
	2	20	0.0995 exp(-j0.75π)
Model 2	1	0	0.286 exp(-j0.75π)
	2	20	0.953
	3	30	-0.095
Model 3	1	0	0.804
	2	3.6	-0.581
	3	15.3	-0.124

Table 1. Recommended multipath models

Frequency response magnitudes of these models are shown in **Fig. 1**.

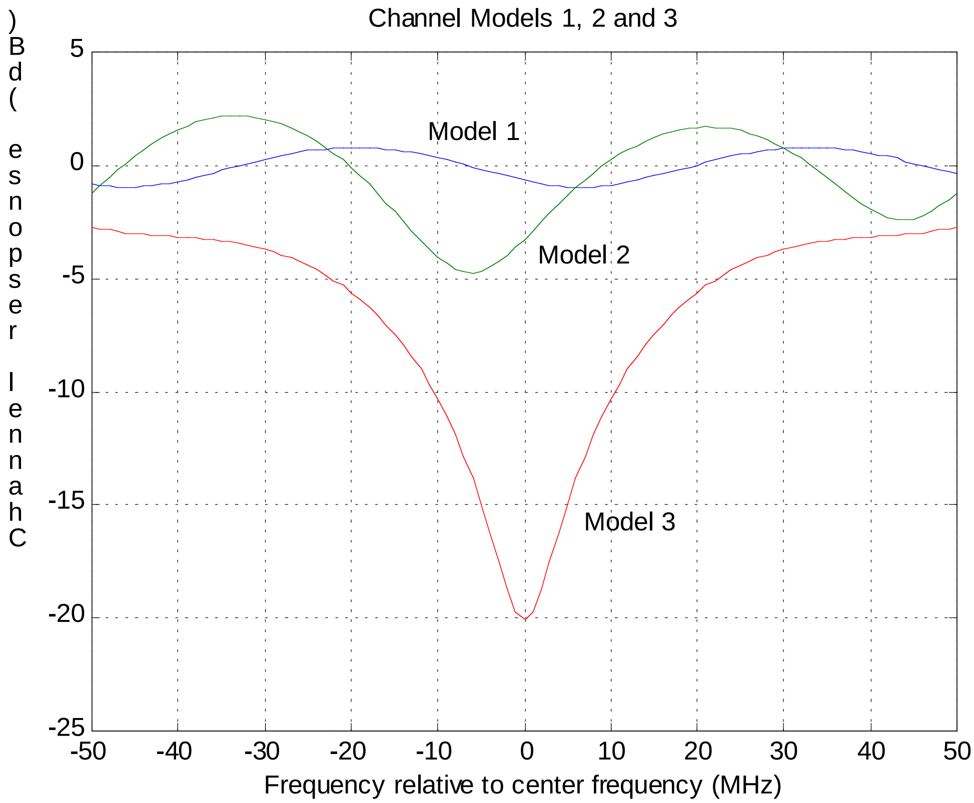

Fig. 1 Frequency responses of Models 1, 2 and 3

As seen in **Fig. 1**, the bad channel (Model 3) in particular displays a severe frequency response notch at the channel center frequency, which would result in significant received signal attenuation (multipath fading), especially for signals with relatively narrow bandwidth about the center frequency. Adaptive equalization can cure intersymbol interference resulting from the multipath, but for a fixed signal bandwidth, cannot cure the loss in receiver input SNR due to the frequency notch. This is illustrated in **Fig. 2**, which shows two curves for each of Models 1, 2 and 3. The top curve in each pair, labeled "SNRin", shows the signal-to-noise ratio observed through a receiver input 25% square root raised cosine filter whose bandwidth is matched to the symbol rate, for 12.5, 25 and 50 Mbaud symbol rates. The input noise level is set so that the input SNR for a perfect (0 dB gain, frequency nonselective) channel would be 30 dB. These curves indicate that the multipath in Models 1 and 2 cause negligible or moderate input signal power loss, whereas Model 3 causes severe signal power loss, especially at lower symbol rates.

The bottom "SNRout" curve of each pair is the signal to noise ratio at the output of a fractionally spaced DFE with two input samples per symbol. The "noise" at the equalizer output is the minimum mean squared error that includes residual intersymbol interference as well as noise. The DFE had one feedback tap, and 4, 6 or 8 forward taps, depending on the symbol rate and channel[1]. Symbol-rate DFE's with a good timing recovery algorithm would likely give similar performance with about half the number of forward taps. No attempt was made to optimize the sample timing, equalizer delay, or number of equalizer taps. An approximate BER estimate for QPSK is $BER = \frac{1}{2} erfc(\sqrt{SNR/2})$, where *SNR* is the equalizer output SNR. The SNRin and SNRout curves for Model 1 coincide. While the sets of curves for Models 1 and 2 appear close together for effective equalizers, it should be noted that they would differ significantly in the absence of equalization. For example,

[1] In the results shown, 4 forward taps were used for Models 1 and 3, while 6 forward taps were used for Model 2 at 12.5 and 25 Mbaud, and 8 forward taps at 50 Mbaud.

Model 1 for a symbol rate of 12.5 Mbaud could achieve a SNRout of about 28.6 dB without equalization, while Model 2 for the same symbol rate would only achieve about 18 dB.

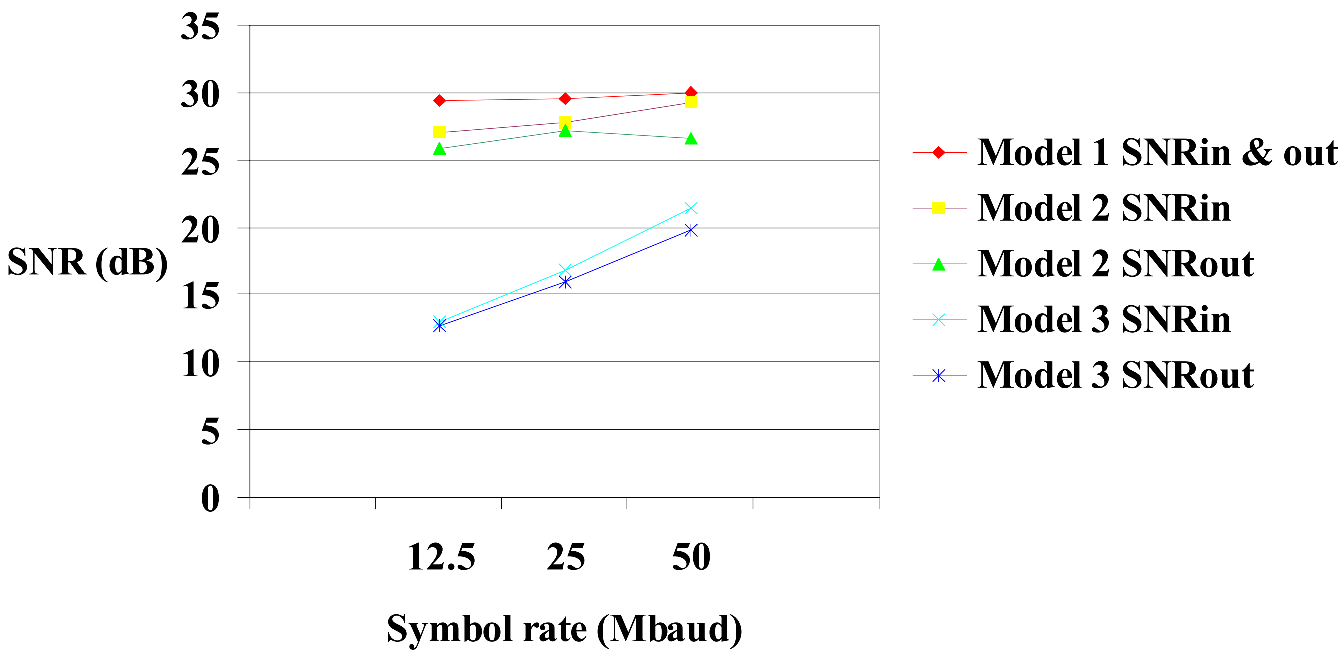

Fig. 2 SNR at receiver input after filtering, and at fractionally-spaced DFE output for Models 1, 2 and 3

3. Time Variability – and Implications for PHY Preambles

3a. Time Variability

There is relatively little measurement data on time variations of fixed broadband millimeter wave radio links [Pap97b]. However measurements of fading bandwidths due to foliage movement, primarily in NLOS links, reported in [Naz99] suggest that a typical worst case fading bandwidth for the amplitude of a 30 GHz carrier could be up to about 200 Hz. This would correspond to a maximum Doppler shift arising from movement of about 2 m/s. We know of no data on time variation of the phase of multipath components. In any case it seems clear that time variation will be extremely slow relative to envisaged bit rates (e.g. one cycle of 200 Hz Doppler spans 10^4 bit intervals at 2 Mb/s, and 10^5 bit intervals at 20 Mb/s. Therefore specification of a precise model of time variability of multipath seems unnecessary.

3b. Implications for PHY Design

Experience with designing adaptive equalizers for rapidly time-varying radio channels [Lo91] gives the following rough rule of thumb for characterizing time variation as "fast" or "slow", with respect to equalizer adaptation tracking requirements:

$$\frac{[\text{Doppler frequency}]\text{X}[\text{Number of equalizer taps}]}{[\text{Symbol rate}]} > .001 \ ? \ \text{"Fast" adaptation required}$$

With 200 Hz Doppler, a minimum symbol rate of about 2 Mbaud, and fewer than 8-10 adaptable equalizer taps, the 0.001 limit is not exceeded, and hence a fast channel tracking capability is not an issue, as it is in some other cellular systems such as IS-136.

For an 802.16.1 system for example, the time variation is slow enough that the channel impulse response estimate and/or equalizer coefficients could be updated and then held fixed for a time slot period of at least 100 μsec without the need for further adaptation in that period. For line of sight environments, the channel will remain fixed for much longer periods. For uplink TDMA transmission, a subscriber transmits a burst once per uplink frame. For frame lengths on the order of 1 ms. or longer, complete updating (retraining) of equalizer coefficients or channel estimates would be prudent, using a preamble at the start of the burst. A preamble is a predetermined sequence of transmitted symbols used for synchronization and for training of equalizer coefficients. For continuous downlink TDM transmission, a preamble for equalizer training should be inserted at periodic intervals. The period may be adjusted according to the time variability of the link, but would generally be expected to be in the range of 100 μs to several ms.

Calculation of equalizer coefficients, using the preamble, and the response of the channel to it, can be done efficiently by a variety of methods involving direct matrix inversion (DMI) of Wiener-Hopf matrix equations, or by RLS (recursive least squares) algorithms [Lo91], [Hay96]. Simpler adaptation methods, such as LMS, are slow, and would require a relatively long preamble. The minimum preamble length, in symbol intervals, to achieve a mean squared error no more than 3 dB higher than the minimum MSE, required for DMI or RLS-type solutions is about two times the number of equalizer coefficients [Hay96]; i.e. on the order of 8 to 15 symbol intervals for 802.16.1 systems [Fal99a]. For TDM downlink transmissions, the preamble could be a distributed one, interspersed with payload data.

4. Acknowledgements

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5. References

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