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Title	**Channel Models and Performance Implications for OFDM-based MBWA**
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Re:	IEEE 802.20, Session #2, May, 2003 Call for Contributions
Abstract	Proposal for a set of SISO channel models for MBWA.
Purpose	For informational purposes only.
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1. Abstract

This document proposes a set of SISO channel models for MBWA. The proposal is simply to leverage the extensive prior modeling work done for ETSI UMTS Terrestrial Radio Access (UTRA) and adopt those channel models essentially unchanged, since the deployment and propagation scenarios for which they were developed are similar to those currently envisioned for MBWA. Also included is a brief overview of how channel characteristics influence OFDM-based PHY, including a probable range of OFDM PHY parameters which would result from adoption of the proposed UTRA models.

2. Proposed Model Ensemble for SISO

For SISO channel modeling, we propose that MBWA adopt, essentially unchanged, the Test Environments and associated SISO channel models put forth for UMTS Terrestrial Radio Access, (UTRA) as described in Annex B of [1]. Our motivations for this choice are straightforward: The deployment and propagation scenarios for which the UTRA models were developed are similar enough to those currently envisioned for MBWA, that developing new models seems unwarranted, at least at this time. Adopting the UTRA models as-is would thus avoid duplication of effort and allows MBWA working group resources that might be spent on such work to be allocated elsewhere.

2.1 Overview of the UTRA Test Environments and Channel Models

Reference [1] defines three broad deployment/propagation scenarios, referred to therein as "Test Environments" (TEs), in which the performance of candidate UTRA radio transmission technologies (RTTs) are to be evaluated. These Test Environments are labeled *Indoor Office*, *Outdoor-to-Indoor and Pedestrian*, and *Vehicular*.[1] Each Test Environment broadly defines a particular wireless propagation scenario, and each scenario in turn has an associated channel model. The TEs are qualitatively characterized as shown in Table 1.

Test Environment	Qualitative description from [1]
Indoor	Base stations and mobile stations located within buildings. "Small" cell sizes. "Low" transmit powers. Doppler rate set by walking speeds.
Pedestrian	Base stations with low antenna heights, located outdoors "Small" cell sizes. "Low" transmit powers. Doppler rate set by walking speeds, with occasional higher rates due to vehicular reflections.
Vehicular	Base stations with roof antennas; users are in vehicles, walking, or stationary. "Larger" cells. "Higher" transmit powers. Maximum Doppler rate set by vehicular speeds; lower rates for walking or stationary users.

TABLE 1. Qualitative Descriptions of the UTRA Test Environments

1. For brevity throughout this document, we will refer to the first two as simply "Indoor" and "Pedestrian" respectively.

The channel model associated with each Test Environment is comprised of the following:

- A deterministic *mean path loss* formula, which specifies the average path loss as a function of BS-MS distance, operating frequency, and in some cases other parameters relevant to the particular TE.
- A pair of representative tapped delay line impulse response specifications, labeled *A* and *B*, which characterize *delay spread*. The *A* model represents a frequently occurring low delay spread situation, and the *B* model a frequently occurring high delay spread situation within that TE. A Doppler velocity distribution model - in all cases, either flat or Jakes' [4] - is also specified. Note that numerical values for velocities are *not* specified in [1]; the only guidance on this are the qualitative hints given in Table 1 above. This is discussed further in Section 4.
- A statistical model which characterizes *long-term (shadow) fading*. For all TEs, shadow fading loss is assumed to be log-normally distributed with a mean of zero, and the specification consists of the standard deviation of this distribution. In addition, for simulations which need to model time evolution of shadow fading loss as a function of position, a positional correlation model for shadow fading is also specified. For all TEs, the form of the model is an exponential autocorrelation function

$$r(\Delta x) = \exp\left(\ln 2 \cdot \frac{|\Delta x|}{d_{cor}}\right) \qquad (1)$$

where Δx is incremental distance (meters) and d_{cor} is a decorrelation length parameter specified for each TE. Note that [1] warns that (1) may not be fully valid for the Pedestrian TE, but requires that it be used anyway for purposes of consistency in shadow modeling.

3. Channel Model Details

The following sections provide the details of these models for each of the Test Environments. The reader is referred to [1] and the references therein for a more detailed discussion of the technical basis of the models and their associated parameters.

3.1 Indoor Test Environment

3.1.1 Path Loss Mean path loss for the Indoor TE is given by

$$L = 30\log_{10} R + 18.3n^{((n+2)/(n+1) - 0.46)} + 37 \qquad (2)$$

where L is the loss in dB, R is the BS-MS distance in meters, and n is the number of floors in the path.

3.1.2 Shadow Fading Shadow fading loss for the Indoor TE is modeled as a log-normal random variable with zero mean and variance 12 dB. The positional correlation model (1) is used, with parameter d_{cor} = 5 m.

3.1.3 Impulse Response The tapped-delay line impulse response parameters for the Indoor TE are shown in Fig. 1. the Doppler spectrum for is specified as flat. The *A* model has 6 rays, an RMS delay spread of 35 ns, and is specified as occurring 50% of the time. The *B* model has 6 rays, an RMS delay spread of 100 ns, and is specified as occurring 45% of the time. It is not clear from [1] how to account for the fact that the sum of the frequencies of occurrence do not sum to 100%.

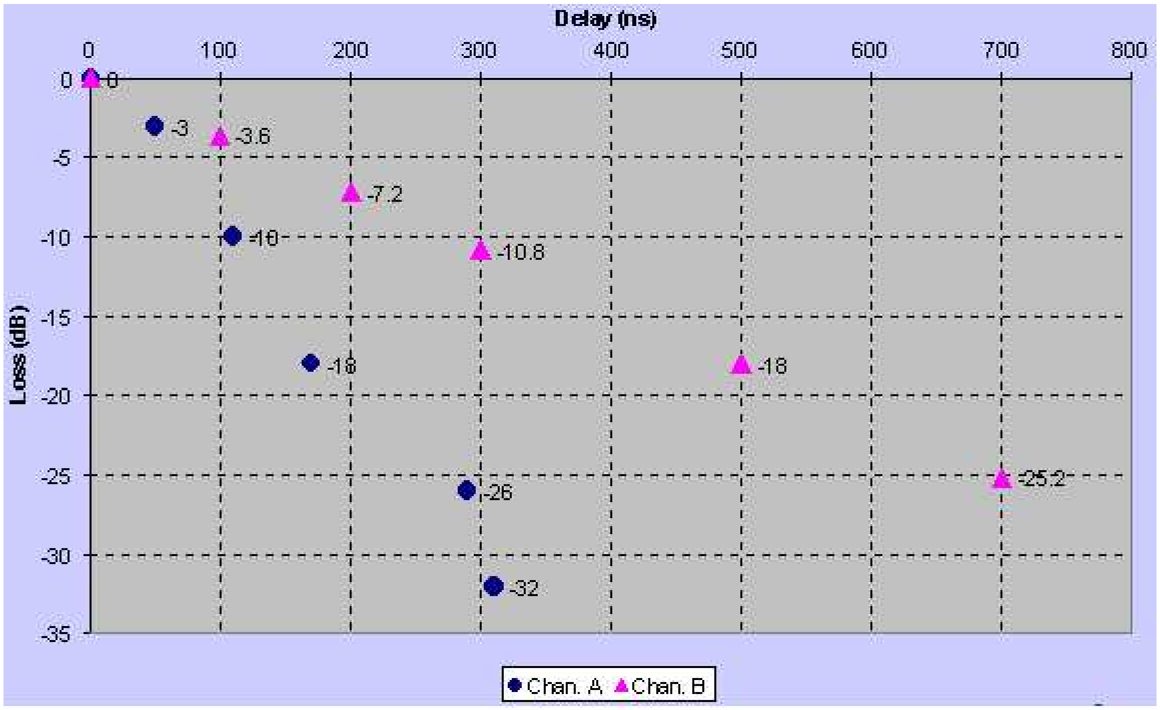

Figure 1. *Indoor TE*: Tapped delay line impulse response specification

3.2 Pedestrian Test Environment

3.2.1 Path Loss Mean path loss for the Pedestrian TE is given by

$$L = 40 \log_{10} R + 30 \log_{10} f + 49 \quad (3)$$

where R is the BS-MS distance in meters, and f is the carrier frequency in MHz.

In [1] it is noted that (3) is to be used for "coverage efficiency evaluation and simple capacity evaluation". A more detailed LOS/NLOS model for modeling urban microcellular environments is also given, but will not be discussed here.

3.2.2 Shadow Fading Shadow fading loss for the Pedestrian TE is modeled as a log-normal random variable with zero mean and variance 10 dB for outdoor users and 12 dB for indoor users. The positional correlation model (1) is used, with parameter $d_{cor} = 5$ m.

The average building penetration loss is specified as 12 dB with a standard deviation of 8 dB.

3.2.3 Impulse Response The tapped-delay line impulse response parameters for the Pedestrian TE are shown in Fig. 2. The Doppler spectrum is specified as *classic* (Jakes' model [4]). The *A* model has 4 rays, an RMS delay spread of 45 ns, and is specified as occurring 40% of the time. The *B* model has 6 rays, an RMS delay spread of 750 ns, and is specified as occurring 55% of the time. As mentioned earlier, it is not clear from [1] how to account for the fact that the sum of the frequencies of occurrence of the two modes do not sum to 100%.

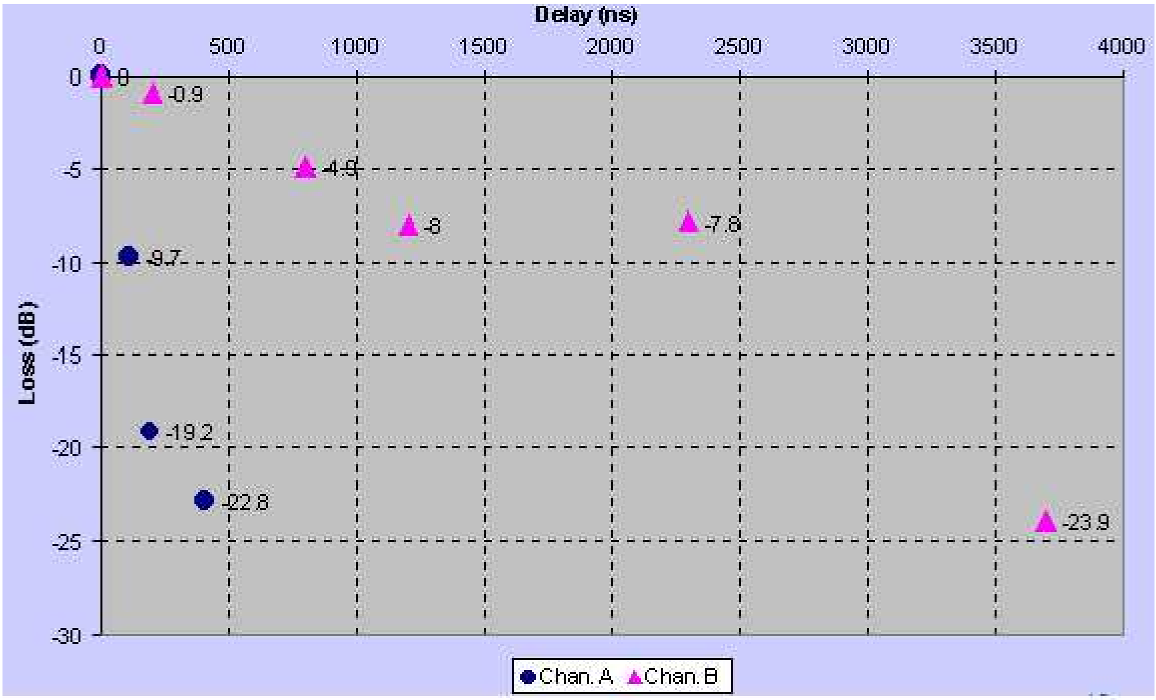

Figure 2. *Pedestrian TE*: Tapped delay line impulse response specification

3.3 Vehicular Test Environment

3.3.1 Path Loss Mean path loss for the Vehicular TE is given by

$$L = 40(1 - 0.004 \cdot \Delta h_b) \log_{10} R - 18 \log_{10}(\Delta h_b) + 21 \log_{10} f + 80 \tag{4}$$

where R is the BS-MS distance in km, f is the carrier frequency in MHz, and Δh_b is the base station antenna height in meters, measured from average rooftop level. This model is valid only over the range $0 \le \Delta h_b \le 50\ m$.

3.3.2 Shadow Fading Shadow fading loss for the Vehicular TE is modeled as a log-normal random variable with zero mean and variance 10 dB in both urban and suburban environments. The positional correlation model (1) is used, with parameter $d_{cor} = 20$ m.

3.3.3 Impulse Response The tapped-delay line impulse response parameters for the Vehicular TE are shown in Fig. 3. The Doppler spectrum is specified as *classic* (Jakes' model [4]). The *A* model has 6 rays, an RMS delay spread of 370 ns, and is specified as occurring 40% of the time. The *B* model has 6 rays, an RMS delay spread of 4000 ns, and is specified as occurring 55% of the time. As mentioned earlier, it is not clear from [1] how to account for the fact that the sum of the frequencies of occurrence do not sum to 100%.

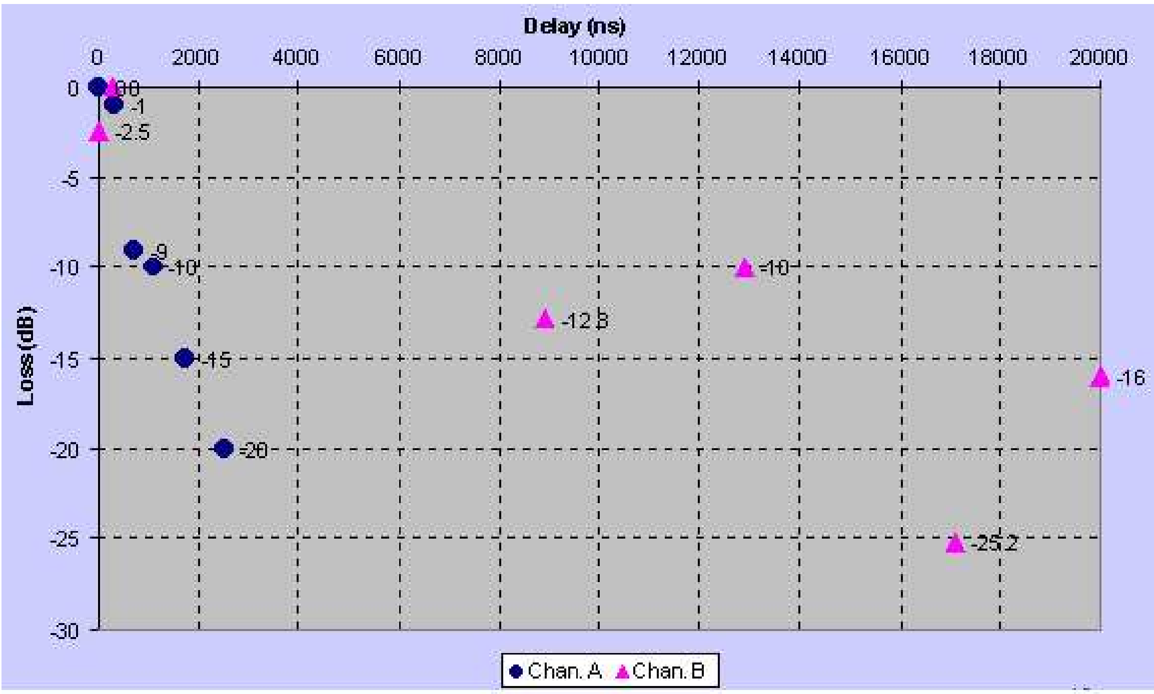

Figure 3. *Vehicular TE*: Tapped delay line impulse response specifi cation

4. Suggested Mobility Rates

As mentioned earlier, the Test Environments given in [1] do not prescribe specifi c mobility rates. In the interest of compromising between the full range of commonly modeled rates (0, 3, 30, 120, and 250 km/h) and the desire to keep the test matrix to a reasonable size, we suggest the set of mobility rates vs. Test Environment shown in Table 2.

Test Environment	**Suggested mobility rates for testing**
Indoor	3 km/h
Pedestrian	3, 30 km/h
Vehicular	0, 120, 250 km/h

TABLE 2. Suggested Mobility Rates for UTRA Test Environments

5. Channel Characteristics and their Influence on OFDM PHY Parameters

Channel characteristics naturally influence the PHY layer design choices. Since orthogonal frequency-division multiplexing (OFDM) is an attractive candidate for the MBWA PHY layer, we briefly outline the general way in which basic OFDM parameters are constrained by channel characteristics.

5.1 Delay Spread Effects

OFDM systems often utilize a cyclic prefi x (CP) to mitigate the effects of intersymbol interference (ISI) due to delay spread. The CP is a coherent extension of each transmitted OFDM time-domain symbol beyond the length of the IDFT/DFT. The CP acts as a guard interval, isolating the latter portion of the OFDM symbol from the delayed echos of prior symbols. At the receiver, the CP is discarded, and the DFT computed only over the remaining portion (the "DFT region") of the OFDM symbol. Thus, if the CP length is at least as long as the worst-case absolute channel delay spread, all interference energy due to prior symbols falls within the CP of the present symbol, and none is present at the DFT output.

However, since the CP represents pure overhead to the modulation process, it is wasteful to size the CP based on the worst-case channel impulse response. In particular, other system requirements, particularly the desired signal to interference ratio (SIR) at the decoder input, determine the acceptable level of residual ISI, hence the CP length appropriate for a given channel ensemble. The constraint imposed on CP length by ISI contribution to the decoder SIR can be expressed roughly as

$$\int_0^{T_{cp}} |h(t)|^2 dt \; > \; (1 - \theta_{cp}) \int_0^{\infty} |h(t)|^2 dt \tag{5}$$

where $h(t)$ is the channel impulse response and T_{cp} is the cyclic prefi x length. The threshold θ_{cp} sets the requirement that the channel impulse response up to time T_{cp} contain at least the fraction $1 - \theta_{cp}$ of the total impulse energy, and is chosen according to system SIR requirements. Thus, to meet a desired ISI contribution of say, k dB, set $\theta_{cp} \geq 10^{k/10}$, so that at most θ_{cp} of the total impulse energy falls in the DFT region where it is visible at the decoder input. Then, based on channel impulse response models (or observations) choose T_{cp} that meets this requirement.

Typical values for θ_{cp} range from 0.02 to 0.25, depending on SIR [2].

5.2 Doppler Effects

Channel Doppler also influences OFDM system parameters. At the receiver, in the presence of Doppler, the DFT is computed over a time-varying channel, distorting the output due to time smearing of the signal. Although the effects are more diffi cult to quantify than for delay spread, the constraint

$$T_{dft} < \theta_d \cdot \tau_{chan} \tag{6}$$

roughly expresses the requirement that the DFT duration T_{dft} should be less than some predetermined fraction θ_d of the channel decoherence time, which in turn depends inversely on the mobility rate. In effect, this is a "quasi-stationarity" threshold, the duration over which the channel can be considered stationary for the purposes of the particular receiver.

Note that the tone spacing in an OFDM system is the reciprocal of the DFT duration. The larger θ_d, the more tones that can be deployed in a given bandwidth. Thus, the highest mobility rate to be supported by a given system determines the most restrictive θ_d.

Naturally, the choice of θ_d takes into account many performance related factors, with higher performance systems (or higher performance modes within a given system) requiring the smallest values. Experience, simulation studies [3], and actual parameters used in fi elded OFDM systems indicate that θ_d is rarely larger than 0.1.

6. Representative OFDM PHY Parameter Ranges Consistent With UTRA Models

We now apply these rough constraints to the design of a hypothetical MBWA system, operating in a bandwidth of 1.25 MHz, at a carrier frequency of 2 GHz, and supporting a maximum mobility rate of 250 km/h. The desired per-subcarrier SINR ≈ 7 – 10 dB.

To determine the CP length, set θ_{cp} based on $k = -10\ dB$[2], i.e. $\theta_{cp} = 0.1$. Applying this to the UTRA model with the largest delay spread (Vehicular B), it can be verified from Fig. 3 that a cyclic prefix length of about 10 μs captures $1 - \theta_{cp}$ or 90% of the impulse energy, and thus meets the constraint (5).

For θ_d, we use a figure of 5%. This is consistent with experience as well as with information presented in Fig. 3 from [3]. The maximum supported mobility rate of 250 km/h at 2 GHz carrier leads to a maximum Doppler rate of about 460 Hz, thus a theoretical channel decoherence time of about 2200 μs. Working backwards thru (6), with $\theta_d = 0.05$, the DFT duration T_{dft} should be limited to something like 110 μs. Finally, adding this to our CP figure of 10 μs gives an overall OFDM symbol period of around 120 μs.

Taken together, these lead to an OFDM system with a symbol rate of around 8.5 ksym/s, tone spacing $T_{dft}^{-1} \approx 9.1$ kHz, and thus around 137 tones or so in our hypothetical 1.25 MHz bandwidth system.

7. Summary

For purposes of SISO modeling in MBWA, we propose adoption of the ETSI UTRA Test Environments and channel models from [1]. Our justification is simply that those models were designed for environments and deployment scenarios similar to those for MBWA. A brief overview of these models is given, and mobility rates -- which are not part of the standard -- suggested for each Test Environment category. Finally, a brief overview of the effects of channel characteristics on OFDM PHY layer parameters is presented, and some ballpark PHY parameter values generated for a hypothetical OFDM-based MBWA system.

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2. This high end of the 7 - 10 dB range is used, because ISI is not the only contributor to decoder input distortion.

8. REFERENCES

[1] ETSI TR 101 112, UMTS 30.03, V3.1.0, Annex B, Sections 1.2.3, 1.3, 1.4.

[2] W. Henkel, et. al., "The Cyclic Prefix of OFDM/DMT - An Analysis", IEEE 2002 Int'l Zurich Seminar on Broadband Comm, Feb.19-21, ETH Zurich, SW.

[3] F. Tufvesson and T. Maseng, "Optimization of Sub-channel Bandwidth for Mobile OFDM Systems", MMT '97, Melbourne, Australia, Dec. 1997.

[4] W. C. Jakes, Ed., *Microwave Mobile Communications*, IEEE Press, 1974.