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Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)		
Title	**A Basic Propagation Attenuation Model for UWB**		
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Re:	[A basic propagation attenuation component in a TG4a propagation model.]		
Abstract	[A basic two slope propagation attenuation model is shown, which can be used in conjunction with a multipath channel description (such as the TG3a model).]		
Purpose	[This document is presented for the use of TG4a in implementing a simple basic propagation attenuation model useful for alternative PHY selection, and as a basis for TG4a performance prediction.]		
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03 August 2004

Basic Propagation Attenuation Model Suitable for UWB and Narrow Band Signals

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<u>Abstract</u>: The following basic attenuation model is from: USTG 1-8/53, 03 May 2004, United States of America, "Suitability of Propagation Models for UWB Transmitter to Narrowband Receiver in Compatibility Studies", submission to the ITU-R TG1/8. It can be used in conjunction with a multipath channel description (which lacks the basic attenuation component in the model), such as that developed for TG3a.

<u>Summary</u>: A theoretical model for UWB signals in multipath initially has a basic $1/d^{2}$ behaviour of spherical wave expansion, and then a further $1/d^{(\gamma-2)}$ behaviour beyond a breakpoint distance d_t due to shedding of energy to multipath dispersion, yielding a total behaviour of $1/d^{\gamma}$. The resulting dual slope propagation model is

$$PL(d) = -10\log\{[c/4p\, d f_m]^{2}\, [1-\exp(-(d_t/d)^{\gamma-2})]\} \qquad (1)$$

with f_m equal to the geometrical mean of the UWB signal frequency, and c is the velocity of propagation. Suitable values of index are γ=3 and d_t=10 m. The formula, with $d_t=h_1h_2 4\pi f_m/c$ and γ=4, is also useful in a two-ray path model when the shape of the UWB wavelet is not specified.

<u>Discussion</u>: The radio channel in a multi-path environment is time-dispersive. Because of the physics of multipath, this directly manifests itself as an increase in the propagation index γ to a value larger than the free space value of γ=2 beyond a breakpoint distance d_t, as shown in reference [1]. There is a relationship between the way energy is shed to multipath dispersion and the resulting propagation index. Observations based on measurements [2] showed that the strongest ray path (this is true for either UWB impulse or narrow band signals) behaves approximately like $1/d^{3}$ in the measured indoor environment. The measured multipath delay spread was also seen to increase with distance (linearly in the reported set of measurements). A basic $1/d^{2}$ behaviour was noted based on spherical wave expansion, and a further $1/d$ behaviour due to shedding of energy to multipath dispersion, yielding a total behaviour of $1/d^{3}$.

The propagation results based on the measurements [2] can be written as a dual slope model with a breakpoint distance d_t . The path loss $PL(d)$ derived from the study, where f_m is the geometrical mean of the UWB signal frequency, and c is the velocity of propagation is

$$PL(d) = -10\log\{[c/4p\, d f_m]^{2}\, [1-\exp(-(d_t/d)^{\gamma-2})]\} \qquad (2)$$

The first term is the usual free space propagation, while the second term in brackets is a modifier to free space propagation which causes the transition to a power law γ beyond the breakpoint distance d_t. Thus the propagation index is 2 initially and transitions to γ beyond a breakpoint distance d_t meters. Suitable values of index $\gamma=3$ with $d_t=10$ are useful for TG4 inside buildings. For line of sight paths over a plane earth, the same formula applies, but with $d_t=h_1h_2 4\pi f_m/c$ and $\gamma=4$ for a two-ray path model between antennas that are h_1 and h_2 meters above a plane earth. This is most useful when the shape of the UWB wavelet is not specified, as further discussed in reference [3] where results for UWB impulse wave forms are shown. That is, it approaches the free space asymptote before the breakpoint and the $20\log(h_1h_2/d^2)$ asymptote beyond the breakpoint.

Figure 1 demonstrates an example of the path loss between two 3 dBi antennas using the dual slope model with f_m=4.7 GHz, and with $\gamma=3$ beyond the breakpoint distance of d_t =3 metres.

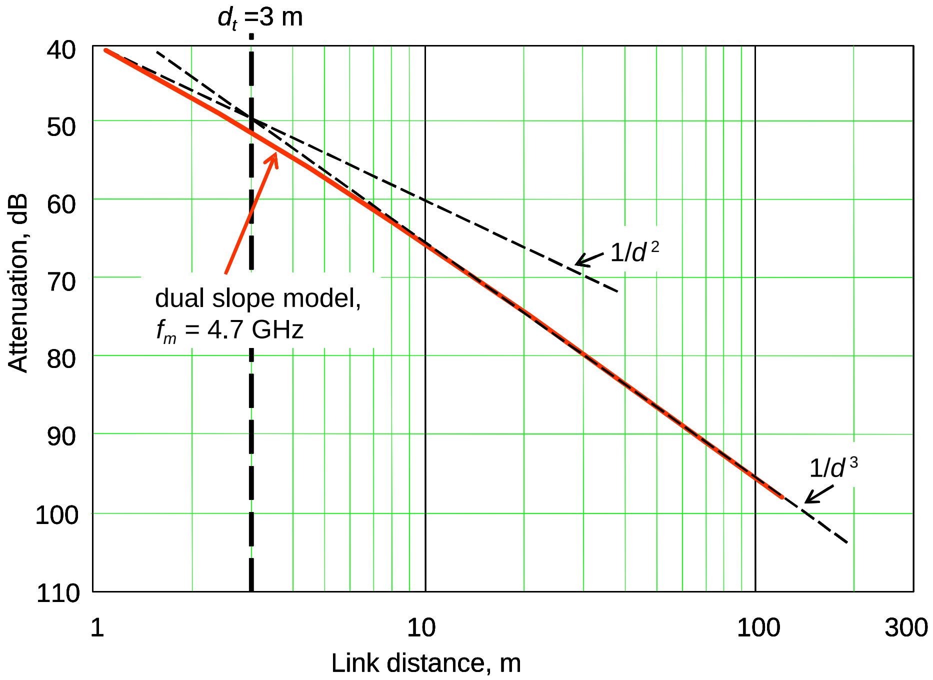

Figure 1. Theoretical UWB propagation model between 3 dBi antennas in multipath.

If all of the energy in the channel impulse response (CIR) were to be coherently collected, the resulting effect would be to nearly nullify the additional 1/*d* effect of multipath. In other words, if a *perfect rake* receiver could be built, its apparent effect would be to exhibit a gain the would make the propagation path (including the perfect rake receiver) appear similar to a free space path. This suggests that *on average*, the theoretical limiting value for rake gain is

$$G_{\max} = -10\log[1-\exp(-(d_t/d)^{\gamma-2}] \tag{3}$$

That supposition involves the construction of a perfect UWB rake receiver that coherently recovers all of the multipath energy, which additionally perfectly adapts to the propagation channel on a per-impulse basis. Under those ideal conditions a UWB receiver could be configured to perform in a way that would effectively make the UWB channel resemble a free space channel. This is one of the benefits of a UWB system: namely, that multipath can be resolved by a UWB receiver, and with sufficient effort, an effective rake receiver could be constructed. Measurements have demonstrated the robustness of impulse UWB signal transmissions in multipath environments varying by less than a few dB when received by impulse UWB receivers.

References:

[1] K. Siwiak, H. Bertoni, and S. Yano, “Relation between multipath and wave propagation attenuation,” Electronic Letters, Vol. 39, No. 1, Jan. 9, 2003, pp. 142-143.

[2] S. M. Yano, “Investigating the Ultra-Wideband Wireless Channel”, Proc. IEEE VTC2002 Spring Conf., May 7-9, 2002, Birmingham, AL, Vol. 3, pp. 1200-1204.

[3] K. Siwiak and D. McKeown, *Ultra-Wideband Radio Technology*, Chichester, UK: Wiley Publications, April 2004.