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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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Abstract: 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.

Summary: 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

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

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 $\gamma=3$ and $d_t=10$ m. The formula, with $d_t=h_1h_2 4\pi f_m/c$ and $\gamma=4$, is also useful in a two-ray path model when the shape of the UWB wavelet is not specified.

Discussion: 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 $\gamma=2$ 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 a 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 $1/d^3$ was noted.

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

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

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 $\gamma=4$ fro aa two-ray path model between antennas 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]. 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 dual slope model with f_m=4.7 GHz, and with $\gamma=3$ beyond the breakpoint distance of d_t =3 metres.

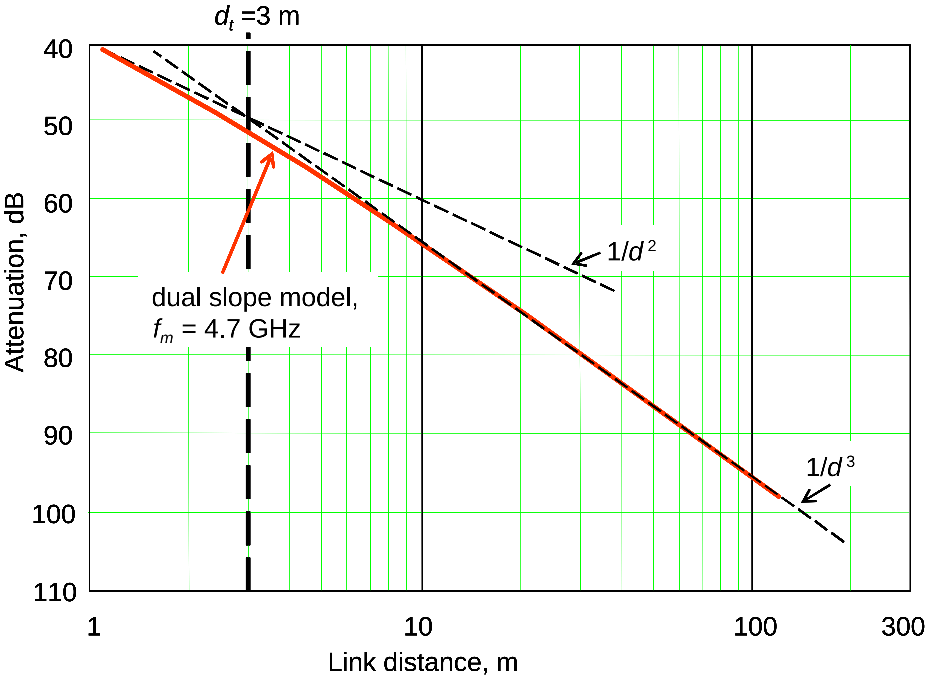

Figure 1. A theoretical UWB propagation model in multipath.

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 in 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 UWB signal transmissions in multipath environments varying by less than a few dB when received by 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.