White Paper:

Comparison of Narrowband and Ultra Wideband Channels

January 2008

DOCUMENT APPROVAL: **DATE:**

Author signature: Satisfied that this document is fit for purpose, contains sufficient and correct detail and complies with DecaWave quality standards.	[signature]	Jan 4th 2008
Checked by: Satisfied that this document has been checked, is fit for purpose, contains sufficient and correct detail and complies with DecaWave quality standards.	[signature]	Jan 4th 2008
Chief Executive Officer: (If required. Otherwise the Author authorises).	[signature]	Jan 4th 2008

1 Table of Contents

1 Table of Contents 2
2 Introduction 3
3 The Difference between UWB and Narrowband channels 4
4 Comparing 20MHz and 500MHz channels 6
5 Path Loss Models 7
6 802.11n Path Loss Model 9
7 Conclusion 13

2 Introduction

This document discusses the differences in narrowband and UWB channels and compares channel path loss models. The gain in signal energy received at the output of a dense multipath channel, typical of indoor office environments, is derived and compared for different signal bandwidths. The UWB channel path loss model proposed by DecaWave is then summarised and compared to the IEEE802.11n model C path loss model. This path loss model has been adopted by the standards committee as an accurate representation of the path loss observed in dense indoor office environments at both 2.4GHz and 5GHz. The DecaWave model is shown to reproduce this model very accurately in terms of mean path loss. It is also shown that the worst 10% of narrowband channels have significantly more attenuation than the worst 10% of UWB channels.

3 The Difference between UWB and Narrowband channels

Consider a dense multipath environment, typical of indoor channels. The response due to an ideal impulse at time *t*, *δ(t)*, can be written

$$h(t) = \sum_{m=1}^{M} \alpha_m \delta(t - \tau_m)$$

where *M* is the number of multipath components, α_m is the fading of the m^{th} component and τ_m the delay associated with this component.
The frequency transfer function is given by the Fourier transform of *h(t)*. This can be calculated to be

$$H(f) = \int_{-\infty}^{\infty} h(t)\, e^{-j2\pi f t}\, dt$$
$$= \sum_{m=1}^{M} \alpha_m \int_{-\infty}^{\infty} \delta(t - \tau_m) e^{-j2\pi f t}\, dt = \sum_{m=1}^{M} \alpha_m\ e^{-j2\pi f \tau_m}$$
$$= \sum_{m=1}^{M} \alpha_m \cos(2\pi f \tau_m) - j \sum_{m=1}^{M} \alpha_m \sin(2\pi f \tau_m)$$

Assume that *M* is large. Therefore the two sums can be approximated by Gaussian random variables. The variance of the real component of this is the sum of the expected value of the square of each component b_m. This is written as (where we have dropped the subscript for convenience)

$$E\{b^2\} = \int_{-\infty}^{\infty} b^2 p_b(b)\, db = \int_{-\infty}^{\infty} \alpha^2 cos^2(2\pi f \tau) p_f(f) df$$
$$= \alpha^2 \int_{-\infty}^{\infty} cos^2(2\pi f \tau) p_f(f) df = \frac{\alpha^2}{\pi} \int_0^{\pi} cos^2(x)\, dx = \frac{\alpha^2}{\pi}\frac{\pi}{2} = \alpha^2/2$$

Where we have used the fact that the cosine function is periodic, hence reducing the limits on the integral, changing the integrating term and reducing the term to have a uniform distribution. This can easily be extended to the complex term. The variance of the Gaussian variables is the same and equal to the sum

$$\sigma^2 = \sum_{m=1}^{M} \frac{\alpha_m^2}{2}$$

Assuming a normalised channel impulse response, i.e. that the sum of the squares of fading terms is equal to one, and that the variance of each Gaussian term is 1/2.
The amplitude of the frequency response at some *f* is therefore the square root of the sum of two Gaussian random variables, which is the well known Rayleigh distribution. More importantly, the power at any *f* is a Chi squared random variable with 2 degrees of freedom.
The total energy received in some bandwidth is the integral of the energies of the frequencies contained in this bandwidth. This would imply that if the energy at *f* and the energy at *f* + *Δf*, where *Δf* is very small are independent, then the energy received in one bandwidth is the same as any other bandwidth scaled by the ratio of the two bandwidths. However, this is not the case in multipath channels. The coherence bandwidth of a channel is the bandwidth over which the frequency response is considered not to change significantly.
So, to compare the energy received by a narrowband (relatively speaking) and an UWB system, we assume the frequency response is divided into bins of bandwidth B_c and each bin has an energy

transfer function given by a Chi Squared variable with two degrees of freedom. Let *N* be the number of bins in the narrowband bandwidth and *K* the number in the UWB bandwidth. Assuming that a unit energy signal is transmitted, the signal energy of each bin is equal to the inverse of the number of bins. The total energy received for the narrowband and UWB system can therefore be written

$$E_N = \frac{1}{N}\sum_{n=1}^{N} \beta_n$$

$$E_K = \frac{1}{K}\sum_{k=1}^{K} \beta_k$$

The energies are scaled sums of Chi Squared variables with two degrees of freedom. Therefore, these sums are simply scaled Chi-Squared variables with *2N* and *2K* degrees of freedom. These energies can be considered as the gain a signal sees going through a channel and we will therefore refer to them as channel gains from this point on.
Hence, the probability distribution function for a channel gain for a bandwidth containing *N* bins is given by

$$p_E(E) = \frac{N}{\sigma^{2N}} \frac{(NE)^{N-1}}{2^N \Gamma(N)} \exp\left(\frac{-NE}{2\sigma^2}\right)$$

Where Γ is the gamma function and σ^2 is the variance of the real and complex terms of the frequency response of the channel. Substituting the calculated value for the variance, the distribution can be written

$$p_E(E) = N\frac{(NE)^{N-1}}{\Gamma(N)} \exp\left(-NE\right)$$

This term gives us the distribution of the channel gain given *N* coherent bandwidths in the bandwidth of the signal.

4 Comparing 20MHz and 500MHz channels

Consider two signals: A narrowband signal with a bandwidth of 20 MHz and a UWB signal with a bandwidth of 500 MHz. We assume a coherence bandwidth of 5 MHz. This is equivalent to a delay spread of 200ns. This is quite a long delay spread. The longer the delay spread, the narrower the coherence bandwidth, so this coherence bandwidth is relatively narrow and is usually significantly wider. The probability distribution function of the two channel gains are given in figure 1.

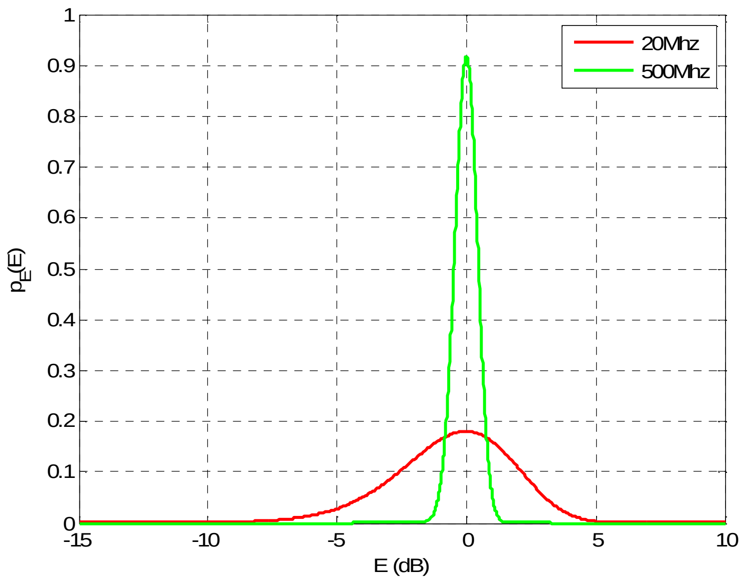

Figure 1: Distribution of channel gains for 20MHz narrowband signal and 500MHz wideband signal

It is apparent that the UWB sees a more well behaved channel gain. The narrowband signal can experience quite a high gain, but also a severe attenuation. The shadowing standard deviation term in the link budget is therefore much higher in a narrowband system than a UWB system.

5 Path Loss Models

In the previous document, the proposed path loss model was discussed. This path loss model consisted of three different Path Loss exponents associated with three different channel types. These are the Line of Sight (LOS) channel, the Soft Non-line of Sight (soft NLOS) channel and the Hard Non-line of Sight (hard NLOS) channel. The soft and hard NLOS channels were proposed to model the difference between NLOS in a typical indoor environment. Typically, most short range obstructions are relatively low attenuating materials such as plasterboard walls and office partitions. These would fall into the soft NLOS category. However, at further distances the obstructions are more likely to be high attenuating materials such as concrete walls. These would fall into the hard NLOS category.

To weight these three different path loss models, the probability that a channel type would occur at some distance was proposed. The probability of each of these channel types occurring at a given distance is shown in figure 2.

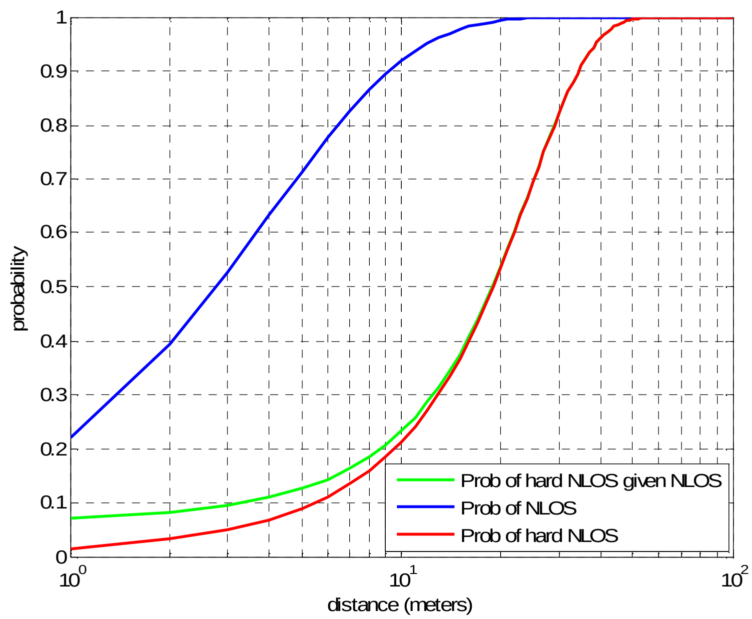

Figure 2 : Probability of channel type with respect to distance

The resulting overall path loss model can then be calculated by weighting the individual channel type path losses. Figure 3 shows the path loss for each channel category with the weighted path loss model. Note that this path loss is the path loss relative to that at one meter.

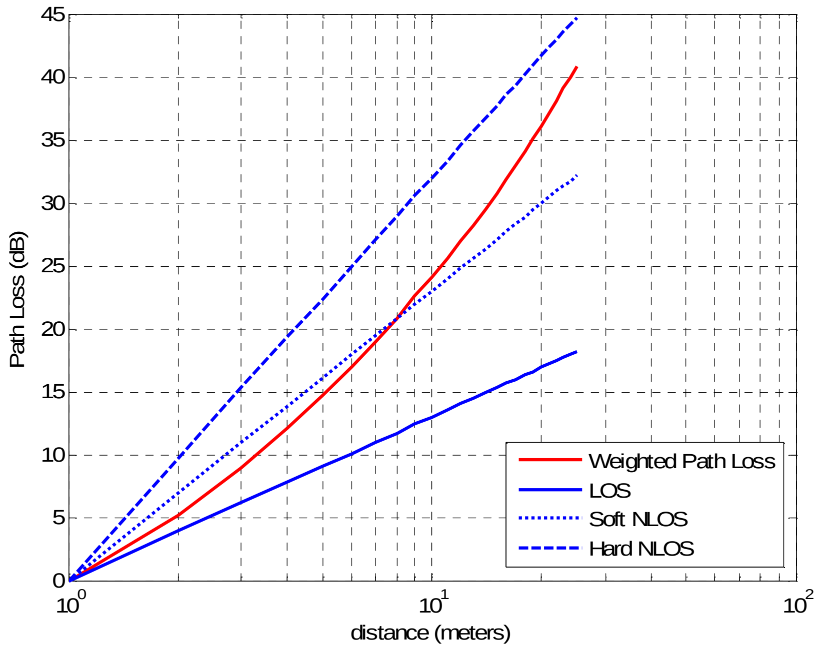

Figure 3 : Different path loss models with the final weighted path loss model

6 802.11n Path Loss Model

The 802.11n channel model models path loss with two exponents and a break point distance. Up until the break point distance, the path loss exponent is two. After this, it is 3.5 from that point. This model is similar to the proposed DecaWave UWB path loss model with the idea that more severe environments occur at higher distances. The 11n model is written as

$$L(d) = L_{FS}(d) \qquad d <= d_{BP}$$

$$L(d) = L_{FS}(d_{BP}) + 35 \log_{10}(d / d_{BP}) \qquad d > d_{BP}$$

Where d is the distance, L_{FS} is the free space path loss and d_{BP} the breakpoint distance. Model C is one of the severe path loss channels, with a breakpoint distance equal to 5. This was estimated from measurements and is for LOS and NLOS channels in both the 2.4 GHz and 5 GHz band. The path loss, again relative to the loss at one meter, is plotted in figure 4.

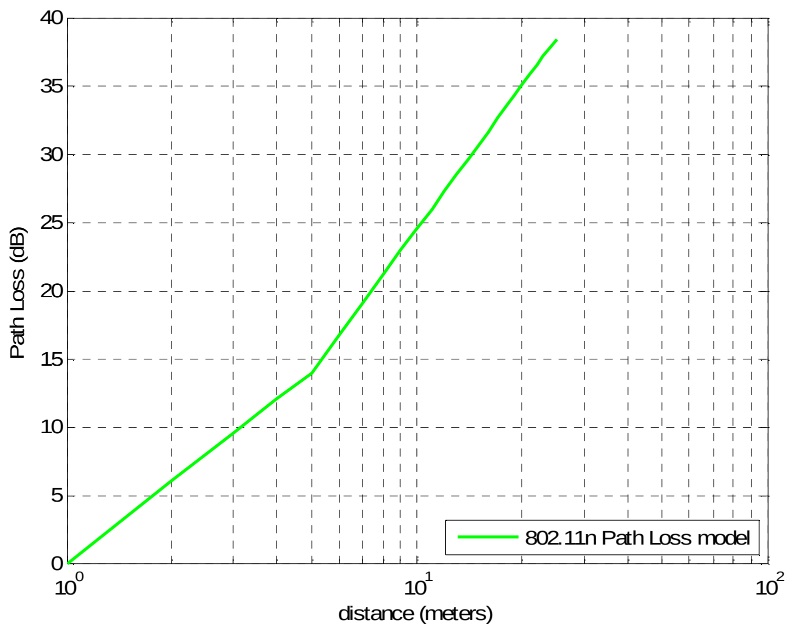

Figure 4 : 802.11n Model C path loss

This environment is similar to the environment of interest for IEEE802.15.4a and is compared to the proposed weighted path loss in figure 5. The two path loss curves are almost identical.

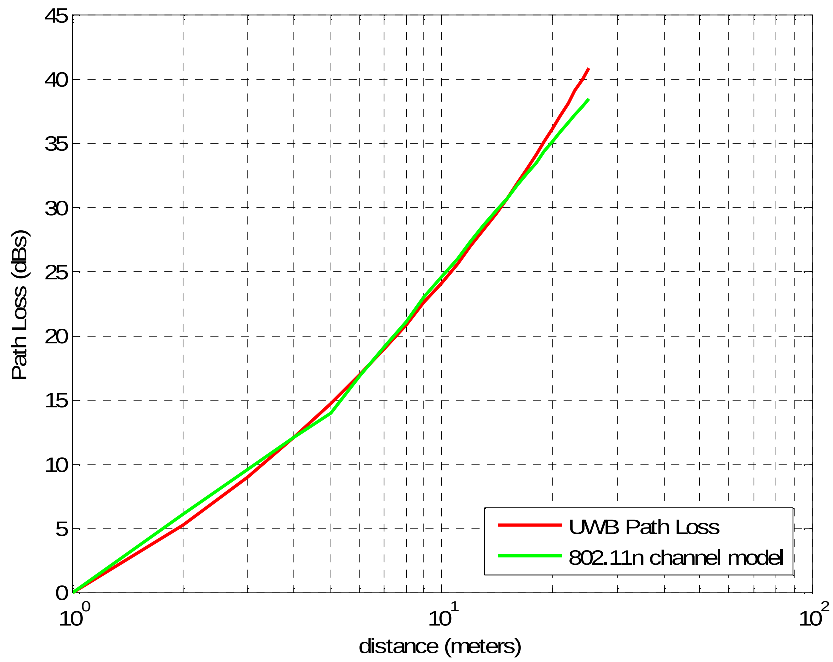

Figure 5 : UWB path loss model and 802.11n model C path loss model

However, these are the mean Path Loss attenuations. Shadowing differs significantly between the narrow IEEE802.11n and wide UWB channels. The shadowing standard deviation for the Model C indoor office model, in the 11n narrowband model, is 8dB. For the ultra wideband model, we chose 3dB after reviewing the literature.

Using these shadowing standard deviations gives the probability distribution functions vs distance for the path loss for the 802.11n narrowband and proposed UWB wideband channel models shown in figures 6 and 7. Figure 8 then shows the path loss models with the minimum loss seen in the worst 10% cases. It can be seen that at 10m 10% of narrowband channels have 35dBs more loss than the average loss at 1m. The ultra wideband channel is more than 7dBs better than this.

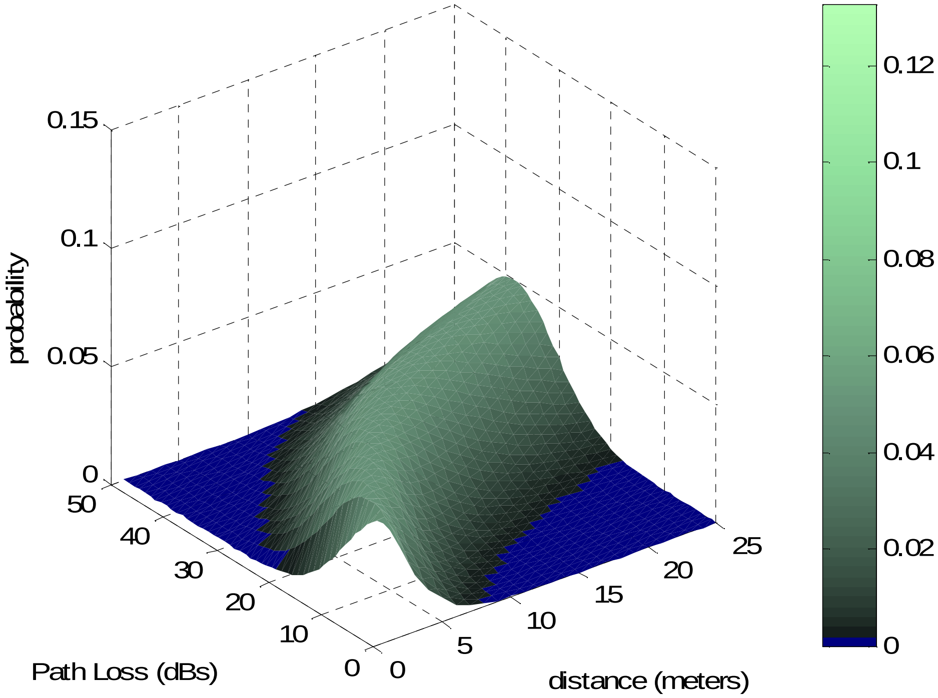

Figure 6: Probability distribution functions for the path loss versus distance for 802.11n channels

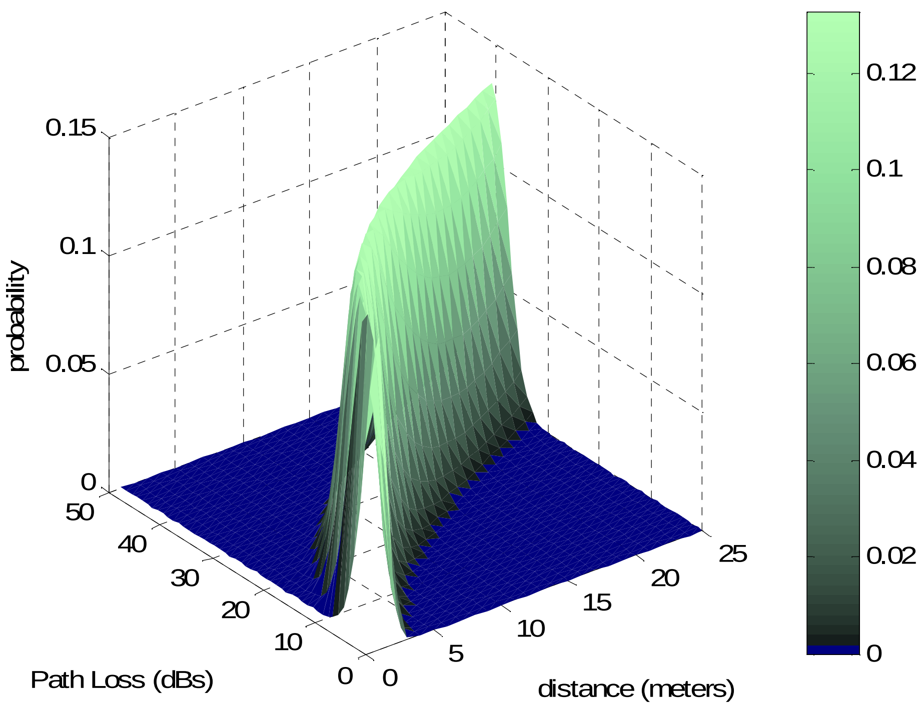

Figure 7: Probability distribution functions for the path loss versus distance for UWB channels

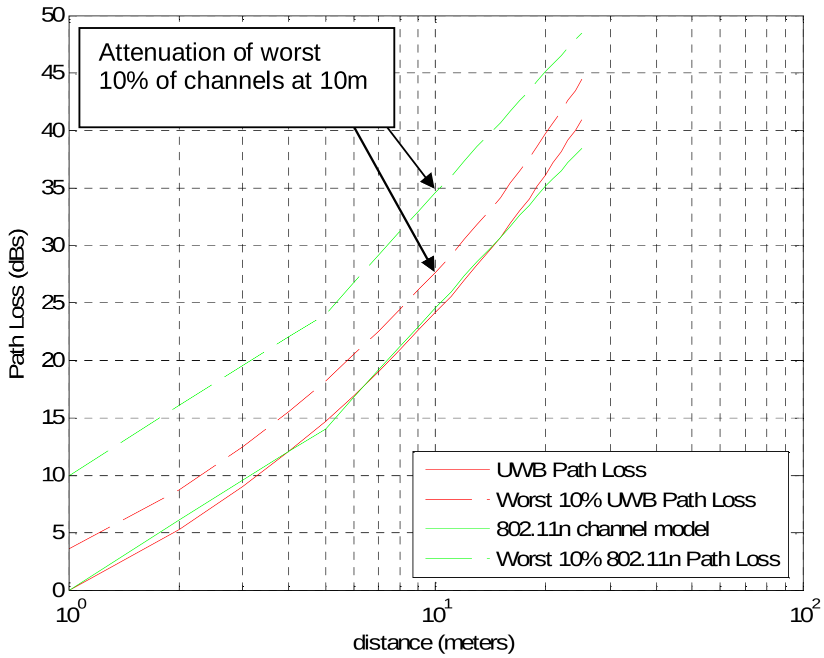

Figure 8: UWB path loss model and 802.11n model C path loss model with minimum Path Loss seen in the worst 10% of cases.

7 Conclusion

This document discusses the differences between narrowband and UWB channel models and attempts to relate the two and explain any differences in the large scale fading statistics. The proposed Path Loss model for UWB is shown to resemble model C of the 802.11n narrowband models very closely. This model was derived from measurements in both the 2.4 GHz and 5 GHz bands in an office environment, which is similar to the environment proposed for the UWB path loss model. However, the shadowing parameter is different for the narrowband and UWB channels, with the narrowband model seeing a much larger shadowing variance. The amount of energy captured from the two types of channels was derived and shown to be significantly different. Finally it was shown that at 10 metres, the worst 10% of narrow band channels have 7dBs more path loss than the worst 10% of ultra wideband channels.