White Paper:

Combined LOS and NLOS UWB Channel Model

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2 Introduction

Traditionally, ultra wideband channel models have been segregated into LOS and NLOS. This is useful for simulating how a system will work in different environments. The problem with this approach is that it is difficult to extrapolate from these models how well a system will work in the real world where you get a mixture of LOS and NLOS channels. This document presents a unified channel model which contains both LOS and NLOS channels. The model has been developed with a thorough survey of existing ultra wideband channel literature. The resultant model will allow simulations to be performed which will allow realistic measurements to be made of real world performance.

3 The IEEE 802.15.4a channel model

The IEEE 802.15.4a channel model is an UWB channel model derived from a large set of independent measurements, as given in [1-4]. This model was produced in order to compare proposals for the 4a standard on an equal footing, but did not distinguish between different types of non line of sight (NLOS) environments. From a comprehensive review of the available channel measurements and reports, it is clear that two distinct NLOS cases exist. A case where the signal is mainly obstructed by relatively low attenuation materials such as plasterboard and doors, and a case where it is mainly obstructed by high attenuation materials such as multiple concrete walls.

To obtain an accurate estimate of the performance of a system, both types of NLOS channel and also the line of sight (LOS) channel need to be considered.

This document details the channel model DecaWave has created to realistically model the UWB channel in different environments which will be utilized for all future IEEE 802.15.4a simulations.

4 Path Loss Models and the IEEE model

Numerous path loss models for UWB in the indoor environment have been reported [2-8]. In order to compare the different proposals for the IEEE 802.15.4a standard, the task group developed a channel model. This channel model was intended to be a compromise between many proposed models and studies reported in the literature. However, this model attempted to create just two channel types; the LOS and NLOS. This is inadequate when simulating real channel conditions, where different materials lead to different statistics, in particular the path loss exponent of the large scale fading.

Figure 1 summarises the path loss at different distances for some of the office models reported in the literature, and in particular [2-8]. Each model is referenced by either the name of the principle company/university or author of the study. Also, each line is plotted only over the distances measured by the study.

It is clear from this that the IEEE office model has a very large path loss relative to all but one of the other models and indeed, from 3 up to 7 metres, it is worse than any of the measured channels. It is not clear why this is the case.

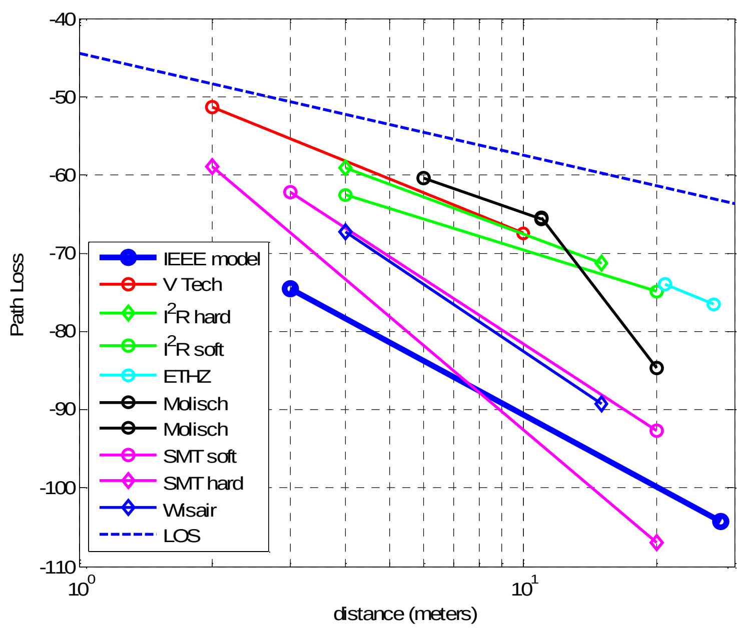

Figure 1. Different path loss models for UWB channels

5 Proposed channel model

The channel model proposed by this document was constructed in order to give the freedom to model different scenarios easily and accurately. Differences are usual between sets of measurements done in Europe compared to those done outside Europe, because of differences in building materials [8]. This is apparent from the graph above. All three of the most attenuated channel measurements were obtained in Europe and all of the other measurements were obtained in the US. This can easily be taken into account in our model by a weighting method which is discussed in detail below.

The model is comprised of three different propagation scenarios.

Line of Sight (LOS): This occurs when a direct line of sight between the transmitter and receiver exists. For example, in a corridor or an open plan office.

Soft Non-Line of Sight (soft NLOS): This occurs when the line of sight path is obstructed by material with relatively low attenuation or by a combination of these materials. It represents the most common channel model over the distances of interest and takes into account most attenuation excluding that which is caused by multiple concrete walls.

Hard Non-Line of Sight (hard NLOS): The hard NLOS channel is attenuated severely due to a multiple concrete walls in the environment. From the literature, this propagation environment is more common in measurements taken in E.U. buildings than in U.S. buildings. This is as one would expect due to the different materials used in the construction of these buildings.

5.1 LOS Path Loss statistics

In general, almost all the measurements reported have approximately the same path loss for the line of sight case, regardless of the measurement environment. Reported values for the path loss exponent range from 1.3 to 1.8 and with a shadowing parameter of about 1.9 dBs (average) [3].

All of these path loss exponents are generally calculated with respect to the total energy received. The channel impulse responses therefore have unit energy. The path loss exponent for free space is 2 but these measured path loss exponents are less than this value. In the LOS channel, the line of sight component is the strongest and this path has an exponent of 2. This exponent can be referred to as the peak path, path loss exponent. Due to the time resolution achievable with UWB, a large number of paths are received. These paths have a lower power than the LOS path, but due to the large number received the total received power increases significantly. The total power path loss is therefore higher than the peak path path loss.

If the normalised channel impulse response power was scaled such that the first path had a path loss exponent of 2, the resultant total energy received would be higher than one.

For example, consider the case where the fraction of the received energy at a distance *d* due to the LOS path is given by $\alpha(d)$. Hence, $1-\alpha(d)$ of the energy is contained in the non line of sight paths. Hence, in order to scale the normalised channel response such that the direct path has a path loss exponent of *2*, we multiply the response by $\sqrt{\beta}$ where:

$$\beta = \frac{1}{\alpha}$$

The received power of the LOS component at a distance *d* is given as (free space and on average)

$$P_{LOS}(d) = P_{Tx} - PL_0 - 20\log_{10}\left(\frac{d}{d_0}\right) \quad (dB)$$

Where P_{Tx} is the transmit power and PL_0 the path loss at the reference distance d_0. However, the total received energy is

$$P_{Total}(d) = P_{Tx} - PL_0 - 10n\log_{10}\left(\frac{d}{d_0}\right) \quad (dB)$$

Where n is the total path loss exponent. The ratio of total power to peak path power is given as

$$P_{Total} - P_{LOS}$$
$$\Rightarrow 10\log_{10}\beta = 20\log_{10}\left(\frac{d}{d_0}\right) - 10n\log_{10}\left(\frac{d}{d_0}\right)$$
$$\Rightarrow \log_{10}\beta = \log_{10}\left(\frac{d}{d_0}\right)^2 - \log_{10}\left(\frac{d}{d_0}\right)^n$$
$$= \log_{10}\left[\left(\frac{d}{d_0}\right)^2\left(\frac{d_0}{d}\right)^n\right]$$
$$\Rightarrow \beta = \left(\frac{d}{d_0}\right)^2\left(\frac{d_0}{d}\right)^n$$

Where we have used the fact that α is the total power present in the first path and hence the ratio is simply β.

From the measurements reported in [5], at a distance of 9 meters (with d_0 equal to one) the energy received due to the line of sight path accounts for 25% of the total energy of the channel impulse response. In order to scale a normalised impulse response such that the first path has a path loss equal to that of free space, we scale the entire response by $\sqrt{\beta}=1/\sqrt{0.25}=2$. This is equivalent to using the normalised channel response with a total path loss exponent of n which is found by

$$\beta = \left(\frac{d}{d_0}\right)^2\left(\frac{d_0}{d}\right)^n$$
$$\Rightarrow \beta = \frac{81}{9^n} \Rightarrow n = \log_9 81 - \log_9\beta = 2 - 0.63 = 1.37$$

The total path loss is then shown to be less than 2. This analysis is for the LOS case only, but can be extended to the NLOS case easily if the peak path path loss is known.

In order to accurately reflect reality, our proposed channel model will scale the normalised impulse response such that the first path has a path loss exponent of 2 (LOS case). The additive white Gaussian noise variance is calculated relative to the total signal to noise energy ratio at a given distance and subsequently scaled by β. This results in a received signal to noise ratio which satisfies the observed total path losses, but reflects the fading of the first component, which is important for realistic ranging.

It is important to note that all the measurements reported use total received energy, so the different path loss models were compared with this measure and from this point on, path loss refers to total path loss unless specified.

5.2 Soft NLOS Path Loss statistics

The soft NLOS channel is defined as a channel without a direct line of sight path and with obstructions with relatively low attenuation such as plastic, glass, plaster board walls, doors and partitions. The majority of reported measurements from US buildings are of this form. The reported path loss exponents are in the range of 1.8 to 2.4 with a shadowing parameter in the range 1.9 to 3.3 [3].

5.3 Hard NLOS Path loss statistics

The hard NLOS channel is a channel which contains concrete walls, usually several, which attenuate the transmit signal severely. Typically, these situations occur more regularly in measurements taken from Europe.

5.4 The Channel Model Parameters

The models used for each of the three cases, and their reasons for being chosen, are discussed here.

5.4.1 LOS

The LOS path loss model chosen for our model is the Virginia Tech omni-directional antenna channel model available online in their report for DARPA [5]. They report a path loss exponent of 1.3 with a shadowing parameter of 2.6. This is report is one of the few which reports the peak path path loss, which as expected for LOS channels is 2. This was chosen for a few reasons. Mainly, it is the most detailed report available in the area of UWB channel modelling. Secondly, it was performed in four different physical environments, whereas most other reports are only performed in one environment. Also, measurements were taken up to 50m, which is greater than much of the measurements performed in other reports. The path loss exponent in this model is on the low side of the observed exponents from other measurements, but the shadowing parameter is higher which balances this somewhat.

The small signal model is slightly different than conventional UWB models. The channel impulse response consists of two clusters of paths. The initial cluster decays rapidly, but starts with a high power. The second cluster decays more slowly, but begins with a lower power. [5] details how this model resembles actual models more accurately than other conventional models such as the S-V channel model. The S-V model has been the standard channel impulse response for UWB to date, but assumes multiple received clusters. However, for the LOS channel, one cluster dominates the entire response and a single extra cluster accurately models the remaining paths.

5.4.2 Soft NLOS

The soft NLOS model was also taken to be the Virginia Tech omni-directional antenna NLOS model [5]. The path loss exponent was found to be 2.3 with a shadowing parameter of 2.8. The peak path path loss was measured in the range of 2.7-4.3. This was measured up to 10 meters. However, this model agrees closely with the I^2R model [2] which was measured from 5-20 meters and the ETHZ [4] model which was measured from 21 to 27 meters. These environments had internal concrete walls but not a high number, with the majority of space divided by partitions or plasterboard.

The small signal model is similar to the LOS model, but with different statistics. Again, this model was shown to generate statistical impulse response models which closely resembled measured responses.

5.4.3 Hard NLOS

The hard NLOS model chosen was the ULTRAWAVES (Wisair) model [8] performed in the University of Oulu in Finland. This environment consisted of numerous concrete walls. Three separate measurements for three different receiver heights (60cm, 110cm and 220 cm) were taken with the transmitter at a fixed height of 220cm. The worst case was for a receiver height of 60cm which gave a path loss exponent of 3.8. This hard NLOS model has similar statistics to what is referred to as a soft NLOS in [7]. However, the model of [7] was derived from an extremely dense environment with a large number of both concrete and plasterboard walls in an extremely small area and does not give a representative example of the standard office channel. Therefore, it is not considered to be a standard soft NLOS channel but to be a hard model.

An accompanying small signal model was not discussed in [8]. For this case, the standard S-V model will be adopted. This is the conventional model for UWB channels which models the impulse response as a set of clusters. This is expected to model the channel response accurately due to the lack of dominant clusters. The model parameters are the ones given in the IEEE 802.15.4a channel model document [1].

5.5 Probability of the three different propagation effects for realistic modelling of the channel

With the defined propagation effects, we will next develop a weighting scheme in order to model any environment as realistically as possible.

A realistic weighting scheme should take into account the probability of each of the three types of channels occurring at any given distance. The probability of a LOS channel decreases with increasing distance. Furthermore, the probability of a hard NLOS channel occurring at short distances is quite low. A possible model could be the model proposed in [9] for the probability of a LOS existing between the transmitter and receiver at some distance. This is shown to be dependent on the volume of the room. The probability of a LOS channel existing decreases exponentially with distance.

Our proposed model extends this such that if a NLOS channel exists, the probability of this channel being a ‘hard’ channel is modelled as a normal distribution. Firstly, the exponential model is only valid for relatively long distances if we applied ‘hard’ channel radius required. Secondly, the ideas of ‘soft’ and ‘hard’ NLOS channels and what causes these effects are very different. Soft NLOS channels are caused when the LOS path is obstructed by some light material, be it a wall, furniture or a door for example, whereas the hard channel occurs when the signal is obstructed by a very high attenuation material such as multiple concrete walls. These concrete walls occur in very regular patterns (rectangular for example). By varying the position of the transmitter within a rectangular space (for simplicity) the probability of the signal being obstructed by a wall with respect to distance is calculated. Due to the large number of different environment dimensions and points within these dimensions the probability was modelled as a Gaussian distribution. Note that this takes into account omni-directional coverage. That is, if the transmitter is mounted on a heavy concrete wall the derived weighting scheme is valid for receivers on the opposite side of that same wall.

With this weighting scheme, the probability of the different types of channels occurring at any distance from the transmitter can be calculated. In addition, this model gives a large degree of freedom for modelling different scenarios.

As an example of the possible weighting for a European office environment, figure 2 shows the probabilities of a NLOS channel, the probability of this channel being hard NLOS and also the probability of a hard NLOS channel occurring. These probabilities are calculated for a soft room radius of 4 meters and a hard room within both length and width ranging from 30 to 50 meters. A possible weighting for a U.S. office environment would set the probability of a hard NLOS channel occurring equal to zero in the ranges of interest to agree with the measurements reported [2-8]. Therefore, the probability of a NLOS channel in figure 2 is simply equal to the probability of a soft NLOS channel.

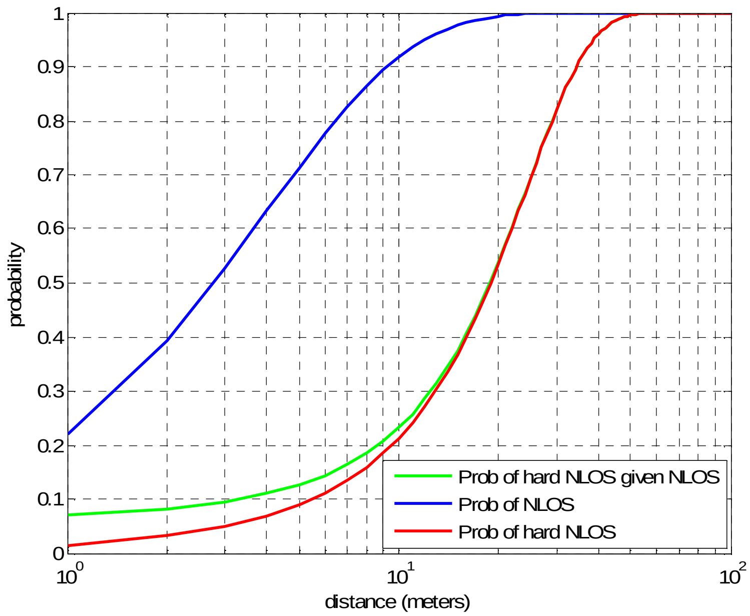

Figure 2. Probability of NLOS channels

6 Simulation set-up

The proposed simulation set up is as follows:

i) The distance between transmitter and receiver is set at a value between 3 and 30 meters. The propagation effect (LOS, soft NLOS or hard NLOS) is generated randomly with probability defined in our weighting scheme for the required channel (e.g. office). The relevant path loss model is used to calculate the total received energy.

ii) Ten packets are generated.

iii) A normalized channel impulse response is generated randomly according to the small signal channel statistics. The ten packets are sent through this channel and received. The packet error rate is calculated.

iv) Steps ii and iii are repeated 300 times.

v) The distance between transmitter and receiver is changed and the process repeated.

vi) The packet error rate versus distance is plotted.

7 Summary

This document outlines a proposed channel model and simulation set-up for all future IEEE 802.15.4a simulations. Propagation effects are broken into three scenarios, LOS, soft NLOS and hard NLOS, with the statistics for each model referenced. A weighting system is developed in order to model a variety of different environments, such as the indoor office environment, accurately and easily by a single channel model. The simulation set up is also proposed in detail.

REFERENCES

[1] A. Molisch et al. (IEEE), "IEEE 802.15.4a channel model - final report", IEEE P802.15-04-0662-04-004a.

[2] K. Balakrishnan (I^2R) et al., "Characterization of Ultra-Wideband Channels: Large-Scale Parameters for Indoor & Outdoor Office Environments", IEEE 802.15-04-0383-00-004a, July 2004.

[3] B. Kannan et al., "UWB Channel Characterization in Indoor Office Environments", IEEE P802.15-15-04-0439-00-004a, August 2004.

[4] ETHZ, "Indoor UWB Channel Measurements from 2GHz to 8GHz", IEEE 802.15-04-0447-00-004a, September 2004.

[5] Virginia tech channel model, http://mprg.org/people/buehrer/ultra/darpa_netex.shtml

[6] A. Molisch et al. "The Ultra-Wide Bandwidth Indoor Channel: From Statistical Model to Simulations", IEEE Journal on Selected Areas in Communication, vol. 20, no. 6 August 2002.

[7] J.Keignart (SMT), "UWB Channel Modeling Contribution from CEA-LETI and STMicroelectronics", IEEE 802.15-02-0444, October 2002.

[8] Veikko Hovinen (Wisair), "A proposal for a selection of indoor UWB path loss model", IEEE 802.15-02-280, June 2002.

[9] T. Zwick et al., "A Stochastic Multipath Channel Model Including Path Directions for Indoor Environments.", IEEE Journal on Selected Areas in Communication, vol. 20, no. 6 August 2002.