Status of models for UWB propagation channels

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***Abstract*—This is a discussion document for the IEEE document of the IEEE 802.15.4a channel modeling subgroup. It gives the current status of the generic channel model for UWB that has been discussed. Feedback from all participants is requested.**

***Index Terms*—UWB, channel model, propagation**

I. INTRODUCTION

This document is a summary of the model that the channel-modeling subgroup of IEEE 802.15.4a has (so far) agreed on. The model is intended for a system operating between 2 and 10 GHz; however, the same structure could/should be used for a lower-frequency model as well (mainly for operation between 100 and 960 MHz. While the modeling is done for a ultrawideband system, this is no restriction on the system. Any narrowband model can easily be derived from the UWB model by narrowband filtering.

II. ENVIRONMENTS

The following radio environments will be parameterized:

1. Indoor office
2. Indoor residential
3. Indoor industrial
4. Indoor open spaces
5. Warehouses
6. Body devices
7. Out door hand held peer to peer device
8. Hand held communicating to fixed location devices
9. Agricultural areas/farms
10. Sport stadiums
11. Disaster areas (houses filled with rubble, avalanches, ...) ...

III. PATHLOSS

A. Frequency dependence

In a narrowband (in the wireless communications sense) channel, the pathloss is defined as

$$PL = \frac{E\{P_{RX}\}}{P_{TX}} = E\{|H(f_c)|^2\} \tag{1}$$

where P_{TX} and P_{RX} are transmit and receive power, respectively, f_c is the center frequency, and the expectation $E\{\}$ is taken over an area that is large enough to allow averaging out of the shadowing as well as the small-scale fading $E\{\} = E_{lsf}\{E_{ssf}\}\}$. A wideband (in the wireless communications sense) pathloss has been proposed in Ref. [1], [2] as

$$PL = E\{\int |H(f)|^2 df\} \tag{2}$$

where the integration is over the frequency range of interest; it is assumed implicitly that this range is much smaller than the center frequency. In a conventional wireless system, any frequency selectivity of the transfer function stems from the multipath propagation, and is thus related to the small-scale fading. Integration over the frequency and expectation $E_{ssf}\{\}$ thus essentially have the same effect, namely averaging out the small-scale fading.

In a UWB channel, this is not the case anymore. As we have seen in Sec. III, there are frequency-dependent propagation effects. It thus makes sense to define a *frequency-dependent pathloss*

$$PL(f) = E\{\int_{f-\Delta f/2}^{f+\Delta f/2} |H(\widetilde{f})|^2 d\widetilde{f}\} \tag{3}$$

where Δf is chosen small enough so that diffraction coefficients, dielectric constants, etc., can be considered constant within that bandwidth; the $total$ pathloss is obtained by integrating over the whole bandwidth of interest.. It is especially noteworthy that the effective antenna areas are a function of the frequency. This affects all measurement campaigns that include the antenna as part of the channel.

Two campaigns have measured and modeled the frequency dependency of the pathloss. Ref. [3] found that

$$\sqrt{PL(f)} \propto f^{-m} \tag{4}$$

with m varying between 0.8 and 1.4, while [4] found

$$\log_{10}(PL(f)) = \propto \exp(-\delta f) \tag{5}$$

with δ varying between 1 and 1.4.

B. Distance dependence

Naturally, the pathloss also depends on the distance. Pathloss modeling can be simplified by assuming that the frequency dependence and the distance dependence can be treated independently of each other

$$PL(f,d) = PL(f)PL(d). \tag{6}$$

The distance dependence is usually modeled as a power decay law

$$PL(d) = PL(1\text{m})\left(\frac{d}{1\text{m}}\right)^{-n} \tag{7}$$

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where n is the the pathloss exponent. Note that this model is no different from the most common narrowband channel models. The many results available in the literature for this case can thus be re-used.

The pathloss exponent also depends on the environment, and on whether a line-of-sight (LOS) connection exists between the transmitter and receiver or not. Some papers even further differentiate between LOS, "soft" NLOS (non-LOS), also known as "obstructed LOS" (OLOS), and "hard NLOS". LOS pathloss exponents in indoor environments range from 1.0 in a corridor [5] to about 2 in an office environment. NLOS exponents typically range from 3 to 4 for soft NLOS, and $4-7$ for hard NLOS. Following the approach of Refs. [6], [7], [8], [9], we suggested to model the pathloss exponent as a random variable that changes from building to building.specifically as a Gaussian distribution. The of the pathloss will be truncated to make sure that only physically reasonable exponents are chosen.

1) Shadowing: Shadowing, or large-scale fading, is defined as the variation of the local mean around the pathloss. Also this process is fairly similar to the narrowband fading. Again following Ref. [6], we suggest to model the shadowing variance as random variable. The total attenuation due to shadowing and pathloss is

$$[PL_0+10\mu\log(d)]+[10n_1\sigma_\gamma\log_{10}d+n_2\mu_\sigma+n_2n_3\sigma_\sigma] \quad (8)$$

where n_1, n_2 and n_3 are zero-mean, unit-variance Gaussian variables.

IV. Delay dispersion, angular dispersion and small-scale fading

A. Arrival statistics of multipath components

We first turn our attention to the power delay profile and the time-of-arrival statistics of the MPCs.

The clustering of MPCs is also reproduced in the Saleh-Valenzuela (SV) model [10], which uses the following discrete-time impulse response:

$$h_{discr}(t)=\sum_{l=0}^{L}\sum_{k=0}^{K}a_{k,l}\delta(t-T_l-\tau_{k,l}), \quad (9)$$

where $a_{k,l}$ is the tap weight of the k^{th} component in the l^{th} cluster, T_l is the delay of the $l-$th cluster, $\tau_{k,l}$ is the delay of the k-th MPC relative to the l-th cluster arrival time T_l. By definition, we have $\tau_{0,l}=0$. The distributions of the cluster arrival times and the ray arrival times are given by a Poisson processes

$$\begin{aligned} p(T_l|T_{l-1}) &= \Lambda_l \exp\left[-\Lambda_l(T_l-T_{l-1})\right],\ l>0 \\ p(\tau_{k,l}|\tau_{(k-1),l} &= \lambda \exp\left[-\lambda(\tau_{k,l}-\tau_{(k-1),l})\right],\ k>0 \end{aligned} \quad (10)$$

where Λ_l is the cluster arrival rate, and λ_l is the ray arrival rate. Note that we have generalized the SV model to account for the (experimentally observed) effect that the cluster arrival rates as well as the path density within each cluster can depend on the delay.

The number of clusters is set to fixed numbers for each environment. More specifically, we define two numbers L_1 and L_2, which are taken on with probabilities p_1 and p_2. Thus, for each "drop" of the MS, we "throw the dice" to determine which of the two cluster numbers is used. L_1, L_2, p_1, and p_2 are parameters of the model.

The intra-cluster arrival rates λ are extracted from the measurements. For those extractions, it is recommended that paths with power that is less than $20dB$ below the peak power are not taken into account.

The power delay profile of each cluster is set to be exponential, though the first arriving path can have higher power than the remainder.

In the SV model, the relative power of each cluster is considered to decay exponentially with rate γ. However, measurements have shown that this is not fulfilled in all environments. Therefore, the relative power of the clusters, as a function of the distance, is an arbitrary parameter that will be determined for each environment separately. No further specifications are done at this point in time.

Furthermore, each cluster undergoes lognormal shadowing that has a constant variance $\sigma_{cluster}$, and that is independent for all clusters. The small-scale fading of the separate clusters

In addition to the disrete paths, there is a superimposed diffuse background radiation

$$h_{diff}(t)=f(t)\zeta \quad (11)$$

where ζ is Rayleigh-distributed random variable. The functional shape of the variance $f(t)$ is not known at this point in time (probably zero at $t=0$, and at very large delays, with a maximum in between). It will have to be extracted from future measurements. The ratio of the power in the discrete components relative to that in the diffuse components is another parameter of the model.

B. Amplitude statistics

The small-scale fading is modeled as Rician or Nakagmai for each delay bin. Both of the two descriptions are admissible (as each has specific advantages in certain contexts). The two distributions are transformed into each other via the relationship

$$m=\frac{(K_\mathrm{r}+1)^2}{(2K_\mathrm{r}+1)} \quad (12)$$

and

$$K_\mathrm{r}=\frac{\sqrt{m^2-m}}{m-\sqrt{m^2-m}}. \quad (13)$$

where K and m are the Rice factor and Nakagami-m factor respectively.

The $m-$factor typically decreases with delay. The exact functional relationship $m(\tau)$ is yet to be determined from measurements (for a low-frequency office environment, [11] give a linear relationship). To simplify the description, the m factor is chosen determistically (in contrast to [11]).

C. Angular dispersion

The different multipath components arrive at the receiver not only with different delays, but also with different angles. This fact is of importance for systems with multiple antennas, as well as for analyzing the impact of nonuniform antenna patterns. In that respect, the angular dispersion does not differ in principle from the widely studied angular dispersion in narrowband systems. The angular power spectrum, i.e., the power (averaged over the small-scale fading) coming from a certain direction, is modeled as a Laplacian function

$$APS(\phi) = \exp(-|\phi - \phi_o|/\sigma_\phi) \tag{14}$$

where the angle ϕ_o of the first arriving cluster is along the (quasi)-LOS, while for the later clusters, it is uniformly distributed between 0 and 2π. Note that the Laplacian distribution needs to be truncated so that $0 < APS < 2\pi$,

The diffuse radiation is distributed uniformly in angle.

V. Summary and conclusions

We gave an overview of the generic model for the IEEE 802.15.4a channels. The next important step is the parameterization of the model.

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