Impulse Based UWB Channel Model for WPAN

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Abstract – The proliferation of wireless communication devices in our lives shows no sign of stagnation. The ever-growing demand for higher quality media and faster content delivery where we work, live, and play drives the quest for higher data rates in communication networks. To meet this demand for capacity in the wireless personal area network (WPAN) space, the IEEE 802.15.3a task group has set out to define a very high data rate alternate physical layer for IEEE 802.15.3, the current high data rate WPAN. Here the channel models for UWB are discussed and the impulse response for Channel model 3 is shown.

Keywords – UWB, WPAN, IEEE 802.15.3, Channel model

I. INTRODUCTION

Wireless communications are increasing the bandwidth occupied by the employed signals. This has caused the increased demand for data rates while new applications like video-on-demand require 10 Mbit/s and more. On the other hand, multiple-access schemes like code-division multiple access (CDMA) require signals with larger bandwidth in order to achieve advantages like robustness to fading, improved multiple-access capabilities, and immunity to interference. Ultra-wide-band (UWB) radio pushes this trend to the limit by occupying bandwidths of 500 MHz or more using a bandwidth that is 20% or larger than the carrier frequency. The design of a wireless receiver and transmitter, the basic building blocks of any wireless product, is significantly dictated by the channel model corresponding to the communication scheme utilized. The accurate design of channel model is a significant issue for ultra wideband WPAN communication system. Such a model creates the facility for calculation of large and small-scale statistics. Specifically large-scale models are necessary for network planning and link budget design and small-scale models are necessary for efficient receiver design. The most famous multipath UWB indoor channel models are tap-delay line, Rayleigh fading model, Saleh and Valenzuela (S-V) model and Δ-K model.

II. DIFFERENCE BETWEEN NARROWBAND AND UWB CHANNELS

Channel impulse response to a UWB pulse is significantly different from the conventional narrowband systems due to the large bandwidth of the pulse, therefore making most previous research on the narrowband wireless channel models inapplicable. Figure 1 demonstrates the difference between the bandwidth of narrowband and UWB signals.

![Fig.1: MPCs in UWB and conventional wideband system](image-url)
III. MEASUREMENTS

The measurement and modeling of UWB channels is a fairly recent field. The 802.15 channel model is based on some of the measurement campaigns published in the open literature as well as on measurement campaigns performed explicitly for the standard.

There are two basic techniques for UWB channel measurements:

1. **Time-domain techniques:**

   The channel is excited by a short pulse, and the receiver records the impulse response directly, by sampling the received waveform. The advantage of this technique is that it gives the waveform directly in the time domain, and time variations of the channels can be easily measured. The drawback lies in the problems of producing ultra-short pulses, and the fact that a no ideal transmit pulse distorts the observed impulse response. Applying a deconvolution of the transmit pulse from the received signal often leads to numerical problems.

2. **Frequency-domain techniques:**

   A chirp is used to excite the channel, so that the received signal is an approximation of the transfer function. In most practical cases, a network analyzer is used as transceiver, since these devices are well-calibrated and readily available in most laboratories. A further advantage of this technique is that a “back-to-back calibration” can be done quite easily. A drawback is that time variations of the channels cannot be easily recorded.

IV. CHANNEL MODEL

The accurate design of channel model is a significant issue for ultra wideband WPAN communication system. Large-scale models are necessary for network planning and link budget design and small-scale models are necessary for efficient receiver design. The most famous multipath UWB indoor channel models are tap-delay line Rayleigh fading model, Saleh and Valenzuela (S–V) model and Delta K model. The S–V channel model shows that the multipath components are arriving in a cluster form. The different paths of such wide band signal can rise to several multipath components, all of which will be part of one cluster. The arrival of multipath components is modelled by using Poisson distribution and thus the inter arrival time between multipath components is based on exponential distribution. The multipath arrival of UWB signals are grouped into two categories: cluster arrival and ray arrival within a cluster. This model requires several parameters to describe indoor channel environments [1]. Ray arrival rate is the arrival rate of path within each cluster. The cluster arrival rate is always smaller than the ray arrival rate. The amplitude statistics in S–V model are based on lognormal distribution, the power of which is controlled by the cluster and ray decay factor [2]. Indoor channel environments are classified as CM1, CM2, CM3, and CM4 following IEEE 802.15.3a standard based on propagation conditions as follows [3].

4.1 CURRENT CHANNEL MODELS

IEEE 802.15 group evaluated three different models and tried to find the one that fits the measurements data the best. Three models, the Tap-delay line Rayleigh Fading, the Delta-K model, and the Saleh-Valenzuela, were considered by the IEEE 802.15 task group.

4.1.2 TAP-DELAY LINE RAYLEIGH FADING MODEL

At any time \(t\) the envelope of the channel \([h(t;\tau)]\) is Rayleigh distributed and the channel is referred to as Rayleigh Fading Channel Model. However the IEEE 802.15 task group did not select the TDL Rayleigh structure for modeling UWB channels since the measurement data did not support the model mainly due to the reason that it does not support multipath fading components.

4.1.3 Delta-K MODEL

The Poisson distribution is the statistical model used to determine the timing of random events that. This model takes into account the clustering property of paths caused by the grouping properties of the scattering objects. The model operates like a state machine with two states The Delta-K model has shown a good fit to the empirical data collected in several urban mobile environments. On the other hand the model is not best suited for UWB channels since two independent Poisson distributions provide more flexibility in determining the cluster and ray arrival times when compared to the Delta-K model.

4.1.4 SALEH-VALENZULA MODEL

The Saleh-Valenzuela model was first proposed to reproduce the multipath effect of wideband indoor environment channels with bandwidths in the order of 100 MHz. It is interesting that even at such bandwidths the cluster and ray effect can be observed. The Delta-K model have modelled the arrival time of clusters and rays using Poisson distribution but instead of changing the average, they have used two independent Poisson distributions to model the cluster and ray arrival time. The channel impulse response is given by:-

\[
h(t) = \mathcal{X} \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \alpha_{KL} \delta(t - T_l - \tau_{kl})
\]

where \(\alpha_{KL}\) is the multipath gain coefficient of \(k\)th ray related to \(l\)th cluster. \(\{T_l\}\) is the delay or arrival time.
of first path of the \( l \)th cluster, \( \{\alpha_{k,l}\} \) is the delay of the \( k \)th multipath component within the \( l \)th cluster relative to arrival time \( T_l \). \( \{\lambda\} \) represents the lognormal Shadowing term.

Saleh-Valenzuela model is the closest fit the measurement data for UWB channels due to the following reasons:

- The model requires four different parameters to describe an environment: the cluster arrival time, the ray arrival time within a cluster, the cluster decay factor, and the ray decay factor. These four parameters provide great flexibility to model very different environments.
- The two independent times, cluster and ray arrival times, are modeled using two Independent Poisson distributions, therefore providing a more accurate model of the paths arrival times.

### 4.2 CHANNEL PARAMETERS

- CM1 describes a line-of-sight (LOS) scenario with a maximum distance between transmitter and receiver of less than 4m.
- CM2 describes the same range as of CM1, but for a non-line-of-sight (NLOS) situation.
- CM3 describes a NLOS medium for separation between transmitter and receiver of range 4-10m.
- CM4 describes an environment of more than 10m with strong delay dispersion, resulting in a delay spread of 25ns with NLOS medium.

### V. SIMULATION RESULTS OF UWB CHANNEL STATISTICAL PROPERTIES

The main characteristics of the channel that are used to derive the above model parameters are as follows: Mean excess delay, RMS delay spread, number of multipath arrivals that are within 10 dB of the peak multipath arrival, average power delay profile. Extensive simulation results under various channel conditions are presented in this section.

<table>
<thead>
<tr>
<th>Target Statistical properties</th>
<th>CM3</th>
<th>Model Statistical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean excess delay (nsec) ( (\tau_m) )</td>
<td>14.18</td>
<td>Mean excess delay (nsec) ( (\bar{\tau}_m) )</td>
</tr>
<tr>
<td>RMS delay (nsec) ( (\tau_{rm}) )</td>
<td>14.28</td>
<td>RMS delay (nsec) ( (\bar{\tau}_{rm}) )</td>
</tr>
</tbody>
</table>
models statistical characteristics have been analyzed through simulation.

VIII. REFERENCES

[1] “A Channel Model for Ultra wideband Indoor Communication” Jeffrey R. Foerster, Member, IEEE, Marcus Pendergrass, Member, IEEE and Andreas F. Molisch, Senior Member, IEEE

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