UWB & UWB Channels

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Abstract

Ultra Wide Band (UWB) signalling is expected to play an important role in the future of communications systems. UWB uses extremely wide transmission bandwidths (in excess of 3 GHz), which results in desirable potentials such as accurate position location and ranging, lack of significant fading, high multiple access capability, secure communications, and possible easier material penetration. These advantages will result in more covert and faster wireless networks and also create new opportunities for the design of wireless positioning and ranging products.

However there are some significant hurdles that need to be passed before commercial UWB products enter the market.

1 Introduction

UWB is a carrierless communication scheme which utilizes nanosecond impulses (bandwidth in the range of 3-7 gigahertz). The wide bandwidth used by UWB transmission enable wireless designers to better support multiple user communication, allocate faster communication links, and develop wireless ranging and positioning products [1]. UWB will also help to relieve the spectrum drought caused by the popularity of wireless communications and the narrow band systems on the market. Low transmission power allows a UWB system to work over a wide bandwidth without interfering with existing narrowband systems, however the lower power limits the range, thus mainly limiting UWB to indoor communication.

The Gaussian pulse represented in figure 1.1 is the most widely used pulse in UWB communications. UWB antenna at the receiver and transmitter influence the UWB pulse due to their limited bandwidth and other factors [7], thus making the received pulse considerably different from what was transmitted as illustrated in figure 1.1. Appendix A provides more information with regard to transmitted and received signals.

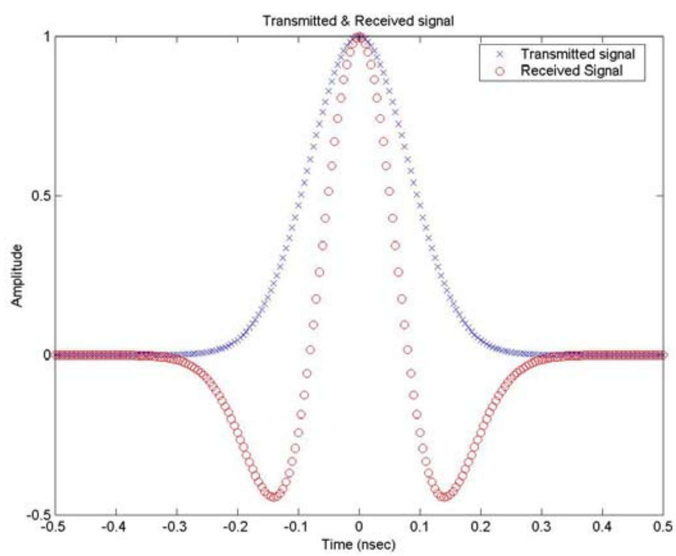

Figure 1-1 Demonstrating the transmitted and received UWB pulses in the time domain[7].

The advantages of UWB have fuelled much academic and industry funded research in this area. Considerable research has been undertaken on the development of a realistic model of UWB channels which is very different from a narrow band channel, thus making most available models ineffective. The *Federal Communication Commission (FCC)* has also set out a transmission bandwidth with certain power limitations that allow wireless UWB products to operate in the same frequency band as the conventional narrow band systems with no interference and Europe and Japan are set to follow soon [1]. Figure 1.2 represents the spectrum assigned to UWB by FCC . The new regulations combined with the undergoing research are very promising and one can be quite confident that UWB products will be introduced to the market in the near future.

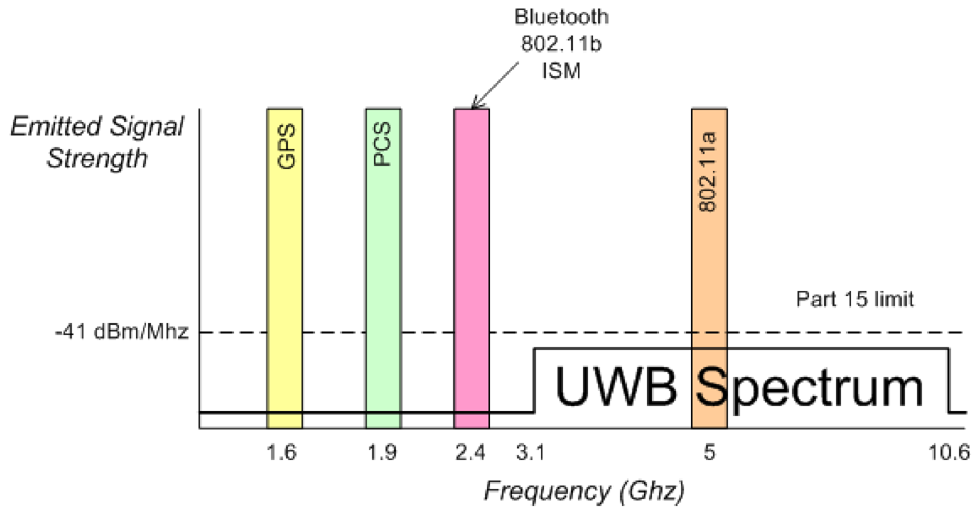

Figure 1-2: The UWB spectrum and the FCC requirements (for one user) [2]

UWB channel models are very different compared to their conventional narrowband counterparts, because first UWB is a carrierless communication scheme and secondly it uses a much wider bandwidth than the conventional wireless schemes. This thesis sets out to characterize a UWB channel and also develops a comprehensive Matlab model of the channel under four different physical settings summarized under *Line of Sight (LOS)* and *Non Line Of Sight (NLOS)*. The developed Matlab models are thoroughly compared with IEEE approved measurement data through sets of specific characterizing parameters to ensure they closely resemble the actual channel impulse response and are valid.

The developed Matlab model provides researchers and developers with the UWB channel impulse response, thus enabling them to:

- Develop the optimum UWB pulse shape
- Develop and test the best UWB transmitters and receivers.
- Carry out performance analysis of UWB wireless systems under different indoor settings
- Use the developed channel impulse response to explore new possibilities and products such as UWB ranging and positioning systems.

2 UWB Channel

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. Comprehensive research has been performed on the narrow band channels, however much more needs to be done to grasp a better understanding of UWB channels. This section focuses on the differences of the narrowband and UWB channels and gives a brief overview of the existing UWB channel models. Consequently the modified Saleh-Valenzuela model which is set as the standard for modeling UWB channels by IEEE 802.15 task group is extensively analyzed.

2.1 Narrow Band VS. UWB

The 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 2-1 demonstrates the difference between the bandwidth of narrowband and UWB signals.

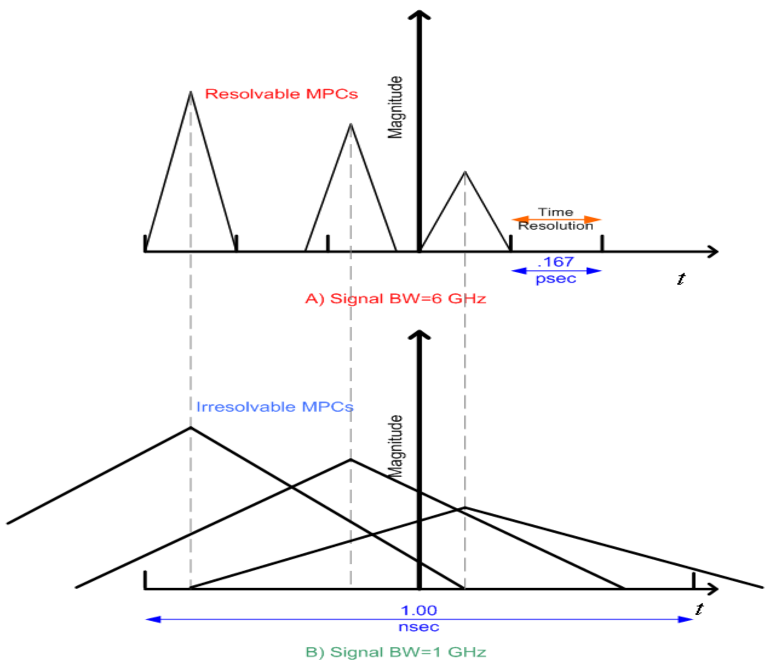

Figure 2-1: representing MPCs in a UWB and conventional wideband system A) UWB system B) Conventional wideband system

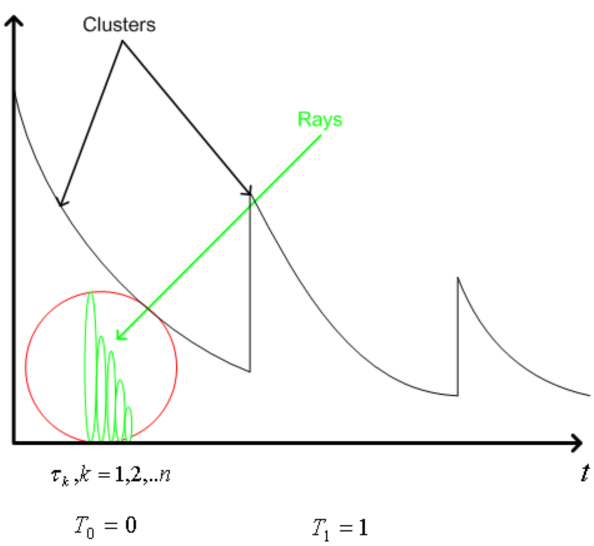

Figure 2-2: Illustration of Clusters and Rays (notice that the clusters and rays decay exponentially) [1, 3]

Figure 2.3 demonstrates the concept of clusters and rays and UWB signaling. Each cluster is formed due to the reflection of UWB waves from different objects, for example one cluster may represent the reflected signals from a wall and another cluster represents the signals reflected from a desk located a couple of meters away. It is also important to note that clusters consists of a number of rays that are separated with a smaller time interval and are usually the MPCs caused by the reflection from the same object.

2.2 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 Δ-K model, and the Saleh-Valenzuela,* were considered by the IEEE 802.15 task group [5]. In the following section I give a very brief outline of these three models and provide the reasoning behind the final choice.

2.2.1 Tap-delay line Rayleigh fading model

Consider the channel impulse response to be defined as follows:

$$h(\tau;t) = h_I(\tau;t)\cos(2\pi f_c t) - h_Q(\tau;t)\sin(2\pi f_c t)$$

$$\tilde{h}(\tau;t) = h_I(\tau;t) + jh_Q(\tau;t)$$

$$h(\tau;t) = \mathrm{Re}[\tilde{h}(\tau;t)\exp(j2\pi f_c t)] \quad \textbf{(2.1)}$$

where $\tilde{h}(\tau;t)$ is the complex impulse response of the channel and τ is the delay element. $\tilde{h}(\tau;t)$ can be modeled as a Gaussian random variable with zero mean [6]. Therefore at any time *t* the envelope, $|\tilde{h}(\tau;t)|$, is Rayleigh distributed and the channel is referred to as *Rayleigh Fading Channel Model.*

The *Tap-Delay Line (TDL)* structure illustrated in figure 2-5 generates multiple time-shifted copies of the transmitted signal, each of which is weighted by a complex gain, therefore making TDL Rayleigh fading model a better fit for conventional wideband transmission schemes (i.e. CDMA), since the multiple delayed signals with complex amplitudes can better simulate the reflected rays arriving at the receiver within different time intervals.

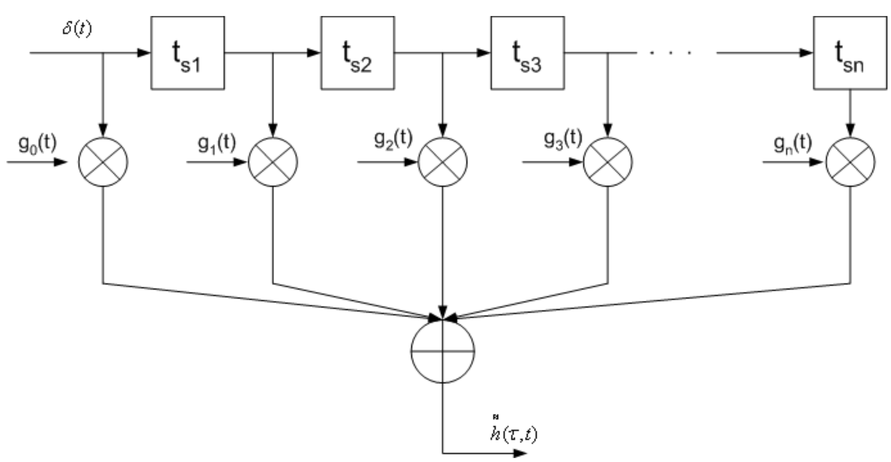

Figure 2-3: TDL structure

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 followings [1, 5]:

- The Gaussian model used in the TDL Rayleigh Fading model does not apply to UWB channel for the reasons explained in section 2.1.

2.2.2 Δ-K Model

The Poisson distribution is the statistical model used to determine the timing of random events that. If *L* denotes the number of paths occurring in a given interval of time duration *T*, the Poisson distribution requires [4]:

$$prob(L = l) = \frac{\mu^l e^{-\mu l}}{l!} \tag{2.2}$$

where $\mu = \int_T \lambda(t)$ and $\lambda(t)$ is the mean arrival rate at time t.

However comparison between the arrival times estimated by the Poisson distribution and the measurement has clearly demonstrated the inadequacy of the model to describe the arrival times for wideband pulses. This is mainly due to the fact that the scattering in an indoor channel is not completely random and the position of the scattering objects results in deviation from the standard Poison distribution.

The Δ-K model, a modified Poisson process, was proposed by Turin et al and Suzuki in 1972 [4]. 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, in state 1 the mean is $\lambda_0(t)$ and in state 2 the mean is $K\lambda_0(t)$. The process starts out in state 1 and if a path arrives at time *t*, a transition is made to state 2. If no further paths arrive in the time interval $[t, t+\Delta)$, a transition is made back to state 1. For *K=1* and *Δ=0* the process is a standard Poison distribution but for *K>1*, the arrival of a path at time t increases the probability of receiving more paths in the time interval $[t, t+\Delta)$. The Δ-K model has shown a good fit to the empirical data collected in several urban mobile environments [4]. 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 Δ-K model [5].

2.2.3 Saleh-Valenzuela 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 described in section 2.1 can be observed. As with the Δ-K model the authors have modeled the arrival time of clusters and rays using Poisson distribution but instead of changing the average, they have used two independent Poisson distribution to model the cluster and ray arrival time [1, 3]. Equation 2.3 describes the channel impulse response:

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{M} a_{k,l} \delta(t - T_l - \tau_{k,l}) \quad \textbf{(2.3)}$$

T_l = the arrival time of the first path in l_{th} cluster,
$\tau_{k,l}$ = the ray arrival time ($\tau_{0,l} = 0$),
$a_{k,l}$ = the amplitude of rays and clusters accordingly, and
X_i = the lognormal shadowing effect.

$$P(T_l \mid T_{l-1}) = \Lambda \exp[-\Lambda(T_l - T_{l-1})],\ l > 0 \quad \textbf{(2.4)}$$

$$P(\tau_{k,l} \mid \tau_{(k-1),l}) = \lambda \exp[-\lambda(\tau_{k,l} - \tau_{(k-1),l})],\ k > 0 \quad \textbf{(2.5)}$$

Equations (2.4) and (2.5) demonstrate the statistical model used to determine cluster and ray arrival times. Λ and λ are cluster and ray decay factor respectively (channel parameters). The amplitude $a_{k,l}$ is modeled using the Rayleigh distribution, however as mentioned before in the case of UWB the Rayleigh distribution is not applicable. More is said with this regard in the following section.

2.3 Modified Saleh-Valenzuela, IEEE 802.15

A modified version of the 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 [1].

- 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.

Unlike the Saleh-Valenzuela model the IEEE 802.15 uses the lognormal distribution (measurements in UWB channels indicated that the amplitude follow a lognormal distribution [1, 5]) instead of the Rayleigh distribution to statistically model the amplitudes of clusters and rays.

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{M} a_{k,l} \delta(t - T_l - \tau_{k,l}) \quad \textbf{(2.6)}$$

3 Matlab model

This section focuses on the procedure used to develop the Matlab model and the channel impulse response based on the IEEE 802.15 described in the previous section.

3.1 Matlab Simulation Results

This section represents the simulation results for four different UWB channels. The channels are simulated based on the modified Saleh-Valenzuela model described in section 2.3.

3.1.1 Line of Sight (LOS)

An LOS channel is expected to have fewer MPCs since the transmitted signal mainly arrives at the receiver through a direct path with few reflections.

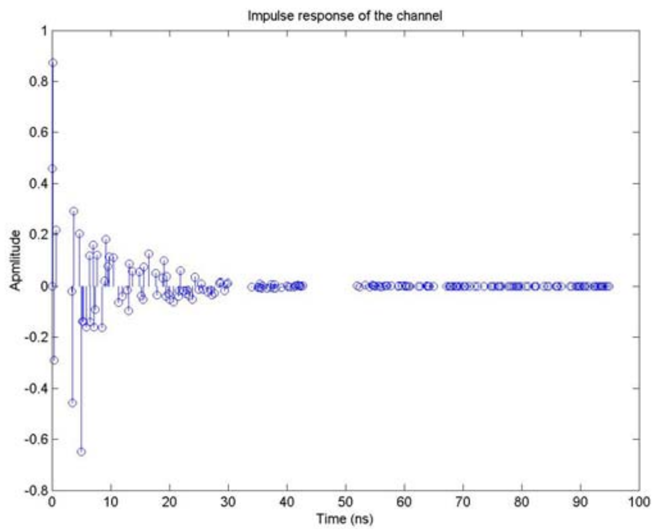

Figure 3-1: Impulse response of a LOS 0-4m UWB channel

3.1.2 Non Line of Sight 0-4m (NLOS)

Unlike the LOS channel the transmitted signal arrives at the receiver through reflections from different objects or obstacles (figure 2-2), therefore increasing the number of MPCs. The NLOS channel also has a bigger mean excess delay and the RMS delay.

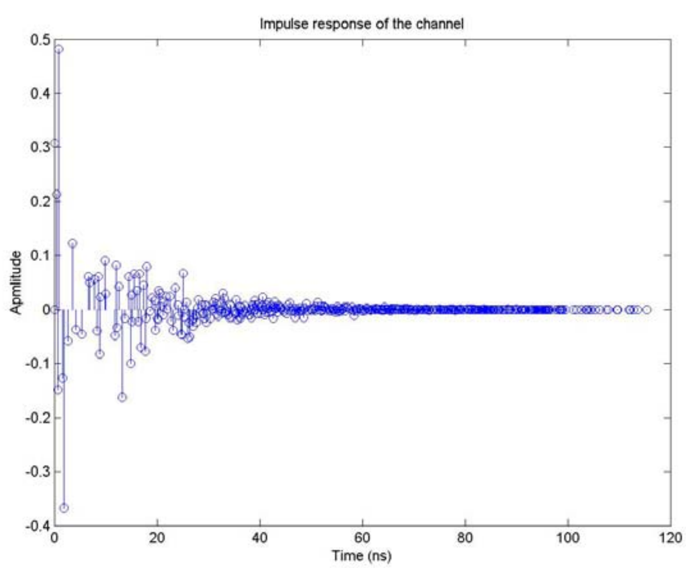

Figure 3-2: Impulse response of a NLOS 0-4m UWB channel

Conclusion

UWB signaling has a range of advantages compared to the conventional narrowband schemes, however it also introduces new challenges to the design and development of wireless products. One of these challenges lies in the response of an indoor environment to a pulse with such a wide bandwidth. The conventional narrowband channel models are simply not applicable in the case of UWB due to the wide bandwidth of UWB pulses. Therefore new models have been developed to better explain an UWB multipath channel.

References

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