Modeling UWB Indoor Channel with Shadowing Processes

Work in progress

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ABSTRACT

In an indoor ultra-wideband (UWB) communication environment, the line-of-sight (LOS) between the transmitter and receiver may be frequently blocked by moving people. Blocking of LOS may significantly affect the quality of service (QoS) of on-going UWB communications. Based on the Angular Power Spectrum and the human blocking models, we build a packet-level UWB channel model considering the shadowing processes. The model is simple enough to be incorporated into existing network simulators and it can be used to facilitate protocol design and QoS analysis for UWB based wireless personal area networks (WPANs).

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*

General Terms

Performance, Design

Keywords

Channel model, UWB, Angular Power Spectrum

1. INTRODUCTION

To enable versatile communications from anywhere, at anytime, and to anybody, broadband home networks, providing the 'last-meter' connectivity inside homes, have raised wide attention in both academia and industry. Wireless Personal Area Networks (WPANs) using Ultra-wideband (UWB) technologies have shown great potential as future home networks [1], because a) UWB achieves very high data rate (> 100 Mbps) at very low transmission power (less than -41.3 dBm/MHz) and interference; b) UWB's relatively short transmission range and high attenuation by barriers such as concrete walls are desirable characteristics to service providers, who do not want their broadband signals to be shared by other (non-subscribing) homes; and c) using wireless technologies can avoid house rewiring, which is critically important to both service providers and consumers.

The indoor Ultra-wideband channel is crucial to determine the achievable performance and Quality of Service (QoS) of the UWB home network. Because of the closed space and dense scatters in home, an indoor broadband wireless channel has typically severe multipath effect and time-varying attenuation. With extensive efforts in measuring the physical indoor channels, (e.g., in [2] and [3]), the IEEE 802.15 WPAN group has standardized the UWB channel models, known as the 3a and 4a models [4] [5]. The 3a model has been widely used for testing indoor system proposals and simulations in the literature.

However, the waveform simulation of transmitting every bit over the wireless channel comes at a high computational cost and a very long execution time. Therefore, a packet-level channel model of the communication system is more desirable for network simulations. A network simulator directly generates the packet error profile for a wireless link. In addition, packet-level channel models can be used to analyze network and protocol QoS performance, like link throughput, delay, etc., in a practical transmission environment.

A packet-level channel model provides the Packet Error Rate (PER) on a packet basis according to statistical channel properties. The 3a or 4a report does not explicitly define the time-varying property of UWB indoor channels, although it has been reported by Molisch [6] and Schell [7]. To the best of our knowledge, there is no packet-level model for UWB indoor channels which considers their time-varying property in the literature.

For a typical indoor UWB channel, the Tx and Rx are stationary, but obstacles (most likely a person in an indoor environment) move and intercept the LOS. Because the LOS, the most significant path, is shadowed off, the channel will not be WSSUS. In addition, the shadowing effect is significant for UWB transmissions even though it may last for a short time period only. This is because the data rate of UWB is typically over 100 Mbps and may carry high data rate multimedia streaming traffic which is delay and loss sensitive. Even a short time shadowing for half a second, more than 50 M bits of data are affected, so is the QoS of the on-going flows.

The main contributions of this paper are two-fold. First, we analyze the shadowing processes of UWB channels based on the concept of angular power spectrum (APS). Second, we propose a continuous-time Markov model to describe the channel shadowing processes in packet-level. This model

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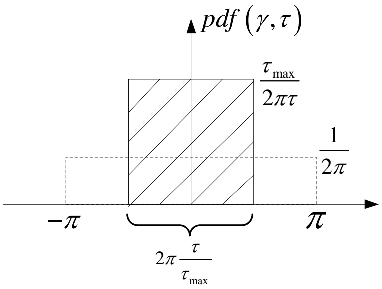

Figure 1: The angular power distribution

can be used for simulations and performance/QoS analysis of IEEE802.15 UWB networks, incorporating the effects of moving people in the realistic indoor environment.

The remainder of the paper is organized as follows. In Section 2, the angular power spectrum of the impulse response of UWB channel is presented based on the 3a model. In Section 3, the shadowing effect of a people's body on the LOS of UWB channel is analyzed based on the angular power spectrum, and a Markov model is proposed to model the shadowing process in Section 4. Concluding remarks and future research plan are presented in Section 5.

2. THE ANGULAR POWER SPECTRUM OF UWB SIGNAL

The effect of shadowing on LOS can be estimated based on the APS. Molisch in [6] suggested a simplified model of the APS and used it to calculate the channel Impulse Response (IR) when the LOS is blocked by an obstacle. Here, we extend Molisch's method to investigate the effect of LOS shadowing. The measurement results in [7] verify that the APS model and our proposed analysis approach for shadowing processes are reasonably accurate.

The APS, $\mathrm{pdf}(\gamma)$, refers to the amplitude of power received at a certain incident angle, or more precisely, the probability density function of power arriving at angle γ. It essentially describes the distribution of power over the incident angles. Due to the multipath components arriving at the receiver with increasing delay, the IR of UWB channel is composed of a number of delayed taps, as generated by the 3a or 4a model. The power of each tap is composed of rays coming from different angles with the same delay and thus each tap has its own APS. Therefore, the APS of UWB channel is also a function of delay, expressed as [6]:

$$\mathrm{pdf}(\gamma,\ \tau) = \begin{cases} \mathrm{rect}(\frac{2\pi\tau}{\tau_{\max}}) & 0 < \tau < \tau_{\max} \\ \frac{1}{2\pi} & \tau > \tau_{\max}, \end{cases} \quad (1)$$

where γ is the incident angle with respect to the LOS component and τ is the delay of the tap. rect is the rectangular function. The $\mathrm{pdf}(\gamma,\ \tau)$ is the arriving angular power spectrum of the signal received at the moment of delay τ, and it also is the probability density function by which the received power at delay τ distributes over a certain angular spread. Fig. 1 shows the angular power distribution $\mathrm{pdf}(\gamma,\ \tau)$ for the UWB channel.

The APS model shows that the power angular spread increases with delay. For the taps with delay $\tau < \tau_{\max}$, the energy distributes uniformly over the angular range of $[\frac{-\pi\tau}{\tau_{\max}},\ \frac{\pi\tau}{\tau_{\max}}]$, while for the taps with delay $\tau > \tau_{\max}$, the energy distributes uniformly over $[-\pi,\ \pi)$. This angular spectrum distribution is reasonable and consistent with the 3a and 4a channel model. This is because, the taps with short delay should travel through short paths and arrive at the receiver within an angular range close to the LOS direction. At the same time, because of the less reflection and path loss, they should have more energy, which is consistent with the exponential decaying model in 3a and 4a. Particularly, the LOS component has the smallest delay and it will not distribute over any angles. On the other hand, if the taps have long delay, they normally undergo long paths and more reflections. Thus, the incident range of them should be large, like $[-\pi,\ \pi)$ and they have less energy due to reflection and path loss.

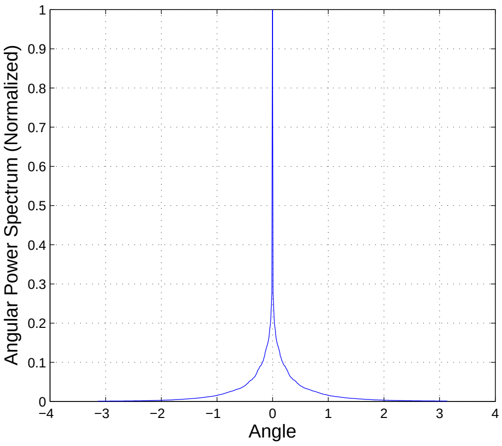

Figure 2: The composite angular spectrum distribution

The composite power spectrum can be expressed as:

$$P(\gamma) = \int_0^{\infty} \mathrm{pdf}(\gamma,\ \tau)\mathrm{PDP}(\tau)d\tau, \quad (2)$$

where $\mathrm{PDP}(\tau)$ is the Power Delay Profile (PDP) of the IR of the UWB channel and are generated by the 3a or 4a model. $P(\gamma)$ gives the total energy that the receiver gets at angle γ, since the integral sums up the energy received on the angle γ at all the delay moment τ. The parameter $\tau_{\max}$ should be chosen such that the RMS angular spread of $P(\gamma)$ is 38 degree, according to the practical measurement of [3].

The composite APS of the UWB channel is calculated using the 100 channel IR realizations provided by IEEE 802.15 group, which are generated by the 3a CM1 model, because CM1 is the scenario of LOS existing. The averaged CAPS is shown in Fig. 2. Each of the channel IR is normalized to have a unit total power.

3. LOS SHADOWING MODEL FOR UWB CHANNEL

We focus on the shadowing process of the UWB channel: a single scatter, normally a person, is moving through the LOS and thus blocking off the most significant power contribution. We will use the setting of people's shadowing procedure as suggested in [3] and [6], which was also recommended by the IEEE 802.15 group to study the time

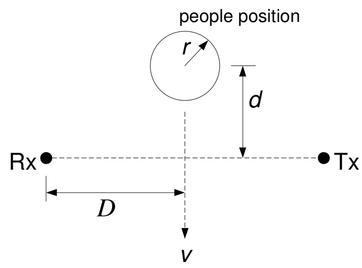

Figure 3: Model of LOS Blocking

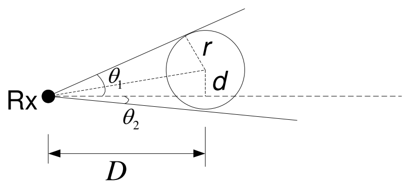

Figure 4: Computation of LOS Blocking Angular Range

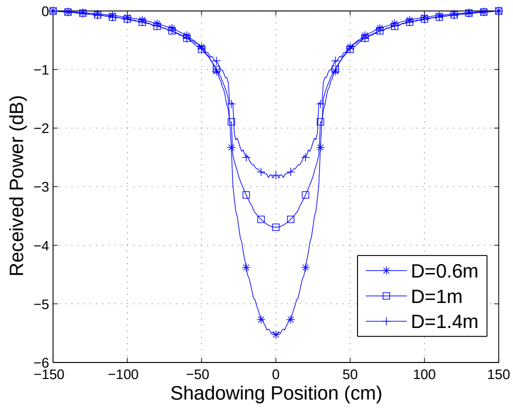

Figure 5: Total received power shadowed by moving people

variance of UWB channels. The channel model for the shadowing process and the analytical results are given below, which have not been reported in the literature.

As shown in Fig. 3, a person moves through the LOS at an average speed of v, e.g., $v = 0.5$ m/s (the pedestrian speed). We assume that the movement is on a line perpendicular to the line connecting the Tx and Rx, with a distance (when it is on the LOS) of D from the receiver. If the movement direction is not perpendicular to the line connecting the Tx and Rx, v equals $v' \sin\theta$, where v' is the speed of the scatter, and θ is the angle between the direction of the velocity and the LOS line. The person is modeled as a cylinder with radius of $r = 30$ cm, as an approximation of a human body. This model was actually used by [7] in the channel measurement setting. They just used a tank of water to emulate a human body, as a large percentage of the human body is composed of water.

As the person steps toward the LOS, he shadows off certain angular ranges, from which the transmission power cannot reach the receiver. The angular ranges can be obtained from simple geometrical computations. For example, the angles θ_1 and θ_2 in Fig. 4 equal $\arctan(\frac{r}{\sqrt{d^2+D^2-r^2}})+\arctan(\frac{d}{D})$ and $\arctan(\frac{r}{\sqrt{d^2+D^2-r^2}}) - \arctan(\frac{d}{D})$, respectively. Using the APS given in Section 2, the *remaining* power of each tap can be calculated and thus the new channel IRs can be obtained at a series of positions occupied by the people along the path.

The basic steps to estimate the shadowing effect of LOS blocking are summarized as follows.

1) Create a random channel realization, with a certain power ascribed to each tap. The CM1 of 3a channel model is used because it considers the scenario of LOS existing.

2) For each delay tap, compute the angular power spectrum pdf(γ, τ) (rectangle pdf with width increasing with delay).

3) Position the obstacle at a certain location. Perform geometrical computations to get the angular range that the obstacle is shadowing off.

4) The *remaining* power for each delay tap is calculated, and thus a new channel impulse response can be obtained.

The shadowing effect on the 100 channel IR realizations of 3a CM1 [4] are evaluated and averaged. Calculations are taken at a series of positions along the path perpendicular to the LOS. The interval of sampling is one cm. The sampling starts at $d_0 = 1.5$ m and ends at 1.5 m on the other end of the path. For different distance between the people and receiver, the averaged shadowed received power is shown in Fig. 5. The result obtained by the analytical model reasonably match the measurement given in [7].

4. MARKOV MODEL FOR UWB CHANNEL WITH PEOPLE SHADOWING

To establish a channel model simple enough to be incorporated into network simulators, we further build a Markov model for UWB channels considering the shadowing processes. In the Markov model, each state corresponds to different quality of the channel in terms of PER.

4.1 The Definition of Channel State

The total received power decreases when the LOS is blocked. Since the SNR is proportional to the received power, the SNR also decreases when the LOS is blocked. A simple modeling method used is to impose a time-varying attenuation on the total received power, as obtained in Section 3. Following the approach in [8], we can partition the SNR into several non-overlap intervals and each interval is a state of the channel. According to the APS and the blocking model, each SNR interval actually corresponds to the spatial zone of the moving obstacle. In other words, once a person enters a particular zone, the channel is in corresponding state due to the shadowing, and the received SNR can be estimated accordingly. The average BER and PER can be further estimated from the average received SNR. The states of the Markov Model can be obtained as follows.

First, divide the area near the LOS into N zones, $\Delta d_n, n = 0, 1, \cdots, N-1$, which correspond to N (an even number) states, S_n, as show in Fig. 6. The SNR interval of S_n is $[\Gamma_n, \Gamma_{n+1})$, where Γ_n is the threshold to divide the SNR range and corresponds to the SNR of position d_n. N should be sufficiently large such that the range of SNR in each state should be small enough.

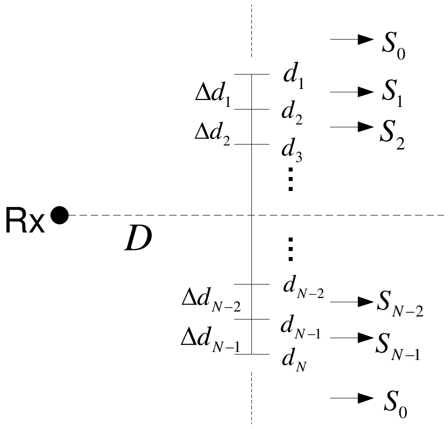

Figure 6: Two dimensional zones corresponding to channel state

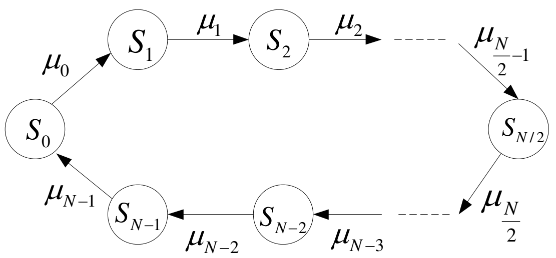

Figure 7: Packet-level Model of Time-varying UWB Channel

Since the state zones are actually symmetric with respect to the LOS line, the received powers and the SNRs of zone n and zone $N-n+1$, are the same. I.e., the SNR of state S_n is the same as that of state S_{N-n}, and the threshold $\Gamma_n = \Gamma_{N-n+1}, n = 0, 1, \cdots, N-1$. The structure of the state model is shown in Fig. 7. State $S_{N/2}$ is the worst one with the obstacle right on the LOS line. State S_0 is the best case that there is no shadowing effect, i.e., nobody near the LOS area. Each state corresponds to attenuation factor due to shadowing, i.e., the ratio of the received power with shadowing to the power without shadowing. Therefore, the average attenuation factor of state 0 is $S_0 = 0$ dB and the thresholds are $\Gamma_1 = \Gamma_N = 0$ dB.

Next, according to the physical layer simulation of DS-UWB or MB-OFDM UWB, the average SNR, BER, PER, and data rate of each state can be obtained.

4.2 State Transition Rate

The transition rate between the states can be determined by the indoor mobility model of people and the geometric state zones. We consider the process of a person passing through the LOS as follows: after the person enters zone 1 from zone 0, he/she will pass zones 2 to zone $N-1$, and finally re-enter zone 0.

First, since the channel state S_n corresponds to the zone $[d_n,\ d_{n+1})$, for $n = 0, 1, \cdots, N-1$, the travel length of each state is $\Delta d = d_{n+1} - d_n$. Given the average speed of the person, v, the average duration of the person stays inside a zone is $t_n = \frac{\Delta d_n}{v}$. We assume that the time the person stay inside a zone is exponentially distributed. Therefore, the transition rate from state n to state $(n+1) \mod N$ is

$$\mu_n = \frac{1}{t_n} = \frac{\Delta d_n}{v} \quad n = 1, 2, ..., N-1. \qquad (3)$$

Because of the symmetry of the shadowing model, we have $\mu_n = \mu_{N-n}$.

Second, the transition from S_0 to S_1 actually means a person arrives and thus the LOS shadowing occurs. We assume that the arrival of a person in the indoor environment is a Poisson process with the arrival rate of μ_0, which actually reflects the density and mobility speed of the people inside the home or office. For a more crowed area, we can assume a higher value of μ_0, and vice versa.

Given the states and the state transition rate, a continuous-time Markov model of the UWB channel is obtained, as shown in Fig. 7.

5. CONCLUSIONS

In this paper, we have investigated UWB indoor channels under people shadowing processes, and proposed a packet-level model for the time-varying UWB channel. The model can be applied for both DS-UWB and MB-OFDM UWB channels. Because of the low computation requirements, the channel model is simple and feasible to be incorporated to existing network simulators like NS-2 or GloMoSim. Networking researchers can use the model to investigate the performance of UWB networks and upper-layer protocols analytically and via simulation.

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