Characterization of Ultra Wideband Channel in Data Centers

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Abstract. In this paper, we present a measurement based characterization of the Ultra Wideband (UWB) channel in a data center environment. We find that although a modified Saleh-Valenzuela model characterizes the UWB channel, some of the model parameters such as delay spread and log normal shadowing are unique to the data center environment.

Key words: Ultra Wideband (UWB), data centers, S-V model, path loss.

1 Introduction

In recent years, Ultra Wideband (UWB) communications has received great interest from both the research community and industry. UWB transmissions are subject to strict power regulations and thus are best suited for short-range communications. The IEEE standards group on personal area networks (PANs) is actively working on UWB based communications under Wi-Media alliance and 802.15.4 task group. UWB has been adopted as the underlying technology for the Wireless USB (Universal Serial Bus) standard – a wireless replacement for the popular wired USB interface, and also being developed by the Wi-Media.

Although WUSB is designed for the client space, its ubiquity will allow it to be exploited in servers for creating an out-of-band fabric which can be used for a variety of applications in a data center. The objective of this paper is to lay a foundation for new applications scenario for UWB in data center management e.g.asset location. The study reported in this paper characterizes UWB propagation in data centers via direct measurements in a real data center in the UWB frequency band (3-8 GHz).

2 UWB Propagation Models

2.1 Indoor Channel Characteristics

Indoor wireless propagation channels have been investigated in the in the context of residential, office or industrial environments in [1–3]. The signal that arrives consists of multiple replicas of the originally transmitted signal; this phenomenon is known as *multipath propagation*. The different multipath components (MPCs) are characterized by different delays and attenuations. In cellular systems, where signal bandwidth is relatively narrow, the multipath components that arrive within short time intervals are not resolvable and therefore combine to produce Rayleigh or Rician distribution of the overall amplitude.

Based on a detailed set of studies, IEEE 802.15.3 committee (now Wi-Media) settled on a modified S-V model [1, 4] to enable comparison of various technologies in the PANs. The actual measurements indicate that the MPCs arrive in clusters rather than in continuum.

2.2 Data Center Environment

A data center can be compared with a library room where we have several metallic racks containing servers. The racks are 78” high, 23-25” wide and 26-30” deep and are generally placed side by side in a row without any spacing (other than a supporting beam). A rack can be filled up with either rack mount or blade servers. Rack mounted servers go horizontally in the rack and have typical heights of 1U or 2U where a “U” is approximately 1.8”. The high density blade servers go vertically in a 19” high chassis, with 14 blades/chassis. If all racks in the data center can be treated as essentially continuous metal blocks, the characterization could be relatively straightforward. The racks are not always filled up with servers, thereby creating many holes through which the radiation can leak. Because of the increasing stress placed by high density servers on cooling and power distribution infrastructure, the racks in older data centers simply cannot be filled to capacity. The net result is a unique environment with “organized clutter”.

2.3 S-V Channel Models

The Saleh-Valenzuela model [4] characterizes the channel behavior via a superposition of clustered arrivals of various delay components. Suppose that the received signal for a transmitted impulse consists of C clusters, and R_c MPCs (or “rays”) within the c th cluster. Let T_c denote the arrival time of the c th cluster (i.e., that of the first ray within this cluster) and let τ_{cr} denote the arrival time of the rth ray within the cluster (relative to the arrival time of the first ray). Then the impulse response $h(t)$ of the channel is given by:

$$h(t) = \sum_{c=1}^{C} \sum_{r=1}^{R_c} a_{cr} \delta(t - T_c - \tau_{cr}) \tag{1}$$

where $\delta(.)$ is the Dirac delta function, and a_{cr} is the relative weight (or multipath gain coefficient) of ray (c, r). The essence of the S-V model is to make specific assumptions about the cluster and ray arrival processes and multipath gain in the above equation. In particular, the basic S-V model assumes that both inter-cluster and inter-ray times are exponentially distributed, thereby making the corresponding counting processes Poisson. That is, $P(T_c - T_{c-1} > x) = e^{-\lambda_c x}$ and $P(T_{c,r} - T_{c,r-1} > y) = e^{-\lambda_r y}$, where λ_c and λ_r are, respectively, mean cluster and ray arrival rates. As for the coefficients a_{cr}'s, the S-V model assumes an exponential decay for both cluster power and ray power within a cluster as a function of the delay. That is, $a_{cr}^2 = a_{00}^2 e^{-T_c/\Gamma} e^{-\tau_{cr}/\gamma}$ where a_{00}^2 is the power of the very first ray, and Γ and γ are the cluster and ray decay constants.

Several indoor measurements have shown that the assumption of Poisson process for ray arrivals does not yield a good fit. Reference [1] discusses a modified S-V model where the ray arrival process is modeled as a mixture of two Poisson processes. We shall see later that our data center measurements agree with this model. In addition to MPC arrival characterization, there are several other aspects to consider in order to fully describe the channel. The *path loss model* indicates how the power decays as a function of distance. For free-space propagation, the path loss at distance d is given by $(4\pi d/\lambda)^2$, where λ is the wavelength. In a cluttered environment, the loss exponent could be significantly different from 2 because of reflection and diffraction.

Path loss, cluster power decay, and ray decay phenomenas discussed above are all parameters of the model. An appropriate way to characterize is to consider cluster and ray power as random variables with associated means and standard deviations. The standard deviations σ_c and σ_r then become essential parameters of the S-V model and need to be estimated.

Another aspect of interest is the *time variance* of the channel. Wireless channel characteristics may be influenced by environmental factors such as temperature, humidity, air flow, movements, etc. Fortunately, in data center environments, such variations are expected to be small and infrequent, and time variance characterization may be unnecessary. Our measurements, though not shown here, are observed to validate this conclusion.

3 Channel Characterization

3.1 Measurement Setup

The measurements were conducted in a medium sized Intel data center using an Agilent 8719ES vector network analyzer. The network analyzer was set to transmit 1601 continuous waves distributed uniformly over 3-8 GHz. The 5 GHz bandwidth gives a temporal resolution of 0.2 ns. Fig. 1 shows the location of the transmitter and the receivers where the two lines indicate opposing racks.

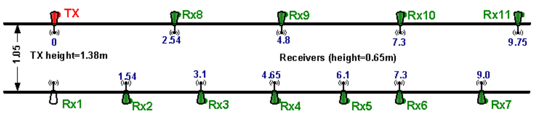

Fig 1. TX/RX Locations

To measure the small scale statistics of the channel the Rx was moved 25 times around each local point over a 5 by 5 square grid with 5 cm spacing. Based on measurements Figs. 2 and 3, show the plots of complementary cumulative distribution functions of ray inter-arrival times and cluster inter-arrival times, respectively. Fig. 2 also shows the S-V model fit labeled as Single Poisson Process, and a mixture of two Poissons, which was proposed as a modified S-V model for the indoor data in [1]. Fig. 2 shows clearly that the modified S-V model provides a better fit to the data than the single Poisson process. For cluster inter-arrival times in Fig. 3, a single Poisson process provides a reasonable fit only if few of the clusters arriving at times greater than 120 ns are ignored. The latter cluster arrivals correspond to multipath due to reflections from a wall of the data center. Hence, a cluster of clusters may be a better description for this behavior than a pure Poisson model.

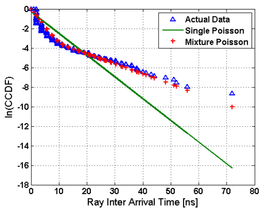

Fig 2. Ray Inter-arrival Times for S-V Model

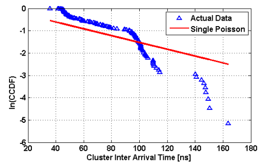

Fig 3. Cluster Inter-arrival Times for S-V Model

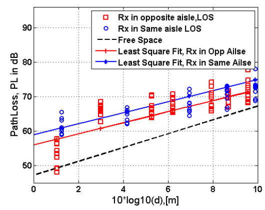

Fig 4. Pathloss Vs Distance from Transmitter

Fig. 4 shows the path loss (PL) in dB versus the distance between different receivers (Rxs) and the transmitter (TX). If we express the path loss as $P_L(dB) = 10n\log(n) + \text{const}$, where n is the path loss exponent and d is the distance between the TX and the RX, Fig. 4 shows that the exponent is about 1.6, as expected in an indoor environment [5]. That is, the path loss in a data center decreases much slower with distance than in free space. This is due to the fact that a large number of diffractions and reflections taking place in the metallic racks and other components present in the vicinity of Tx and Rx contribute to a much increased received power than is possible in free space.

Environ -ment	Path Loss Exponent		Fading std. dev.		Mean delay spread (ns)	
	LoS	NLoS	LoS	NLoS	LoS	NLoS
Residential	1.79	4.58	1.79	4.58	5.44	30.1
Office	1.63	3.07	1.9	3.9	n/a	n/a
Data center	1.6	n/a	2.3	n/a	18	n/a

Table 1. Comparison of Indoor Environments

Table. 1 compares available data center channel parameters against those for other indoor environments [5] in terms of path loss exponent, standard deviation of the assumed log-normal fading characteristics, and the mean delay spread. It is seen that the last two parameters are higher for data centers, perhaps as a result of a lot of metallic clutter in this environment.

In summary, this paper characterizes the UWB propagation within a data center environment and shows that the data center environment is similar but not identical to other indoor environments that have been studied in the past. To the best of our knowledge, this is the first study of its kind and lays the ground work for further exploration of UWB communications in a data center.

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