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Characterization of the 60 GHz Wireless Desktop Channel

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Abstract: In this paper we measure and characterize 55-65 GHz wireless channels for a typical desktop environment. Due to the presence of many obstructions and reflectors on the desktop the 60 GHz desktop channel differs from an intra-room propagation environment as described in the literature. A modified Saleh-Valenzuela (S-V) model is used for the desktop environment. Key S-V model parameters such as Cluster Decay Factor, Ray Decay Factor, Cluster Arrival Rate, and Ray Arrival Rate are extracted from the measured data.

Key–Words: Millimeter wave propagation, radio propagation, multi-path channel

1 Introduction

The unlicensed spectrum around 60 GHz became available in recent years in the US, Europe, Japan and Australia. This availability has unlocked significant opportunities for developing ubiquitous gigabit wireless connectivity. Significant research activity is now being undertaken to design next generation high-speed wireless communication systems in this millimeter band. An important component in the design of these systems is understanding the propagation environment to assist in choosing appropriate modulation and space time coding schemes.

A potential application of millimeter wavelength wireless communication systems capable of multi gigabit per second data rates is to connect computer components and peripherals that reside on a desktop. Consequently an accurate channel model for a desktop is required. The aim of this measurement campaign is to determine the appropriate S-V model [1][2] parameters that accurately describe a 60 GHz desktop channel. We are not aware any other 60 GHz channel measurements on desktops.

In this paper experiments are developed and executed to measure the 55-65 GHz band wireless channel on typical desktop environments. The results show that the 60 GHz desktop channel has unique characteristics and significant differences compared to intra-room or outdoor propagation at 60 GHz. The modified S-V model is applied to model the desktop environment. Key S-V model parameters such as Cluster Decay Factor, Ray Decay Factor, Cluster Arrival Rate, and Ray Arrival Rate are extracted from the measured data.

The paper is organized as follows. In Section 2 we describe the modified S-V model for the desktop propagation environment. In Section 3 we describe our experimental setup. In Section 4 we describe our measurements and the extracted S-V parameters are presented. Section 5 concludes the paper.

2 The Modified S-V Model

In this work a modified Saleh-Valenzuela (S-V) model is used. Based on previous work in the field [1], a log-normal distribution, rather than a Rayleigh distribution, for the multi-path gain magnitude is used.

The Saleh-Valenzuela multi-path model [3] is given by the discrete time impulse response:

$$h(t) = \sum_{l=0}^{L-1} \sum_{k=0}^{K_l-1} \alpha_{k,l} \delta(t - T_l - \tau_{k,l}) \qquad (1)$$

where:
L = number of clusters;
K_l = number of multi-path components (MPC), rays or paths in the lth cluster;
$\alpha_{k,l}$ = multi-path gain coefficient of the kth ray in the lth cluster;
T_l = arrival time of the first ray of the lth cluster;
$\tau_{k,l}$ = delay of the kth ray within the lth cluster relative to the first ray arrival time, T_l;

By definition, we have $\tau_{0,l} = 0$ and we set $T_0 = 0$. The clusters and rays form a Poisson arrival process with distributions given by

$$p(T_l|T_{l-1}) = \Lambda exp(-\Lambda(T_l - T_{l-1})), l > 0 \qquad (2)$$

$$p(\tau_{k,l}|\tau_{(k-1),l}) = \lambda exp(-\lambda(\tau_{k,l} - \tau_{(k-1),l})), k > 0 \quad (3)$$

where:
Λ = Cluster Arrival Rate;
λ = Ray Arrival Rate.

Here it is assumed that all clusters have the same ray arrival rate, however, some wideband measurements indicate that the arrival rate is larger for clusters that arrive later in time.

The multi-path gains are defined as follows:

$$\alpha_{k,l} = p_{k,l}\beta_{k,l} \quad (4)$$

with $p_{k,l}$ equiprobable ± 1 representing signal inversions due to reflections. In the original S-V model the amplitudes of each arrival are assumed to be Rayleigh distributed with

$$E[\beta^2_{k,l}] = \Omega_0 e^{-T_l/\Gamma} e^{-\tau_{k,l}/\gamma} \quad (5)$$

where $\Omega_0 = E[\beta^2(T_l = 0, \tau_{k,l} = 0)]$ is the average power of the first ray of the first cluster. That is, both the clusters and rays have amplitudes which decay exponentially with time, and are characterized by

Γ = Cluster Decay Factor;
γ = Ray Decay Factor.

For the wideband channel we follow [1] and assume a log-normal distribution for the multi-path gains given by

$$20log10(\beta_{k,l}) \propto Normal(\mu_{k,l}, \sigma^2) \quad (6)$$

or

$$|\beta_{k,l}| = 10^{n/20}, n \propto Normal(\mu_{k,l}, \sigma^2) \quad (7)$$

where $\mu_{k,l}$ is given by

$$\mu_{k,l} = \frac{10ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{ln(10)} - \frac{\sigma^2 ln(10)}{20} \quad (8)$$

In [1] the clusters are assumed to fade independently of rays. For example, each multi-path arrival has a fading term associated with the cluster arrival and a fading term associated with the ray arrival. If the fading for both the cluster and ray amplitudes are log-normal, this modification changes the channel coefficients in the following way, (note that the product of two log-normal random variables results in a log-normal random variable):

$$\alpha_{k,l} = p_{k,l}\xi_l\beta_{k,l}, \quad (9)$$

with

$$20log10(\xi_l\beta_{k,l}) \propto Normal(\mu_{k,l}, \sigma_1^2 + \sigma_2^2) \quad (10)$$

or

$$|\xi_l\beta_{k,l}| = 10^{(\mu_{k,l}+n_1+n_2)/20},$$
$$n_1 \propto Normal(0, \sigma_1^2), n_2 \propto Normal(0, \sigma_2^2) \quad (11)$$

where n_1 and n_2 are independent, $\mu_{k,l}$ is now given by

$$\mu_{k,l} = \frac{10ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{ln(10)} - \frac{(\sigma_1^2 + \sigma_2^2)ln(10)}{20} \quad (12)$$

In the above equations, ξ_1 reflects the fading associated with the lth cluster, and $\beta_{k,l}$ corresponds to the fading associated with the kth ray of the lth cluster.

For the modified S-V model there are six key parameters that define the model:

Table 1: Key parameters which define the modified S-V model

Parameter	*Description*
Λ	Cluster Arrival Rate
λ	Ray Arrival Rate (within each cluster)
Γ	Cluster Decay Factor
γ	Ray Decay Factor
σ_1, σ_2	Cluster and Ray log-normal std.

Along with these model parameters we model the number of clusters and the number of rays within clusters. All of the required information will be estimated from the measured channel impulse responses. Extracting these parameters from the measured impulse responses is conducted in fashion similar to the procedures described in [4].

3 Measurement Setup

Spatial and temporal measurements of Time of Arrival (ToA), number of multi-path components, and component amplitudes for five desktops in different size offices, cubicles and laboratories were made.

An Anritsu 37397 Vector Network Analyzer (VNA) was used to measure the channel transfer function. At the two ports of the VNA two 0.5 meter 60 GHz millimeter-wave cables were attached. Two 30dB broadband power amplifiers were used on the transmit and receive ports of the VNA. The amplifiers were connected to the antennae used in the experiment. The setup is shown in Fig. 1.

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3.1 VNA Setup

In this setup the VNA was set to sweep between 55-65GHz with a frequency step of 25MHz for 401 data points. This setup is consistent with the requirements presented in [5][6][7].

3.2 Calibration

The system was calibrated using the short open load and through (SOLT) procedure in an anechoic chamber. In this calibration the "through" standard was built by aligning the maximum of the radiation pattern of the two antennas to be used in the experiment at 0.5 m in an anechoic chamber. The correction coefficients were loaded into the VNA. This process was performed to ensure that impedance mismatches due to numerous effects such as antenna impedance and waveguide-to-coax transitions are not attributed as channel effects [6][7].

3.3 Antenna Configuration

An omni-directional antenna is employed at the transmitting side and a 21dBi directional pyramidal horn antenna at the receiving side. The antennae voltage standing wave ratios were better than 1.5:1 over the entire frequency of interest. The antennae were mounted on rails that permit the precise positioning required at 60 GHz (5mm wavelength). For AoA measurements a directional antenna was sweeping from 0 to 360 degrees in 4 degree steps. For each angle the time impulse response was measured.

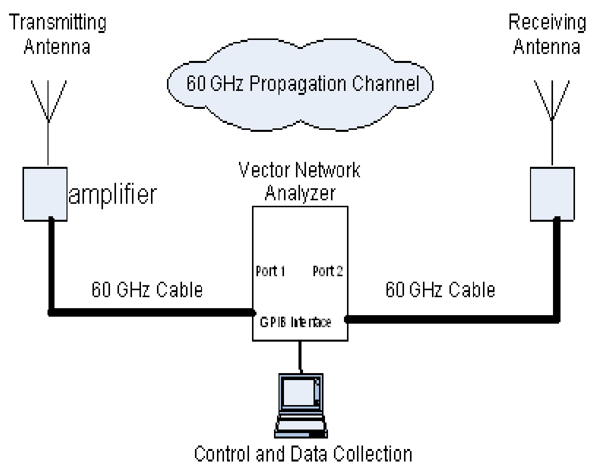

Figure 1: Experimental Setup

4 Measurements Results And Extracted S-V Parameters

Measurements were made on five desktops at different times and relative location on the desktop. In Fig. 2 a picture of an example desktop is shown. In Fig. 3 the measured angle of arrival profile is shown. It is important to note that the signal is clustered in discrete angles of arrival in azimuth. In Fig. 4 the power delay profile is illustrated for the dominant angles of arrival, namely zero (0) and three hundred and eight degrees (308) in azimuth. Note the delay and relative reduction of power of the signal at 308 degrees to the line of sight signal at 0 degrees.

From the measurements captured from the experimental setup described in section 3 the following S-V parameters were extracted:

Table 2: Extracted Modified S-V Model Parameters

Parameter	*Description*	*Extracted Value*
Λ	Cluster Arrival Rate	0.3 $(1/ns)$
λ	Ray Arrival Rate	8.7 $(1/ns)$
Γ	Cluster Decay Factor	1.5 (ns)
γ	Ray Decay Factor	1.0 (ns)
σ_1, σ_2	Cluster, Ray std.	2.1, 2.1 (dB)

Figure 2: Picture of a typical desktop with significant amount of clusters.

5 Conclusions

In this paper we measured and characterized the desktop 55-65 GHz wireless channel. Due to the presence of many obstructions and reflectors the 60 GHz

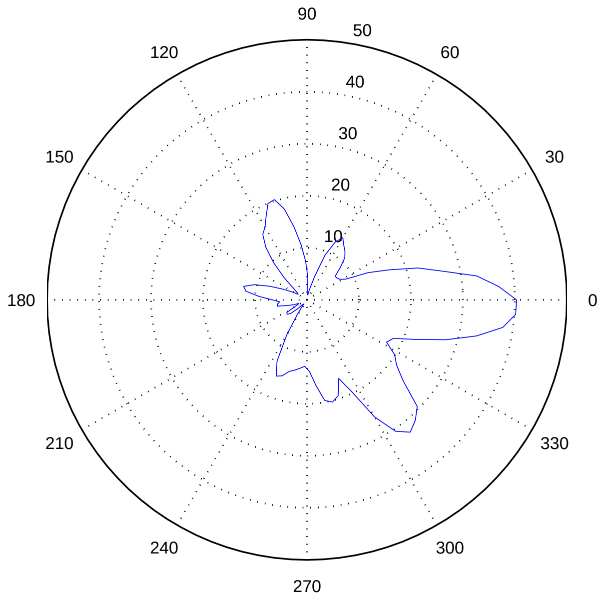

Figure 3: Angle of Arrival Profile for the desktop pictured in Fig. 2. Note that signal is received in multiple angles in azimuth.

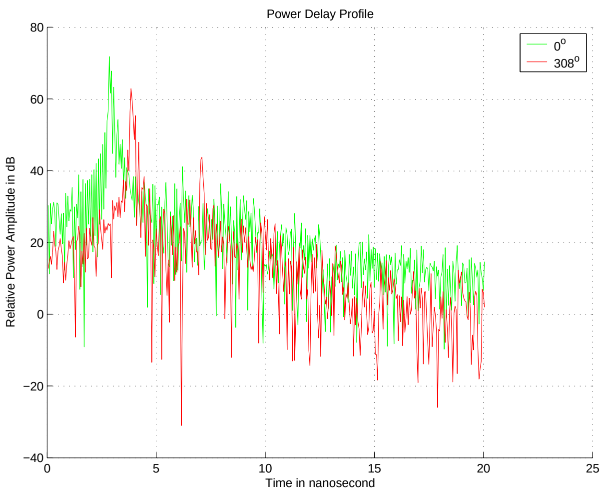

Figure 4: Power delay profile measured at desk pictured in Fig. 2. Note the delay and relative reduction of power of the signal received at 308 degrees in azimuth.

desktop channel was found to be significantly different from the intra-room propagation environment that is described in the literature. Key S-V model parameters such as Cluster Decay Factor, Ray Decay Factor, Cluster Arrival Rate, and Ray Arrival Rate were extracted for the measured data.

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