INDOOR WIRELESS RECEPTION IMPROVEMENT USING CROSS-POLARIZED MULTIPATH SIGNALS

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Abstract

Previous work has noted the distinct characteristics of vertically and horizontally polarized multipath components for indoor non-line-of-sight (NLOS) environments. Using measured data, the receiver signal-to-noise ratios (SNRs) for coherent and noncoherent combining of the co- and cross-polarized multipath components are compared to those obtained with omnidirectional reception for vertical or horizontal polarizations. It is seen that significant improvements in SNR can be achieved using intelligent combining with polarization diversity. Furthermore, it is observed that when the receiver is unable to resolve multipath components, coherent combination of both orthogonally polarized signals components provides a consistent advantage over vertically or horizontally polarized omnidirectional reception. At higher bandwidths, the increased resolution improves the performance of all techniques however the dual polarization multipath combining retains its relative advantage over the other techniques.

Keywords— *Wireless indoor channels characterization, propagation, polarization.*

1 Introduction

The cross-polarization of an electromagnetic (EM) wave can be seen as the amount of power that is received orthogonally polarized with respect to its transmitted polarization state. The cross-polarized multipath components (MPCs) in indoor environments are mostly originated from the interaction of the transmitted signal with scatterers located in the proximity of the receiver [4]. These cross-polarized MPCs are important not only for polarization diversity systems but also for their potential to boost the receiver power when a signal is transmitted with a single linear polarization. Polarization diversity systems generally exploits the EM wave polarization to multiplex data streams into separate channels [6]. When using this approach, cross-polarization degrades the performance by increasing the correlation between these channels [9]. On the other hand, in linear single polarization links, cross-polarized signals are normally ignored as negligible in comparison with the co-polarized received power. In this work, our approach was to study the receiver SNR improvement by coherent and noncoherent combining of orthogonally polarized signals and to determine how the performance of this proposed system is affected by the receiver bandwidth (BW).

Path differences of scattered signals in indoor environments at GHz frequencies are in the order of tens of centimeters or less. In order to estimate the performance as a function of the system capability of resolving MPCs, we need a wideband characterization of the indoor propagation at frequency bands of interest nowadays. Therefore, we carried out a measurement campaign to determine the cross-polarization of EM waves in the 5-6 GHz band. In this work, we compare the system performance achieved by the omnidirectional reception of MPCs with vertical and horizontal polarization, and the coherent and noncoherent combination of both signals.

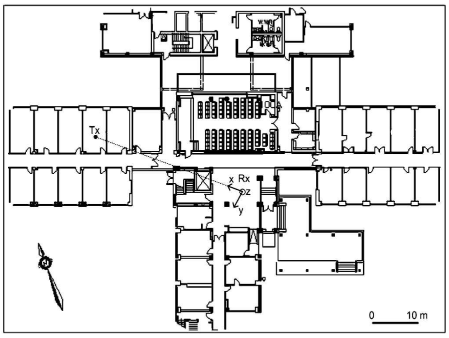


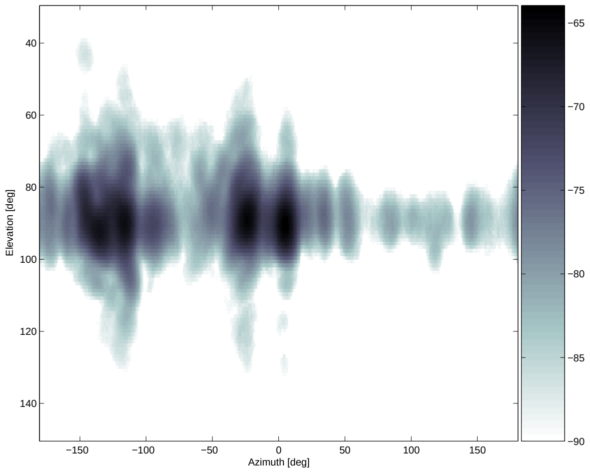
Figure 1: Transmitter and receiver location

2 Measurement Location

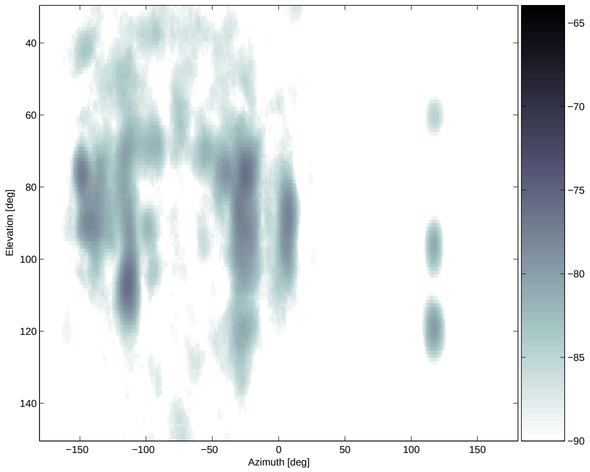
A typical office space environment at the Communication Research Centre was chosen to conduct the measurements. Figure 1 shows the NLOS transmitter and receiver locations chosen for our experiment. The transmitter location is a fully furnished office space and the receiver location is an open room with diverse indoor clutter. Heating ducts, pipes and electric wires run above the ceiling, which varies from 2.5 to 2.9 m [2]. Double layer plywood, concrete and brick walls, steel reinforced concrete columns as well as typical office equipment are in the surroundings. The distinctive characteristic of a real indoor scenario in comparison with a simulated environment commonly used in ray-tracing simulations lies in the effects of tens of potential scatterers such as indoor clutter, structural details, etc. In order to have maximum control over the variables that could affect the channel measurement, we conducted the tests during the weekend when the effects of personnel in the test area were minimized.

3 Channel Sounding Technique

The channel complex impulse response (CIR) was measured using a network analyzer and a specially



(a) Vertical polarization



(b) Horizontal polarization

Figure 2: Total received power distribution.

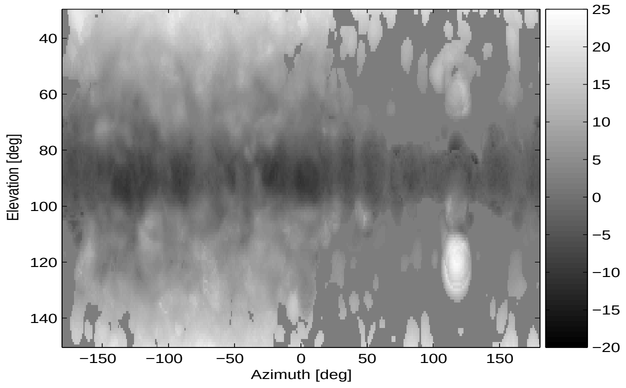


Figure 3: Cross-polarization ratio.

designed receiver antenna system that allows us to scan the radio environment for selective AOAs. The acquisition apparatus consists of a square planar array of 8 by 8 elements with a pencil-like radiation pattern, 10^o half-power beamwidth (HPBW) and -20 dB sidelobe levels. The 5.10-5.85 GHz band was chosen for the tests because of its relevance to new wireless LAN standards. A positioning system scanned the wideband antenna to the desired azimuth (ϕ) and elevation (θ) angles. The scanning was performed from 0^o to 355^o in ϕ and from 30^o to 150^o in θ, both in steps of 5^o. After applying a three term Blackman-Harris window to reduce the temporal sidelobe effects [1], the channel resolution obtained was 2 ns, which allows us to resolve multipaths with a path difference of 40 cm. Special consideration was made to diminish the near-field effects caused by the indoor clutter in the receiver surroundings. A biconical antenna located at the chosen test points (Figure 1) was used to transmit a continuous wave (CW) which was swept across the BW of interest in 1.875 MHz frequency steps. The snapshots of the channel were acquired at half of the half power beam width, obtaining four correlated sets of realizations of the CIR. We further use these data to extrapolate a high resolution spatial-temporal estimate of each CIR using a deconvolution technique (CLEAN) [8] and 2-D signal processing.

4 The Data Processing

The received signal for each AOA can be modeled as

$$s_i(\theta,\phi,\tau) = \sum_{n=1}^{N_\theta}\sum_{m=1}^{N_\phi}\sum_{k=1}^{N_\tau}\beta_i(n,m,k)\delta(\theta-\theta_n)\delta(\phi-\phi_m)\delta(\tau-\tau_k) \quad (1)$$

where δ is the Dirac's delta function, the index i, such that $i = V, H$, is used to denote vertical or horizontal polarization, respectively, $\beta_i(n,m,k)$ is the complex amplitude of the k^{th} multipath, N_ϕ, N_θ, and N_τ are the total number of resolution bins in azimuth, elevation and delay, respectively, θ_n and ϕ_m specify the look angle, and τ_k is the delay of the k^{th} multipath.

The threshold to discriminate valid MPCs was estimated using the constant false alarm rate defined in [7]. In addition, the total received noise power was estimated from (1), using the samples after the last valid multipath for each captured signal.

The XPOL is used in this work as a measure of the cross-polarized vs. co-polarized total multipath power as a function of the AOA. It is defined as follows

$$XPOL(\theta,\phi) = \frac{P_H(\theta,\phi)}{P_V(\theta,\phi)} \quad (2)$$

where P_V and P_H are the total power received due to vertically and horizontally polarized signals as a function of the azimuth and elevation angles, respectively.

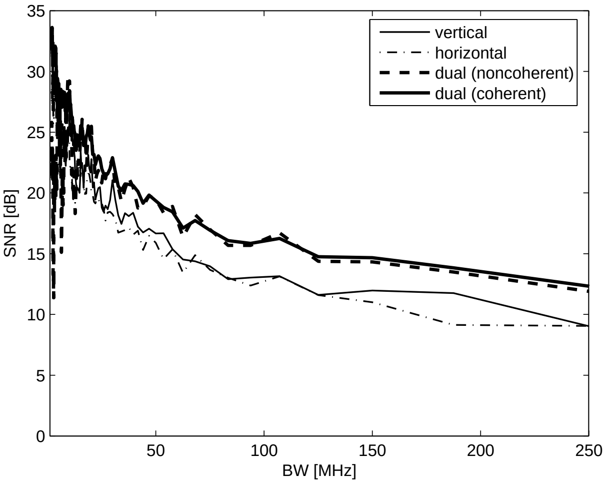


Figure 4: SNR vs. BW.

The time-domain signal resulting from the omnidirectional noncoherent signal combination was obtained from

$$f_i(\tau) = \sum_{n=1}^{N_\theta} \sum_{m=1}^{N_\phi} s_i(\theta_n, \phi_m, \tau) \tag{3}$$

where the index i is used to denote vertical or horizontal polarization, respectively, and s_i was defined in (1). The total coherent power for each polarization was estimated as follows

$$P_i = \sum_{k=1}^{N_\tau} |f_i(\tau_k)|^2 \tag{4}$$

where the index i is the same as in (3) and f is the resultant of the omnidirectional noncoherent signal combination for each polarization. Notice that we use the term omnidirectional to refer the ideal, direction independent and linearly polarized RF reception, without representing any particular antenna. The case of dual polarized antennas with RF combining was emulated using noncoherent addition of the vertically and horizontally polarized signals arriving from every AOA, while coherent addition was used to evaluate the impact of smart baseband combining. For each case, the total power was calculated by adding coherently the multipath signal in time domain in the case of maximum BW (minimum path difference resolution).

5 Results

The total power distribution as a result of the coherent addition of MPCs for both polarizations is shown in Figure 2. Notice that, while vertically polarized MPCs are distributed in the proximity of the horizontal plane ($\theta = 90^o$), cross-polarized components appear in clusters that are more uniformly distributed with respect to the elevation AOA. After combining the information obtained from Figure 2(a) and 2(b), the XPOL as a function of the elevation and azimuth AOAs was extrapolated (Figure 3). Notice that the higher XPOL can be associated with multipaths coming from above and below the horizontal plane ($\theta = 90^o$). This does not imply necessarily the presence of horizontally polarized MPCs with significant strength coming from sharp elevation angles but the relative absence of co-polarized MPCs for those AOAs, which is consistent with the observations extracted from Figure 2.

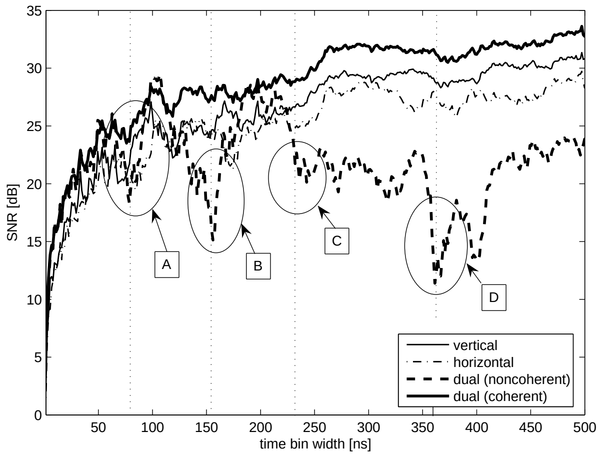


Figure 5: SNR vs. time bin

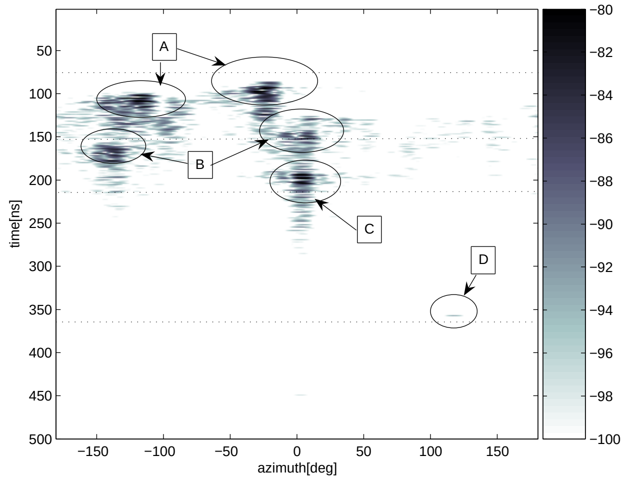


Figure 6: Delay vs. azimuthal power at 90^o elevation.

The ideal RF omnidirectional reception of both orthogonally polarized signals was evaluated using (3). Table I shows the power estimations for each case of study. These results represent the case of maximum channel BW, or equivalently, minimum time bin width. The effect of the variation of channel BW in the performance is shown

TABLE I

Comparative results of the total coherent multipath power

Combining technique	Received Power [dBm]
Vertical	-49.1
Horizontal	-50.0
Dual (noncoherent)	-47.0
Dual (coherent)	-46.5

in Figure 4. A gain of around 3 dB with respect to the vertically polarized reception was attained by coherently combining both polarization signals and this performance was maintained over high BWs.

The relationship between the receiver performance and its time resolution is shown in Figure 5. While the coherent combination of orthogonally polarized signals maintains its advantage for decreasing temporal resolution, the noncoherent combination exhibits fluctuations in the SNR performance. The points marked as A-D in Figure 6 coincide with the clusters arrival delays seen in Figure 5. For these delays, cross- and co-polarized MPCs are combined destructively in the same time bin, degrading the performance. Obviously, the coherent polar combination avoids this, outperforming the other techniques.

6 Conclusions

Using our experimental data, we have simulated different approaches to combining polarized multipath components. We found that the coherent combination of MPCs from the omnidirectional reception of co- and cross-polarized signals increased the received SNR for a NLOS indoor environment. This improvement was possible due to the significant amount of signal power that is decoupled into orthogonally polarized MPCs [4]. The coherent combination of both polarized signals exhibits better performance than the single polarization combination in all cases of channel BW. We measured clusters of significant power arriving from diverse AOAs at different delays for each polarization. These clusters of MPCs are added destructively affecting negatively the noncoherent polar combination. Furthermore, we estimated that the total power of vertically polarized signals after omnidirectional reception drops considerably, again because of the destructive addition of MPCs arriving simultaneously from distinctive AOAs. It is possible to eliminate this destructive effect, taking advantage at the same time of the rich scattering indoor environment, combining multi-beam antenna systems and polarization diversity.

In addition, we found a strong dependency of the cross-polarization of multipath components on the elevation AOA. While vertically polarized multipaths are confined exclusively to the region around the horizontal plane, cross polarized MPCs can have sharp AOAs. The latter can be explained by reflections in floors and ceilings in the surroundings of the receiver. We can conclude that the spatial distribution of the scatterers in the proximity of the receiver is a decisive factor in the creation of decoupled MPCs.

Acknowledgments

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