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POWER AZIMUTH SPECTRUM MEASUREMENTS IN HOME AND OFFICE ENVIRONMENTS AT 62.4 GHZ

Dr. Ioannis Sarris
Mitsubishi Electric ITE B.V.
Visual Information Laboratory
Guildford, U.K.
ioannis.sarris@vil.ite.mee.com

Prof. Andrew R. Nix
University of Bristol
Centre for Communications Research
Bristol, U.K.
andy.nix@bristol.ac.uk

ABSTRACT

The high demand for unlicensed spectrum mandates the use of higher frequencies, such as the 60 GHz band, where large amounts unlicensed bandwidth exists. In this paper, the results from Power Azimuth Spectrum (PAS) measurements in a home and an office environment are presented with a view of revealing the amount of scattering power at that frequency and its relative power to the Line-of-Sight (LoS) signal. Moreover, a tractable scheme is proposed for the estimation of the Power Azimuth Spectrum from absolute power measurement data which produces a very close fit with the measured PAS. A discussion is made on the accuracy of this method which is dependent on the directionality of the antenna elements, the fading in the channel and the presence of noise.

I. INTRODUCTION

The large penetration of Wireless Local Area Networks (WLANs) in the residential and office environments along with the ever increasing demand for higher bandwidth is expected to eventually overflow the already congested radio spectrum at microwave frequencies [1]. A potential solution to this problem, from a technological point–of–view, is a combination of spectrum efficiency enhancing techniques (such as Multiple–Input Multiple–Output (MIMO) technology) with the exploitation of additional (higher) frequency bands.

This paper examines the potential of the 60 GHz frequency band for indoor WLAN applications. This band is viewed by many as a very attractive candidate for future communication systems due to a high reuse factor which is the result of increased signal attenuation from free-space propagation, scattering and oxygen attenuation compared to lower (microwave) frequencies. The high reuse factor has allowed for an enormous bandwidth (between 5 and 7 GHz) to be allocated globally for unlicensed use [2, 3], however, it is undisputable that the successful employment and utilisation of this bandwidth requires profound knowledge of the propagation characteristics in this frequency range.

The authors have a specific interest in the area of MIMO technology where multiple antenna elements are employed in both ends of a communication link. A crucial parameter that governs the performance of such systems is the existence of scatterers in a given environment [4]. Information about the scattering objects can be derived from the Power Azimuth Spectrum (PAS) which determines the spatial distribution of the received power over the azimuth domain. Hence, it is of vital importance to identify accurately the spatial channel properties to ultimately be able to make accurate predictions on the potential performance of MIMO systems at that frequency.

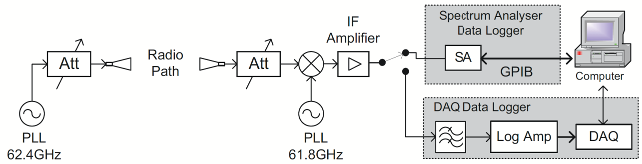

Figure 1: Measurement system

Recently, the deconvolution scheme was proposed for the estimation of the PAS from complex electric field pattern measurements [8, 9]. In this paper, a number of (real valued) power measurements were performed and therefore a deconvolution scheme was found unsuitable. Instead, a simplified serial cancellation scheme is employed which is based on an iterative process of Multipath Power Component (MPC) identification.

II. MEASUREMENT DESCRIPTION

The measurement equipment employed in this study was borrowed from the University of Glamorgan (U.K.) and has been used in numerous measurements in the past [10, 11, 12]. A description of this equipment is presented in the following paragraphs.

A. *Measurement equipment*

The system employs Phase Locked Loop (PLL) synthesisers which have an enhanced frequency stability (± 1 kHz) that allows the use of a narrow IF filter at the receiver. The transmitter consists of a 20.8 GHz PLL whose signal frequency is multiplied by a factor of three by means of a frequency multiplier, leading to an output frequency of 62.4 GHz. This signal is fed to a waveguide attenuator and subsequently to an appropriate transmitting antenna.

The received signal is mixed with a 61.8 GHz PLL local oscillator obtaining a very stable IF of 600 MHz. This IF signal is then used to evaluate the received signal strength via a logarithmic amplifier (LogAmp). To further decrease the noise floor of the 600 MHz DAQ data logger, an IF band pass filter is used to reduce the noise power at the LogAmps input which lowers the noise floor to -57 dBm.

A laptop computer was responsible for the control of the two servomotors where the transmitter and receiver modules were mounted. Moreover, this laptop employed a data–acquisition card with 4 channels and 100 ksamp/s sampling frequency that

Table 1: Omni antenna characteristics

Specified Frequency Range	59 to 64 GHz
Gain Variation Elevation	2 ± 1.5 dB
Gain Variation Azimuth	$\pm$ 1 dB
Polarisation	Vertical
Nominal 3 dB Beamwidth	Greater than 60^0

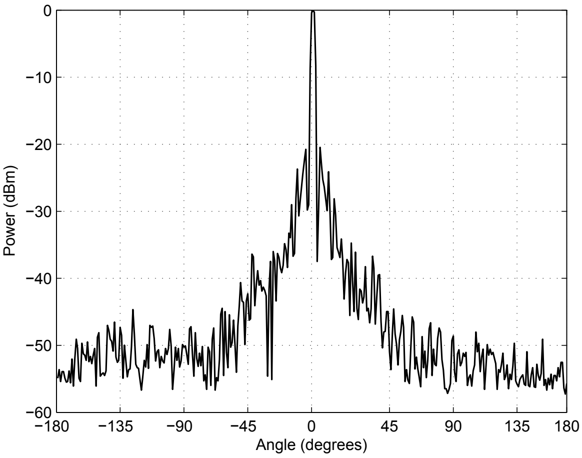

Figure 2: Normalised field pattern on the *E* plane

was used to perform the data acquisition. The turn tables were connected to the PC serial port and were controlled via a dedicated indexer with a proprietary control language. This language was programmed into the measurement software code, allowing the software to fully control the turn tables. All the measured data was recorded into a structured Matlab data file for further processing.

B. Antenna Elements

For both measurement campaigns two different types of antennas were used; at the transmitter (Tx) an omni–directional antenna was deployed while the receiver (Rx) was connected to a custom–made 36 dBi directional lens horn antenna. The omni antenna has been specifically designed to provide a vertically polarised 360^0 field of view in the azimuth with the widest possible acceptance angle in the elevation. The main characteristics of this antenna are given in Table 1.

On the other hand, the lens horn antenna had a 3 dB–beamwidth of approximately 1.5^0 and was used to measure the received power by obtaining power samples over 360^0 in the azimuth plane in steps of 1^0. The normalised field response on the *E* plane is illustrated in Fig. 2.

III. MEASUREMENT RESULTS

Two different propagation environments were investigated in this study; namely a home and an office environment. For the home environment a 4.7 m × 3.5 m lounge area was employed with a number pieces of furniture and a staircase Fig. 3. The office environment was an 18 m × 12.4 m office at the University of Bristol with several desks, chairs and computer equipment separated by partitions as shown in Fig. 8.

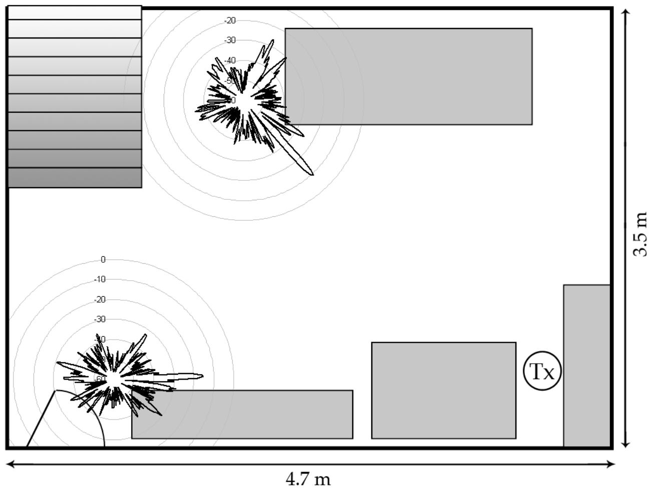

Figure 3: Home environment floor–plan showing the received power distribution after the log–amp.

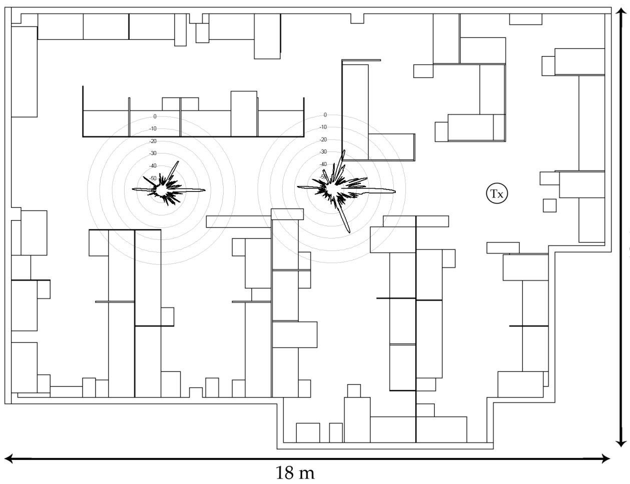

Figure 4: Office environment floor–plan showing the received power distribution after the log–amp.

By rotating the lens antenna in the azimuth plane it was possible to identify the strength of the LoS signal and individual reflected signals at two different receiver locations in each environment. The measured PASs are superimposed in Fig. 3 and 8.

In the home environment a significant difference between the power of the LoS and the reflected components can be easily observed. In detail, differences of approximately 15 dB were observed between the LoS signal and the strongest (first–order) reflections. In the office environment the results are similar with differences of around 13 dB between the powers of the LoS signal and the strongest reflection at a Tx–Rx distance of 5 m. For an increased T–Rx distance however (10 m) a smaller difference of 8 dB was observed.

Table 2: Effective MPCs

Location	Number of effective MPCs
Home 1	41
Home 2	43
Office 1	28
Office 2	27

IV. Power Azimuth Spectrum Estimation

The measured powers from this measurement campaign were post-processed using a PAS estimation technique. In detail, a serial cancellation algorithm was used to remove the antenna pattern effect from the received PAS. Since the Tx antenna had an omni pattern this process was performed directly on the received power. The algorithm used for this study is shown below using MATLAB notation.

Input: Measured Power Spectrum (PAS_{meas})
Antenna Pattern (AP)

Output: Estimated Multipath Power Components (MPC)
Reconstructed Power Spectrum (PAS_{rec})

for i=1:q **do**

[$maxValue$ $maxIndex$] = **max**(PAS_{meas});
$MPC(i,:)$ = [$maxValue$ $maxIndex$];
$tempAP$ = **circshift**(AP, $maxIndex$).*$maxValue$;
$PAS_{meas} = PAS_{meas} - tempAP$;
$PAS_{rec} = PAS_{rec} + tempAP$;

end

In order to determine the number of MPC (q) that were effectively contributing to the PAS, the minimum Root Mean Squared Deviation (RMSD) between the measured PAS and the reconstructed PAS was calculated as follows for different values of q.

$$RMSD = \sqrt{\overline{(PAS_{meas} - PAS_{rec})^2}} \quad (1)$$

The number of MPCs that corresponded to the minimum RMSD are shown in Table 2.

The measured and the reconstructed PAS along with the identified MPCs are shown in the following figures for the two locations in each environment.

It is clear that there is a very close fit between the reconstructed and the measured PAS. In detail, it was found that the RMSD was less than 1 % in all the examined scenarios. However, as far as the identified MCSs are concerned it is also clear that there is a number of cases where the number of detected MPCs is more than one for each peak of the received PAS. This unavoidable inaccuracy can be attributed to the noise in the environment and the limited directionality of the system. Moreover, the effect of multipath fading decreases the accuracy of the method even more especially in the non-LoS orientations. To increase the accuracy, a higher directionality antenna could

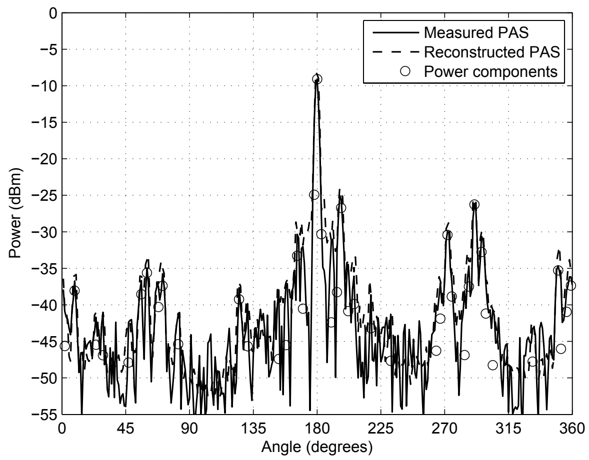

Figure 5: Received and reconstructed PAS for home environment, Location 1

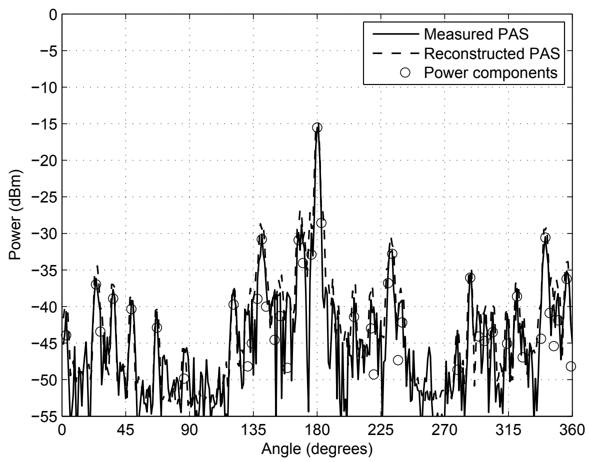

Figure 6: Received and reconstructed PAS for home environment, Location 2

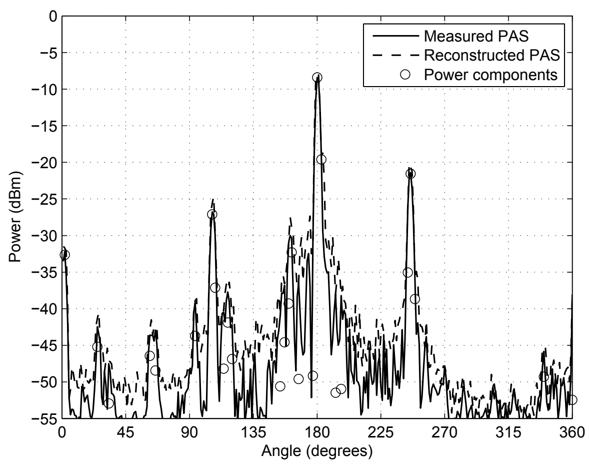

Figure 7: Received and reconstructed PAS for office environment, Location 1

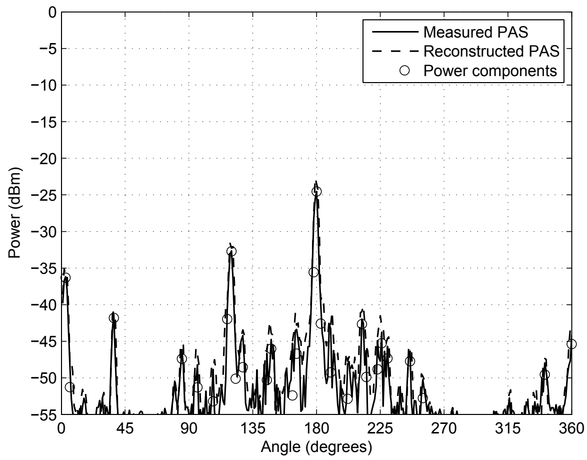

Figure 8: Received and reconstructed PAS for office environment, Location 2

be employed and several measurements in adjacent positions to counteract for the effect of the noise and the channel fading.

For the purposes of our investigation, the results are proven sufficiently accurate and demonstrate very clearly that the LoS signal along with the first and second order reflections dominate the PAS. In non-LoS locations, the dynamic range that was available in the measurement system ($\approx$ 48 dB at a 5 m distance) did not allow us to receive any signals above the noise floor.

V. CONCLUSION

This paper presented the procedure and the outcomes of a measurement campaign conducted in a home and an office environment at 62.4 GHz. The PAS was measured in two locations in each environment using an omnidirectional transmitting antenna and a highly directional lens horn antenna at the receiver. In the post-processing stage a serial cancellation algorithm was used to estimate the MPCs. The exact number of these MPCs was decide from calculations of the RMS deviation between the measured response and the reconstructed PAS.

By comparison of the measured and the reconstructed PAS the aforementioned method was shown to provide sufficiently accurate results for the purpose of our investigations. However, it was also shown that the procedure is inherently ill-conditioned due to the real-valued information that was available from the measurement and also that the method's accuracy was highly dependant on the antenna directivity.

To increase the accuracy of this method a larger number of spatially discrete measurements is suggested so that the effect of noise and fading could be minimised.

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