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Site Specific Prediction and Measurement of Indoor Power Delay and Power Azimuth Spectra at 5 GHz

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Abstract – This paper describes a newly developed three dimensional ray launching model for complex indoor environments. The model is capable of predicting detailed temporal and spatial multipath. To investigate and evaluate the accuracy of this model, predictions are compared with detailed measurements recently taken in an office environment. Power Delay and Power Azimuth Spectra are measured using a multi-element Medav channel sounder operating with 120 MHz of bandwidth in the 5 GHz band. Prediction accuracy was found to be sensitive to the accuracy of the basestation height, the permittivity of the surrounding materials and the number of reflections permitted in the model. Overall, the results indicate that with careful modelling and well calibrated measurements, good site specific spatial and temporal multipath agreement can be achieved.

I. INTRODUCTION

A detailed knowledge of spatial and temporal multipath is considered vital in the design and optimisation of next generation terminals. The use of directional, sectorised and beam steered antennas is already well established for improving the site specific coverage and/or capacity of a given system. More recently, Space Time Coding (STC) techniques have promised significant capacity gains using antenna arrays at both ends of the radio link [1]. However, these gains are directly dependent on the spatial (transmit and receive) and temporal statistics of the channel. In turn, these statistics are highly dependent on the operating environment and the location of the basestation and terminals. Hence, an efficient and accurate site-specific propagation model is required for predicting the space-time characteristics of an arbitrary radio link.

Site specific channel measurements represent an important and necessary step in characterising the performance of a radio channel. The problem with this approach is the need for specialised and expensive equipment, particularly when recording temporal and spatial data. The process is also time consuming and requires considerable manpower to collect statistically representative data. Propagation models are able to generate vast data sets for any site specific environment. This data can then be used in the design and deployment of radio networks. However, to develop, optimise and then validate the propagation model, detailed site specific channel measurements are vital. In this paper, spatial/temporal measurements are obtained using a MEDAV RUSK channel sounder [2].

The propagation model presented here is based on the principles of ray launching. In section II, a detailed description of the path search engine is presented. This section explains the ray launching method and the use of

reception spheres, or angular information, to determine rays arriving at the receiver. The 5 GHz measurement system and the indoor test environment are briefly presented in section III. In section IV, the sensitivity of the model to basestation height, material permittivity and reflection order is considered. Having configured the model, measured and modelled power delay and power azimuth spectra are compared. Finally, section V provides a number of conclusions and observations.

II. THE RAY LAUNCHING TECHNIQUE

Deterministic ray based propagation models generally use one of two key path-searching techniques: (i) image based or (ii) ray launching. Such methods have been used for many years with references dating back to the early 1980s [3-7].

Image based technique use the electromagnetic theory of images. They consider all objects as potential reflectors and calculate the location of transmitter images. Ray paths are formed based on the location of the receiver, the transmitter and its associated images. A ray launching technique, on the other hand, sends out test rays at a number of discrete angles from the transmitter. As they propagate, the rays interact with objects present in the environment. The propagation of a ray is terminated when its power falls below a preset threshold. Both methods have been expanded to enable transmission and diffraction to be considered in the model.

Figure 1: Methods used to determine a path from the Tx to the Rx. a) the use of distance dependent reception spheres. b) the use of the angular information at the virtual transmitter.

Figure 1 illustrates two common methods by which received paths are deemed to have occurred. In the first method, a

propagation distance dependent reception sphere is used. A path from the transmitter to the receiver exists if a ray intersects this reception sphere. The second method uses angular information at the image, or virtual transmitter, to determine if a ray path exists. A path is found if the azimuth and elevation angles of the test path at the virtual transmitter are close enough (within an acceptable error bound) to the azimuth and elevation angles of the ray. The geometry of the test path is shown in Figure 1b. The location of the virtual transmitter is determined by reverse propagating the ray by an amount equivalent to the unfolded path length. The ray launching mechanism at the transmitter is clearly linked to the method used at the receiver to determine ray path existence.

If reception spheres are used then rays must be uniformly spaced to ensure that no more than three rays touch any given reception sphere. A common method that achieves this requirement is to launch rays such that they pass through the vertices of a unit geodesic sphere enclosing the transmitter. A geodesic sphere is constructed by tessellating the faces of a regular polyhedron and projecting the vertices to the surface of a unit sphere [8].

Figure 2: Rays launched from the transmitter pass through the vertices of sphere A if reception spheres are employed, otherwise sphere B is used.

If angular information at the virtual transmitter is to be used then rays must be uniformly spaced in the azimuth and elevation planes. Figure 2 shows the two different launching spheres around the transmitter.

The ray launching technique has a number of advantages when compared with image based ray tracing methods. Using image theory, the number of images increases significantly as additional reflecting surfaces are introduced (i.e. with increasing database complexity). Ray launching methods do not suffer from this problem, however they do possess alternative shortcomings. Ray launching suffers from resolution problems and care must be taken to prevent the double counting of single ray paths. Ray launching is unable to calculate the exact paths as identified using an image based method. The resolution problem is minimised by increasing the number of launched rays at the transmitter. However, this approach will increase the overall computational complexity. Double counting of a single path is an inherent problem when using reception spheres to detect received paths. A common remedy is to apply additional filtering to remove errored paths, since repeated rays will have the same path length and arrival angle.

The model developed in this paper launches rays that pass through the vertices of sphere B in Figure 2. Each ray then propagates in the environment and interacts with objects as

they are encountered. Propagation is terminated when the number of ray-object interactions reaches a defined limit. An array of tree structures is used to hold the geometric ray information.

To find ray paths from the transmitter to the receiver, the array of tree structures and the location of the receiver are used in conjunction with the angular test described in Figure 1b. Rays passing this test are deemed to arrive at the receiver and their complex field contribution is calculated.

Traditionally, diffraction is difficult to include in a ray-launching model. The process requires re-launching of rays from each illuminated edge. This model uses a novel diffraction technique previously reported in [9]. Using this method, all first order diffraction and multiple reflection-diffraction and diffraction-reflection ray paths can be identified in a three dimensional space (including off-axis diffraction paths).

The complex electric field, E_i , associated with the i -th ray path is determined by:

$$E_i = E_o \prod_j \bar{R}_j \prod_k \bar{T}_k \prod_l \bar{D}_l A_l(s_l, s_l') \frac{e^{-j\beta d}}{d} \quad (1)$$

where E_o is the reference field, R_j the reflection coefficient for the j -th reflection, T_k the transmission coefficient for the k -th transmission, D_l and A_l the diffraction coefficient and the spreading attenuation for the l -th diffraction and $e^{-j\beta d}$ the propagation phase factor ($\beta = 2\pi/\lambda$ and d represents the unfolded path length). The expressions for the various coefficients can be found in [10][11]. The reference field E_o is given as:

$$E_o = \sqrt{\frac{P_t G_t Z_o}{4 \pi r^2}} \quad (2)$$

where P_t represents the transmitted power, G_t the gain of the transmitting antenna, Z_o the intrinsic impedance of free space and r the distance at which E_o is measured.

III. THE MEASUREMENT SYSTEM

The University of Bristol's multi-element MEDAV channel sounder was used to obtain the site-specific validation data presented in this paper. The sounder supports far-field measurements at bandwidths up to 120MHz. The unit currently operates in either the 2 GHz (Bluetooth, IEEE 802.11b) or 5 GHz (Hiperlan/2, IEEE 802.11a, HiSWANa) band. The sounder makes use of an 8 element receiving array and is based on the transmission of a multi-tone sequence. The equipment is capable of resolving multipath components separated by 8.3ns (~2m) in the time domain and 2-3 degrees in the azimuth domain. Spatial separation is achieved using a super resolution ESPRIT algorithm. The measurement campaign was performed in a large open plan communications laboratory at the University of Bristol. The test site is a typical office environment with partitioned work areas containing desks, chair and computers as shown in Figure 3.

Figure 3: Communication Research Laboratory of the University of Bristol (modern office measurement site).

Figure 4 shows the location of the receiving array (point 'A') and the 5m long route along which the measurements were made. The measurements were conducted in the 5 GHz band with a transmission power of 27 dBm. The transmitter was a vertically polarised dipole antenna, while the receiver used the carefully calibrated 8 element Medav array (with calibration performed in the University's anechoic chamber).

Figure 4: Location 'A' indicates the position of the receiving array while the red line shows the measurement route.

The transmit unit was pushed at a slow walking pace using a specialised measurement trolley. The received complex frequency domain was sampled at each of the 8 receiving elements once every 3 cm. Using the Medav MATSYS toolbox, the data was processed to generate the Power Delay Profile (PDP) and the Power Azimuth Profile (PAP) at each measurement point. This data was then combined to form the Power Azimuth Spectrum (PAS) and the Power Delay Spectrum (PDS).

IV. SENSITIVITY AND PREDICTION ACCURACY

An accurate three dimensional database was generated for the measurement environment (see figures 4 and 5). This database includes all desks, partitions and pillars. The data was then fed into the ray launching model described in section II. Each object in the database can be assigned a specific value of permittivity and conductivity. The model is then used to generate the full complex impulse response between any two points in the room, including azimuth and elevation angles for each ray. Figure 5 shows an example of

the predicted ray geometry at a sample point along the measurement route for three orders of reflection. To emulate the measured data, point predictions were taken every half a wavelength along the measurement route.

Figure 5: Ray geometry of a sample point along the route.

A. Sensitivity

An initial sensitivity study was performed to determine the impact of certain model's settings on the output prediction. The measurements were taken from a single basestation location. Given that the exact location of the basestation could not be determined to within a wavelength, the impact of imprecise basestation location was investigated. Figure 6 shows the average power delay profile along the entire route for three different antenna heights.

Figure 6: The sensitivity of the time averaged delay spectrum delay profile to the different locations of Tx. (3 orders of reflection)

The prediction data was processed to match the temporal resolution of the sounder (to enable direct comparison). However, this implies that rays within the time resolution of the sounder will vectorially add. Although averaging along the route was performed to reduce these variations, it is well known that spatial average at both the transmitter and receiver is required to remove sensitivity to the exact antenna location. Hence, for small fluctuations in the basestation location, a certain degree of signal variability can be expected. From figure 6, a variation of around 3-4 dB was observed per time bin, with slightly higher variability in the weaker time bins. Accuracy between predictions and this particular measurement cannot exceed this value. Greater accuracy could have been obtained if further measurements

were taken and averaged over a range of basestation heights (within plus and minus one wavelength).

higher permittivity values.

Figure 7: The sensitivity of the time averaged delay spectrum to the different values of the reflection coefficients. (relative permittivity 3, 5 and 7, conductivity 0.005 S, height 2.95m)

Next, the sensitivity to material permittivity and conductivity was examined. Figure 7 shows the predicted average power delay profile along the route for three different values of bulk relative permittivity. The left-hand plot shows the result for a relative permittivity of 3. As expected, this results in the lowest reflection co-efficient and hence the weakest multipath components. The middle and right hand plots show the graphs for relative permittivities of 5 and 7 respectively. In the right hand plot, the first order reflected field is approximately 6-7 dB higher than that of the left-hand plot. Significant higher order multipaths are also observed for the

Figure 8: Predicted time averaged delay spectrum using 2(right) and 3(left) orders of reflection. (relative permittivity 5, height 2.90m)

Figure 8 shows the impact of increasing the reflection order in the model from two orders (right hand plot) to three orders (left hand plot). Although the general shape of the average power delay profile remains largely unchanged, an additional significant component can be seen in the third order case at a time delay of around 50ns. The peaks at 100ns and 140ns are also seen to vary as additional rays are now included in these time bins. While on average the mean power is expected to rise, since the time bins are averaged over a fading process, the addition of further rays can result in constructive or destructive interference. Hence, from figure 8 it can be observed that the field at 100ns has dropped with three orders

Figure 9: Measured Delay Spectrum

Figure 10: Measured delay averaged azimuth spectrum.

Figure 11: Predicted delay spectrum (3 orders of reflection)

Figure 12: Predicted averaged azimuth spectrum (3 orders of reflection)

of magnitude, while the field at 140ns has risen. These fluctuations would be expected to reduce if basestation location averaging were applied.

B. Prediction Accuracy

Using the results from the previous section, the model was configured using three orders of reflection and a material relative permittivity of 5. Figures 9 and 10 show the measured PDP and PAS for the route highlighted in figure 4. Figure 9 shows a delay spread of around 160 ns for a 30 dB power window. The strongest time bin (which includes the line-of-sight) has a peak field strength of around -65 dB. Figure 10 shows that the dominant component arrives at the basestation at an angle of 5 degrees for the start of the route and moves to around -15 degrees by the end of route. Encouragingly, the PAS shows the variation in arrival angle as the trolley moves along the route.

While many indoor models have been shown to accurately predict average power or delay spread, in this analysis we wish to demonstrate the model's ability to predict the measured PAS and PDP. Figures 11 and 12 show the modelled results for the identical route. A visual comparison of figures 9 and 11 confirm that the model is accurately predicting delay spread and power levels. The peak field strength in the model is slightly higher than the measured value, and this may be due to calibrations errors (although every effort was taken to minimise this source of error) in the sounder or inaccuracies in the basestation height (see earlier section). Comparison of figures 10 and 12 shows the spatial accuracy of the prediction tool. Clearly the core spatial components are accurately predicted in the model, however the measurement contains a richer degree of weaker multipath. There are numerous potential sources for this multipath. The missing components in the model are most likely the result of weaker diffracted or scattered fields, most probably from smaller objects missing in the database.

Figure 13: Measured and predicted time averaged delay spectrum using 3 orders of reflection.

From the data in figures 9 and 11 it is possible to calculate the measured and predicted average PDP along the measurement route. This data is shown in figure 13. As mentioned earlier, the predicted field is slightly higher than the measured result, although within the variability observed given uncertainties in the basestation height. Generally, the prediction maps well to the measured data, however

multipath components at around 80ns are missing in the prediction (see earlier paragraph for possible reasons).

V. CONCLUSIONS

This paper has presented a new fully three dimensional indoor propagation model that can predict site specific spatial and temporal multipath. To demonstrate the accuracy of the tool, a detailed set of spatial and temporal measurements were performed at a carrier frequency of 5GHz. Predictions were sensitive to basestation height, material permittivity and reflection order. A comparison of the measured and modelled PDS and PAS confirmed the accuracy of the predictions. In practice, the measurements were seen to possess a higher number of weaker multipaths. Future work will attempt to determine the source of this discrepancy.

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