Analysis of AOA of Multipath Signals Inside Buildings: A Comparison between MUSIC and Ray Tracing

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1. Introduction

The rapid growth in wireless communications has necessitated research to understand radiowave propagation mechanisms inside buildings. A large number of research papers describing the indoor multipath propagation channel have appeared in recent years [1-4], however there are only a few studies related to Angles Of Arrival (AOA) of multipath signals especially in indoor environments. Due to limited frequency spectrum resources new techniques such as adaptive antennas are being implemented to increase channel capacities. Analysis of AOA for each individual multipath signal in different indoor environments can provide useful inputs for the design of adaptive antennas in such a situation.

The AOA of multipath can be obtained by measuring the complex field data which will then be processed by using high resolution techniques such as MUltiple SIgnal Classification (MUSIC) [5]. Alternatively AOA of multipath may be predicted by using simulation methods such as a ray tracing. Since physical measurements are expensive, numerical simulation methods are more attractive. Further, the results on AOA obtained via measurements have to be validated with other techniques. Geometrical-optics based ray tracing techniques have been in use for the prediction of indoor and outdoor propagation mechanisms such as path loss and delay spread [2-4]. However, comparisons of AOA of multipath signals in indoor environments are not available.

In this paper we present a comparison between predicted results of AOA of multipath obtained by a three Dimensional (3-D) image-based ray tracing and estimated results obtained via measurements with data processed by spatially smoothed MUSIC. A 3-D ray tracing program for predicating AOA of multipath signals based on building geometry for indoor micro-cells has been developed. The distributions of AOA of multipath signals inside a 30 story building of the University of Technology at Broadway, Sydney have been analysed. Prediction results via ray tracing simulation are compared with measurement results which are processed by spatially smoothed MUSIC for a small classroom as well as a large convention hall (Great Hall) located in the building. The close agreement between ray tracing predication and measurement/MUSIC estimation indicates that the 3-D ray tracing program can be a valuable tool in the predication of AOA of indoor multipath.

2. Ray Tracing Model for AOA Prediction

The ray tracing model is based on geometrical optics which involves tracing of rays in 3-D from structures inside a building to determine AOA of multipath both in azimuth and elevation. In the lower microwave frequency band, the surfaces of most of the walls, floors and ceilings can be assumed to be relatively smooth. The walls of the rooms are assumed to have dimensions much larger than the propagating wavelength and all reflecting planes are assumed to be orthogonal. In order to simplify ray tracing, the effects of the furniture are ignored in the simulation model. The furniture within rooms could be treated as multiple scattering sources, however, multiple scattered rays are not included in the simulation since their strength decrease rapidly with distance.

The 3-D ray tracing model has been set up with the building structure information taken from blueprints and for given positions of transmitter and receiver antennas. Multipath sources have been established by using the image method, as shown in Fig.1. The ray paths have been ordered by the number of reflections they undergo. The Line Of Sight (LOS) ray is defined as the zero-th order ray and the AOA for this ray has been calculated by the geometrical positions of the transmitter and receiver. The rays that hit one object and get reflected to the receiver are the first order rays. The rays that are reflected twice and then reach the receiver are the second order rays, and so on. For the second order reflection, AOA of rays have been determined from the location of the secondary images which are determined by treating the first images as sources. Thus, Nth order ray paths are determined by (N-1)th images. According to image theory M reflecting planes will generate M first order rays, M(M-1) second order rays, M(M-1)(M-1) third order rays, etc. Due to the finite dimensions of all walls, ceilings and floors, existence of rays needs to be examined by testing the intersections between rays and planes. Fig.1 shows the image sources due to the walls lying in XY plane where I, II, III • • • • represent the first, second, third • • • • orders of sources. A 3-D sketch can be obtained straightforward by combining the images due to XY, YZ and ZX planes. In Fig.1 some of zero, first and second order rays are also shown. For minimising the computation time, certain ray branches of the ray tree which are not useful and/or any ray path that will not intersect the reflecting planes have been ignored. Since the program operates for 3-D, the angles of arrival of rays are traced at receivers both in azimuth and elevation.

3. AOA Obtained via Measurement and MUSIC

The number of multipaths reflected by the building structure in theory can be infinite, however for a good model of using measurements one can obtain only a finite number of dominant multipath components. The measurement system includes a vector network analyser (VNA) coupled to an automatic scanning system that moves a receiver antenna around a rectangular planar grid forming a synthetic rectangular array. The methodology for measurements of AOA of multipath in indoor environments has been provided in detail in [6]. The measurements have been conducted in two sites inside the Tower Building of our university (UTS) viz. a small classroom and a larger room (Great Hall) located on levels 23 and 5 respectively. The height of transmitter antenna and locations of the transmitter as well as the receiver have been varied, so that they represent typical indoor micro-cell environments. The details of the measurement plans and the locations of the transmitters and receivers are provided in [6]. Spatially smoothed MUSIC for processing the complex field data of measurements has also been developed in [6] with the number of dominant multipath components decided by MDL criterion [7]. The measured data has been processed by these methods to obtain AOA of dominant multipath. The results on AOA obtained via measurements and MUSIC are presented in table I and II for the classroom and Great Hall respectively.

4. Comparison of Results

A comparison is made between AOA obtained through measurement/MUSIC and those predicted AOA via the ray tracing simulation. Two receiver locations and four transmitter positions has been used for both the classroom and Great Hall. Table I and II provide the prediction results by ray tracing along with the estimation results by measurement/MUSIC for the classroom and Great Hall respectively. From the tables the Differences between Measured and Predicted Results (DMPR) are calculated. In most cases DMPR is within 2 degrees with the worst case DMPR in the classroom being 5 degrees and in the Great Hall being 19 Degrees. The error appears to be increasing with the size of the room.

Cumulative probability distribution functions of DMPR for the classroom and Great Hall are also shown in Fig.2, from which we can obtain that: i) the mean values of DMPR for the classroom and Great Hall are 1.31 and 2.21 degrees respectively, ii) the standard deviation values of DMPR are 1.48 and 3.55 degrees respectively, and iii) in the classroom, for 61% of the cases the probability of DMPR lies within ± 2 degrees, and in the Great Hall, for 56% of the cases the probability of DMPR lies within ± 2 degrees. The results on AOA obtained via the ray tracing compare well with the results provided by measurement/MUSIC.

5. Conclusions

This paper presents a comparison of AOA of significant multipath inside buildings between results obtained by a three dimensional image-based ray tracing simulation and estimated results obtained via measurement data processed by spatially smoothed MUSIC. A 3-D ray tracing approach has been used to determine the AOA of individual signals both in azimuth and elevation. AOA have been estimated from both measured data as well as simulated data. The simulated results on AOA obtained via ray tracing compare well with the results obtained via measurement /MUSIC and agreement appears to be quite close in the case of small room environments.

Acknowledgment

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Reference

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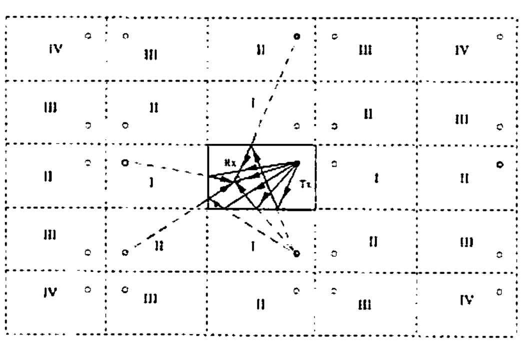

Fig. 1 Ray tracing technique for multi-reflection sources localisation

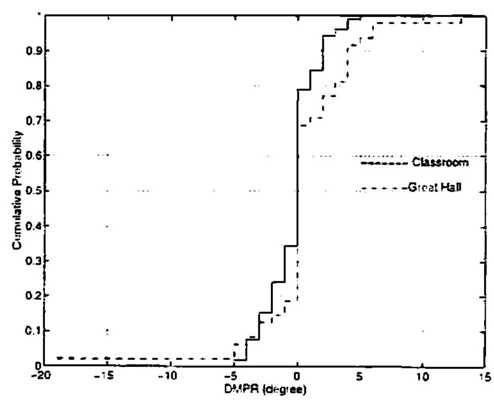

Fig.2: Cumulative distribution of DMPR

Antenna Height	H1 = 1.7m							
Transmitter Location	T1				T2			
Receiver Location	R1		R2		R1		R2	
MUSIC/Ray Tracing	M	R	M	R	M	R	M	R
AOA degrees (AZ. EL)	133. 90	129. 90	0. 90	0. 90	153, 90	148, 90	0. 90	0, 90
	186. 90	184. 90	128. 90	124. 90	181, 90	185, 90	145. 90	143. 90
	194, 51	194. 53	180. 55	180. 52	187. 69	187, 69	180. 70	180. 69
	194. 90	194. 90	180. 90	180. 90	185, 90	187, 90	180. 90	180. 90
	194. 120	194. 124	180. 125	180. 124	187. 109	187. 109	180. 110	180, 109
	237. 90	240. 90	236. 90	236. 90	222. 90	221, 90	216. 90	217. 90
	349. 90	353. 90			355, 90	355, 90		
Antenna Height	H2 = 2.7m							
Transmitter Location	T1				T2			
Receiver Location	R1		R2		R1		R2	
MUSIC/Ray Tracing	M	R	M	R	M	R	M	R
AOA degrees (AZ. EL)	130. 81	129. 83	0. 81	0. 84	152. 84	148. 85	0. 84	0. 86
	186. 90	184. 87	125. 81	124. 84	181. 84	185. 86	145. 82	143. 85
	193. 60	194. 61	180. 60	180. 60	189. 73	187. 74	180. 72	180. 74
	193. 76	194. 79	180. 75	180. 77	189. 84	187. 84	180. 82	180. 84
	193. 130	194. 131	180. 133	180. 131	189. 116	187. 114	180. 116	180. 114
	237. 83	240. 84	236. 82	236. 84	217. 83	221. 86	212. 82	217. 85
	348. 83	353. 84			351. 85	355. 86		

Table I: AOA in the classroom

Antenna Height	H1 = 1.7m							
Transmitter Location	T1				T2			
Receiver Location	R1		R2		R1		R2	
MUSIC/Ray Tracing	M	R	M	R	M	R	M	R
AOA degrees (AZ. EL)	137. 90	132. 90	0. 90	0. 90	199. 90	199. 90	180. 90	180. 90
	212. 90	212. 90	126. 90	120. 90	199. 101	199. 98	180. 112	180. 99
	212. 107	212. 103	180. 90	180. 90				
	332. 90	337. 90	180. 107	180. 105				
Antenna Height	H2 = 2.7m							
Transmitter Location	T1				T2			
Receiver Location	R1		R2		R1		R2	
MUSIC/Ray Tracing	M	R	M	R	M	R	M	R
AOA degrees (AZ. EL)	136. 84	132. 87	0. 83	0. 87	199. 90	199. 88	180. 90	180. 87
	211. 110	212. 106	126. 90	120. 88	199. 104	199. 100	181. 105	180. 101
	212. 85	212. 86	180. 82	180. 85				
	332. 85	337. 87	180. 90	180. 109				

Table II: AOA in the Great Hall