Comparisons of Ray Tracing Predictions and Field Trial Results for Broadband Fixed Wireless Access Scenarios.

G.E. ATHANASIADOU*, I.J. WASSELL+

*University of Peloponnese, Department of Telecommunications Science & Technology, Terma Karaiskaki, Tripoli 22100, GREECE

+University of Cambridge, Laboratory for Communication Engineering, Dept. of Engineering, William Gates Building, 15 JJ Thomson Ave., Cambridge, CB3 0FD, UNITED KINGDOM

Abstract: In this paper, results from a three-dimensional (3D) ray-tracing propagation model are compared with field trial measurements. The ray tracing algorithm is optimised for Broadband Fixed Wireless Access (BFWA) operational scenarios. The model works with raster terrain as well as 3D vector building and foliage databases. It considers reflections off building walls, off-axis diffractions on roof tops, terrain and tree tops, as well as foliage attenuation. Outputs include the received power and the impulse response of the wireless channel. The field trial measurements carried out for different scenarios (propagation conditions, antenna heights, distance from the access point, etc.) in the city of Cambridge (UK) with a commercial BFWA operating system (3.5 GHz). The analysis studies the propagation characteristics of the BFWA radio channel and the accuracy of the presented deterministic propagation modelling approach, and it shows that the simulated results follow the measured with a mean error of 2.8 dB and a standard deviation of 6.7 dB.

Key-words: Propagation modeling, Ray-tracing, Power Measurements, Broadband Fixed Wireless Access.

I. Introduction

Fixed Wireless Access (FWA) systems have the potential to provide widespread high performance broadband wireless access and are of particular interest in regions not covered by cabled broadband. FWA spectrum at 3.5 GHz represents a useful compromise between the superior range associated with the use of lower frequency bands and the wide bandwidths available at higher frequencies.

In the last few years a combination of the alignment of international spectrum allocations in these bands and the availability of a new generation of high performance FWA equipment has created significant opportunities for the provision of broadband services with extensive geographical coverage. In developing countries FWA can provide an immediately available alternative to cabled networking, while in developed countries it holds the possibility of providing broadband services in rural locations.

Radio spectrum is a scarce and valuable resource which must be used as efficiently as possible in order to deliver widespread wealth-creating services. This research project [1] has sought to investigate the wireless channel and hence the factors which govern how a FWA system can be optimally configured and operated in order to maximise its efficient use of bandwidth.

Ray-tracing techniques have been used extensively for the modelling of the propagation characteristics in small cells [2], [3] and/or in conjunction with large cell models which operate with raster databases [4]. In microcellular environments the dominant propagation mechanisms are reflection and corner diffraction. Ray-tracing models suitable for medium sized cells [5] still only support roof diffractions after the reflection points. In this model, emphasis is given to off-axis diffractions on roof tops, terrain [6] and also, tree tops. These diffractions are fully supported both before and after reflections, since this is the dominant propagation mechanism in the situation where antennas are positioned on building tops or high on the outside walls.

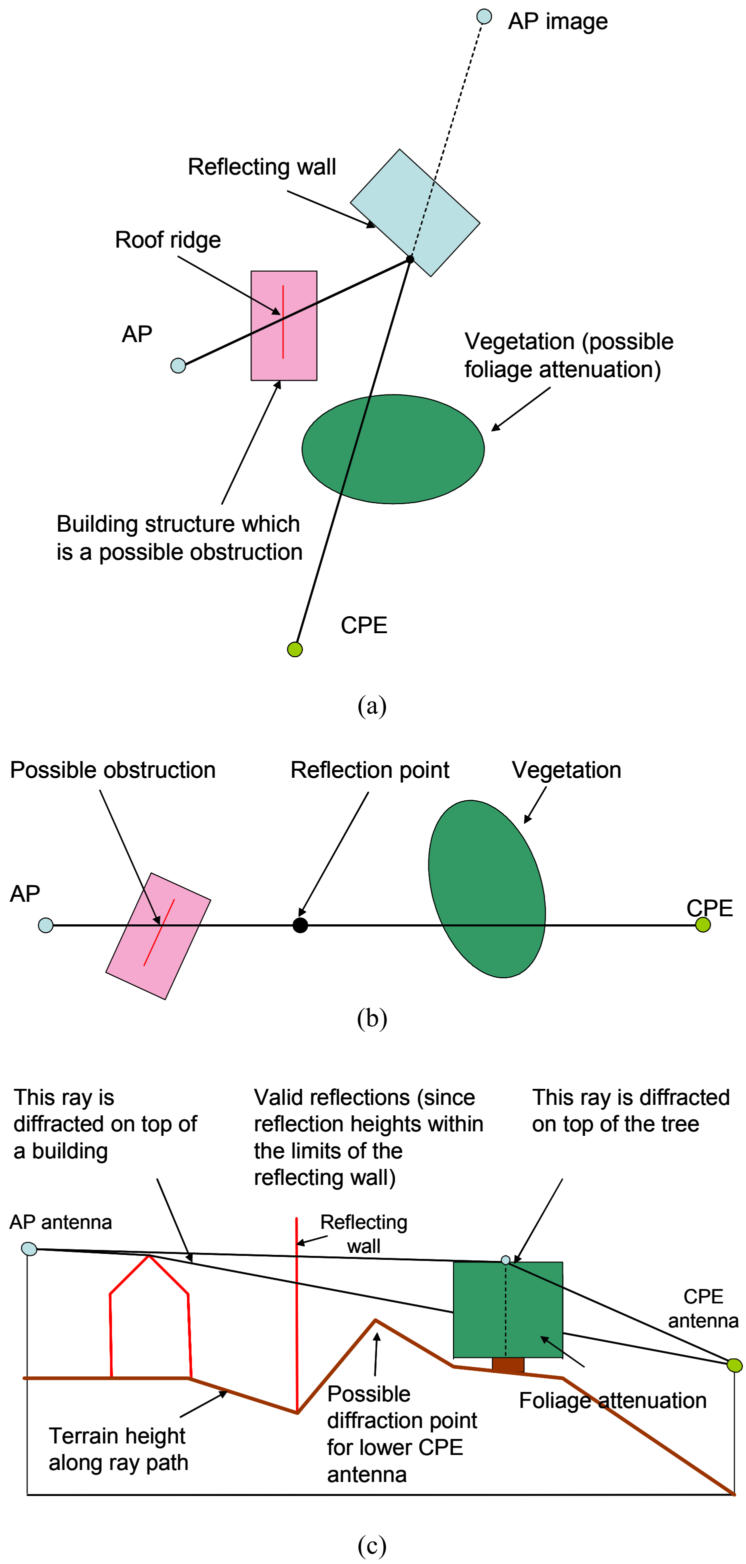


Figure 1: The ray tracer: (a) The image map of the AP is generated for all possible reflectors despite possible building/terrain/vegetation obstructions. (b), (c) When an image is illuminating the examined CPE, the vertical profile along the path is produced. The reflected paths are valid if the height of the reflection point is within the limits of the reflecting wall.

A three-dimensional (3D) ray-tracing propagation model has been developed. The algorithm is optimised for Fixed Wireless Access (FWA) operational scenarios, i.e. the Access Point (AP) antenna is well above the height of the building clutter and the Customer Premises Equipment (CPE) antenna is at roof top height. The model works with raster terrain as well as 3D vector building and foliage databases. It considers reflections off building walls and off-axis diffractions from roof tops and terrain, while it traces the rays that are diffracted on top of the trees, as well as those that pass through foliage. Outputs include the received power and the impulse response of the wireless channel and as such the tool permits a detailed and realistic assessment of the performance of a broadband system, including network planning and deployment issues.

Results from field trial measurements carried out in the City of Cambridge using the Cambridge Broadband Ltd network equipment are compared with simulation results produced with the ray-tracing propagation model. The field trials were carried out under the project 'A Study on the Efficient Dimensioning of Broadband Wireless Access Networks', which was funded by the Office Communication, UK [1].

II. Description of the Ray-Tracing Algorithm

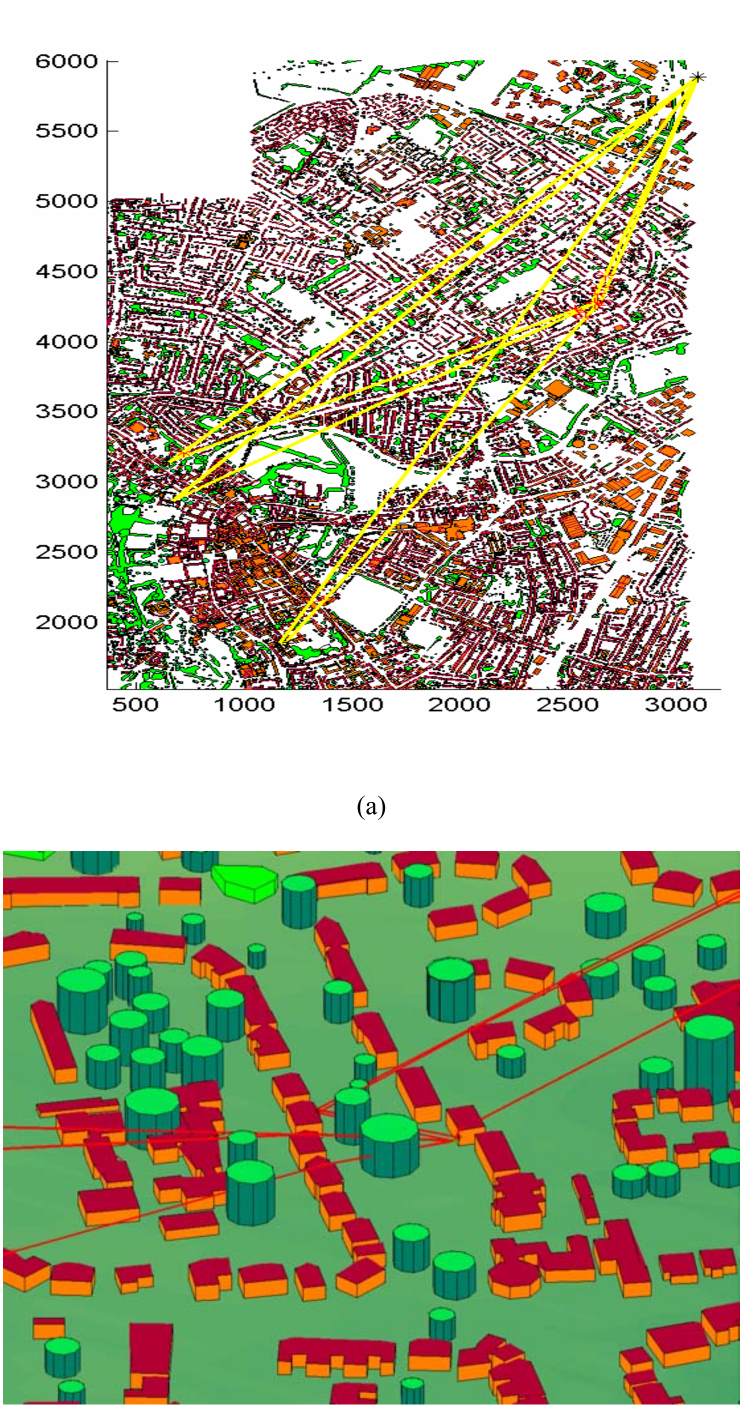
The ray-tracing algorithm is written in the C++ programming language, while MATLAB code is used to drive the model and also display the output results. The main steps of the program are:

Loading and processing of the building, foliage and terrain databases

A database containing all terrain, foliage and building data are stored as a file in .DXF format. The first time the tool reads the DXF file it extracts all useful information and extensive pre-processing takes place so that the model can use the data in an efficient way. Consequently, the map is divided in sub-areas, and all buildings and trees in each sub-area are classified by their map position to permit fast access. The terrain is processed as 10 m by 10 m tiles rather than points, and the representative vectors (i.e., a vertical vector in the middle of each tile) are saved. This enhances the speed of the calculation of the terrain points along a particular path.

Creation of the AP image map

For a given AP position, the image tree is created, i.e., the mirror images of the AP with respect to the building walls. In a similar way, the AP images are used to create their own images, which will eventually yield paths owing to second and higher orders of reflection. During this process the heights of the reflection walls and the AP are taken into account, as well as the actual position, orientation and size of each wall in order that only images that can generate feasible reflections are considered, and hence limit significantly the size of the image tree. Also, the reflections from the inner side of the walls are not considered. The



(a)

(b)

Figure 2: 2D, (a) and 3D, (b) ray tracing visualisation

obstructions from other buildings or terrain result in rooftop and terrain diffractions.

Path tracing

After the image tree of the AP is created (or loaded from a previous study), the path tracing can begin. For each CPE position, the heights of the terrain points along the path from the AP to the CPE antenna are calculated. All buildings and trees in the database along this path are also found, and the x-y coordinates and the heights of the exact points of intersection are evaluated (Figure 1). Hence the vertical profile along the path is generated; this is used to find whether there is a LOS path between the two antennas, or in the case of obstructions, the exact coordinates of the diffraction points on buildings, terrain and/or trees. Rays that pass through foliage, as well as those diffracted on top of the trees are considered. The points that the ray path intersects with foliage, and from that, the path length inside foliage, are also calculated.

After the direct rays, the reflected rays are traced. The algorithm goes through the image tree to find those AP images that illuminate the specific CPE antenna under consideration. Each such image is examined in order to determine whether it can produce valid paths. First, the reflection points are found and then, the vertical profile along the whole path is generated, i.e., the terrain, building and foliage points along this ray path. From the vertical profile, the algorithm calculates the exact points of diffractions and the heights of the reflections (Figure 2). As with the direct ray, both the rays that pass through foliage, and those diffracted on top of the trees are considered.

Field calculations

When the exact geometry of a ray is found, the calculation of its field strength starts. The angles of arrival (azimuth and elevation) at the AP and CPE antennas are calculated and the respective antenna gains are considered during the field calculations. From the analysis for the direct ray, the orientation of the CPE antenna is determined, so that the CPE antenna is pointing towards the serving AP (the direction of maximum power in the vast majority of cases). The model computes the diffraction and reflection coefficients along each path as a function of the incident and departing angles, using Uniform Theory of Diffraction and Geometrical Optics. The algorithm performs full calculation of the vector electromagnetic field and the depolarization of the power is taken into account. Hence, both linear and circular polarization can be modelled, as well as the reception between antennas with different polarization. The foliage attenuation as a function of the path length inside vegetation is also considered. The foliage attenuation models incorporated are the ones recommended by COST-235 [7] for the cases of trees in and out of leaf, as well as models which suggest that the foliage attenuation is directly proportional to the path length in trees [8].

Channel characterisation

When the algorithm has gone through all the images in the image tree, found the valid paths for the specific CPE antenna position, and computed their power and time delay, it then has the complete power delay profile of the radio channel. From that it calculates the total received power, RMS delay spread, mean and excess delay, and the K-factor. In order to avoid misleading results from relatively weak but long delayed rays, all delay parameters are calculated within a 30 dB power window relative to the strongest ray.

COMPARISON OF PRELIMINARY MEASURED AND SIMULATED RESULTS

Set-up of measurement campaign [1]*:*

- *Access Point position:* *On top of tall buildings and hills (as marked in Figure 3)*
- *Access Point Antenna:* *4x1 patch antenna, 90^o horizontal beamwidth*
- *AP antenna directivity:* *16 dBi*
- *CPE Antenna:* *3x3 patch antenna pointing towards the AP, 23^o horizontal beamwidth*
- *CPE antenna directivity:* *13 dBi*
- *CPE antenna:* *on a telescopic mast on top of a van, pointing towards the APantenna*
- *Polarisation:* *Right Hand Circular*
- *Transmitted Power:* *29 dBm*
- *Losses:* *3 dB*
- *Frequency:* *3.5 GHz*

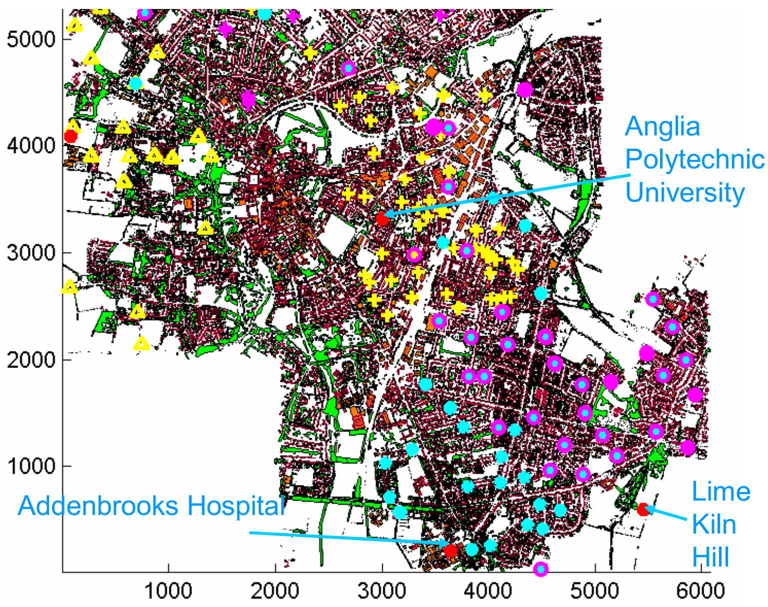


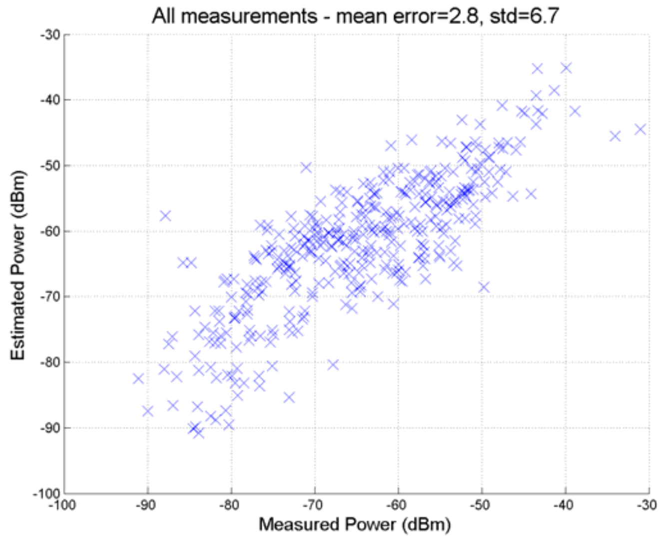
Figure 3: APs and measurement positions.

Measurements outside or at the edge of the simulated building database were not considered. Simulation results were averaged over five positions (the GPS location and four positions, 2m away and at the same height). Also, a threshold equal to the measurement noise floor (-98dBm) was employed for the simulated power results.

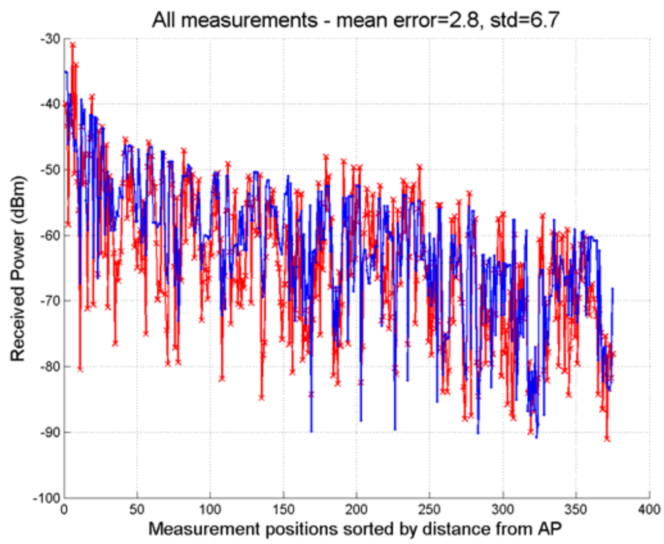
The digital geographical database of the simulated area included ~180000 building vectors and 160000 vegetation vectors for a total area of 31 km^2. Rays with up to two reflections and unlimited roof diffractions were considered for the simulation analysis. Also, the foliage attenuation was calculated with the COST model for vegetation in leaf.

Results:

A total of 375 measurements were considered at the CPE positions shown in Figure 3 at a number of different antenna heights.



(a)



(b)

Figure 4: (a) Measured vs. simulated power results. (b) Field trial (red line with x) and ray-tracing results (blue line with dots) as a function of distance from AP.

Figure 4 (a) shows the measured versus the simulated power results for the various CPE positions and (b) shows both of these results as a function of distance from the AP. The simulated results follow the trend of the measured. The calculated mean error and standard deviation are 2.8 dB and 6.7 dB, respectively. The field trial results show a higher variance due to the limited spatial averaging. Unlike measurements for mobile communications where results are usually averaged over distances of many wavelengths [2], for these measurements the antenna is positioned on a telescopic mast on top of a van which cannot be moved during the measurement procedure. Hence, the measured results are only time averaged. This confined averaging is a limiting factor in order to achieve better agreement between the measured and simulated results.

CONCLUSIONS- FUTURE WORK

In this paper, results from a 3D ray-tracing propagation model for Broadband Fixed Wireless Access systems were compared with field trial measurements. The measurements carried out for different scenarios (propagation conditions, antenna heights, distance from the access point, etc.) in the city of Cambridge (UK) with a commercial BFWA operating system at 3.5GHz. The analysis showed that the simulated results followed the measured with a mean error of 2.8 dB and a standard deviation of 6.7 dB. In the longer term, the ray-trace approach will permit realistic assessment of system performance, network planning and deployment issues.

ACKNOWLEDGEMENTS

The field trials were funded by the Office Communication, UK [1]. Georgia Athanasiadou would like to thank Dr Malcolm Sellars from Cambridge Broadband Ltd for his valuable help and support throughout this project.

REFERENCES

[1] ‘A Study on the Efficient Dimensioning of Broadband Wireless Access Networks’, Cotares Ltd., Cambridge University Engineering Dept., Cambridge Broadband Ltd, Ofcom Ref: AY4463, http://www.ofcom.org.uk/research/industry_market_research/technology_research/ses/ses2003-04/ay4463a/

[2] G.E.Athanasiadou, A.R.Nix, J.P.McGeehan, ‘A Microcellular Ray-Tracing Propagation Model and Evaluation of its Narrowband and Wideband Predictions’, *IEEE Journal on Selected Areas in Communications,* Wireless Communications series, vol 18, no 3, pp. 322-335, March 2000.

[3] G.E.Athanasiadou, A.R.Nix, ‘A novel 3D Indoor Ray-Tracing Propagation Model: The Path Generator and Evaluation of Narrowband and Wideband Predictions’, *IEEE Transactions on Vehicular Technology*, vol. 49, No 4, July 2000, pp. 1152-1168.

[4] G.E.Athanasiadou, E.K.Tameh, A.R.Nix, ‘Channel Impulse Three-dimensional Rural-Urban Simulator (CITRUS): An integrated micro-macro ray-based model which employs raster and vector building databases simultaneously’, *IEEE PIMRC ’99,* Osaka, Japan, September 1999.

[5] G.Liang, H.L.Bertoni, ‘A New Approach to 3D Ray Tracing for Propagation Prediction in Cities’, *IEEE Trans. Antennas and Propagation*, vol.AP-46, pp. 853-863, 1998.

[6] G.E.Athanasiadou, I.J. Wassell, C.L. Hong, ‘Deterministic propagation modelling and measurements for the broadband fixed wireless access channel’ *IEEE VTCF 2004*, Los Angeles, USA, 26-29 September 2004.

[7] COST235, ‘Radiowave Propagation Effects on Next Generation Terrestrial Telecommunications Services’, *Final Report*, 1996.

[8] G.Durgin, T.S.Rappaport, H.Xu, ‘Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85GHz’, *IEEE Transactions on Communications*, vol.46, no 11, November 1998.