On the Use of an Intelligent Ray Launching for Indoor Scenarios

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***Abstract*—Indoor propagation models attract much interest these days because of their importance in the applications of 3G/4G network planning and optimisation. The accuracy and running speed directly affects the practical use of such models. This paper extends a discrete ray launching model IRLA (Intelligent Ray Launching Algorithm) to indoor scenarios. A typical office room will be selected to validate this model. The efficiency and suitability of IRLA for indoor scenarios will be investigated and comparison with two referenced indoor models are given. The comparisons show that the modified IRLA for indoor scenarios obtains high accuracy within a reasonable time scale. It is promising because it is uniquely efficient on computation of rays, which outperforms most of the propagation models.**

I. Introduction

Wireless propagation modelling becomes even more important when dealing with wireless network planning and optimisation process [1] [2]. The modelling of radiowave propagation in indoor environments plays a crucial role in the investigation of 3G/4G network planning applications (such as localisation). Compared to outdoor environments, indoor scenarios usually involves more irregular objects and material types, which makes modelling complex. Many outdoor propagation models such as [3] are accelerated based on the simplification that outdoor buildings are 2.5D polygon with flat roofs. However, as objects in indoor environments can be of any shapes and anywhere such as lamps, indoor models face even a bigger challenge because the effects of such obstacles cannot be ignored in order to obtain an accurate prediction.

Roughly, the indoor propagation models are composed of two kinds: empirical and deterministic. Empirical models refer to the approaches that are mainly based on factors such as distance or frequency. These models are computational fast. Because they do not consider much environmental information, the accuracy of empirical models is limited, which limits their use. For example, on the one hand, the ITU (International Telecommunication Union) Model for Indoor Attenuation [4] is based on a single equation and the path loss prediction is valid only for frequency range from 900 MHz to 5200 MHz and floors from 1 to 3. Similarly, LAM (Linear Attenuation Model) [5] relies on measurement data, on which a linear equation can be built. On the other hand, deterministic approaches mainly account for environmental information such as object materials. These approaches are more time-consuming than empirical models but provide higher accuracy. For example, in [6], the authors propose a accelerated dominant ray-based method for indoor scenarios. Despite many acceleration techniques such as [7], [8] and [9], the use of and accurate propagation modelling for indoor scenario remains limited due to complex indoor propagation environment. Apart from these two categories, some propagation models consider both empirical and deterministic factors, which are categorised as semi-empirical (or semi-deterministic) approaches. For example, MOTIF [10] can be considered as a semi-deterministic approach that includes stochastic factors and deterministic computation. Such models usually perform faster than deterministic approaches such as ray tracing and their accuracy is considerably high in some scenarios. For example, MOTIF is limited in 2-D scenarios.

This paper will extend an outdoor model, IRLA, to indoor scenarios. Acceleration techniques are proposed to make this model suitable in practical wireless applications. Performance via this model will be studied through comparison with two referenced models: MR-FDPF (Multi Resolution Frequency Domain ParFlow) [11] and COST231-Multi Wall [12].

The rest of the paper is organised as follows. First, the outdoor model IRLA [2] [13] will be briefly described. Next the details will be investigated to make this model suitable for indoor scenarios. An indoor measurement campaign will be described, which is used to validate the model. Performance (such as speed, accuracy) will be analysed, in comparison with the results obtained via MR-FDPF and COST231-Multi Wall models. Finally, the future prospectives are described, which concludes this paper.

II. IRLA Model

The discrete ray launching model IRLA [2] is composed of three main components: LOS (Line-of-Sight), VD (Vertical Diffraction) and HRD (Horizontal Reflection and Diffraction) respectively, for outdoor scenarios. LOS is responsible for marking visibility pixels, collecting direct paths from emitter and most importantly the secondary pixels for the use of VD and HRD. Mathematically, reversely, calculating dominant multiple roof-top diffractions by a fast pixel checking principle that draws the shortest edges between the emitter and receivers is achieved by VD. HRD carries the actual 3-D ray launching but rays are abandoned when they hit the roofs due to the fact that there seldom exists dominant rays which are a combination of vertical and horizontal planes. IRLA for outdoor has been tested to show suitability (in the aspects of both speed and accuracy) in use for wireless network planning applications and the inherent principle of IRLA is easily parallelisable. In [13], a parallel implementation of IRLA via POP-C++ (Parallel Object Oriented Programming in C++) has been presented and performance is evaluated.

To apply IRLA in indoor scenarios, modifications have to be made. First the component VD has to be eliminated from indoor IRLA because it is not applicable to calculate vertical diffractions in indoor scenarios. Calculating vertical diffractions is self-contained in indoor HRD. LOS and HRD are kept as two fundamental components with slight modifications. Both components are optimised via a new approach proposed in [14] to solve angular dispersion of ray launching. Multipath are obtained and hence channel characteristic such as PDP (Power Delay Profile) can be simulated. The process of IRLA prediction for indoor scenarios starts with launching rays in all 3-D directions. Based on the discrete data set, the resolution and the number of cubes along each dimension (X, Y and Z) are known. Therefore the number of discrete rays required can be obtained by connecting the emitter to all the cubes at the fringe of the scenarios [14], which is

$$N = 2N_xN_y + 2(N_z - 2)(N_x + N_y - 2)$$

where
N is the number of discrete rays.
N_x, N_y, N_z are the number of cubes in dimension X, Y and Z respectively.

This ensures no pixels are missing due to angular dispersion of ray launching [14] from component LOS. The use of such ray launching mechanism is useful in distribution of rays, e.g. in parallel. The secondary cubes collected in component LOS serve as input to HRD, which iteratively traces discrete rays. Rays disperse as they propagate, which causes coverage gaps. To solve this, an intelligent procedure is proposed in [14], which dynamically accounts for rays that fill the gaps. Material indices are recorded within each cubic entry and applied to discrete rays that are being followed. Based on a few measurement locations, the material values are calibrated once and applied to predictions.

III. Indoor Scenario

A typical office scenario (Figure 1) has been selected as the indoor testbed for the indoor propagation models. It has three rooms and 255 polygons all together. The dimension for this scenario is 16 X 9 X 4 (m3). The emitter is a 3.525GHz signal generator (power 6dBm) with an omni-directional antenna (gain 2.8dBi, EIRP Equivalent Isotropically Radiated Power 8.8dBm). This frequency has been chosen in order to study WiMax (Worldwide Interoperability for Microwave Access) indoor base stations. The emitter is located on the table (1.35 meter height) in the meeting room (see Figure 1) and measurement locations (0.98 meter height) are positioned by the grid pattern on the floor. To avoid as much noise disruption as possible, a measurement campaign is carried when there are few people in the room. To avoid the interference of human bodies when manually triggering the spectrum analyzer, the measurement data of the first few and last few points are removed. Several measurement snapshots are taken to average the final signal strength. The measurement techniques and the removal of human body influence has been detailed in [15].

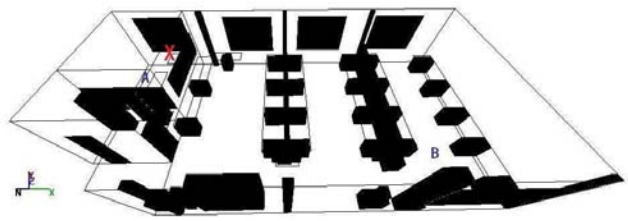

Fig. 1. Indoor office; 'X' represents the emitter; 'A' and 'B' are LOS and N-LOS locations, respectively.

IV. Experiments

To validate the changes made to the IRLA model, the indoor scenario described above is used. This section will introduce the experimental results. Based on the prediction, comparisons can be investigated and recommendations are given.

A. IRLA Validation

First, a 3-D path loss matrix can be obtained by a single run of IRLA. To make it even more efficient, only selected layers (locations) can be considered. Coverage prediction at 1 meter height is plotted in Figure 3. Second, multipath information for selected locations are computed. In this case, around 200 measurement locations gridded by 0.5-meter-square [15] on ground-level 1.5 meter height are chosen (See Figure 4). With this information, channel characteristic can be investigated. However, since IRLA is actively following discrete rays, the requirement for multipath data does not incur extra overhead since this can be easily recorded together with path loss. To improve the accuracy of the model, a calibration of the parameters, based on a simulated annealing approach, has been implemented [2].

A single run using a standard PC (2.5 GHz CPU, 4G RAM) on this scenario takes around 1 minutes for the computation of the 3-D path loss and multipath information. By proper calibration, the prediction results comparing to measurements show an agreement, with the RMSE (Root Mean Square Error) 3.5 dB and the mean error 0.01 dB. It is observed that most predictions are accurate within the ranges of $[-10, +10]$ dB difference. There are few points that prediction tends to be either too optimistic or pessimistic. From Figure 3, the prediction errors can be visualised geographically. It can be seen that most optimistic predictions are distributed within a short distance range from the emitter and receivers (such as

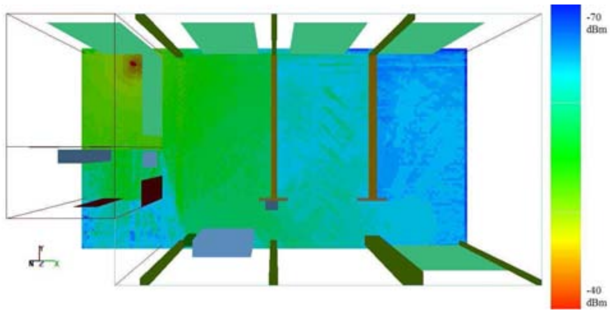

Fig. 2. Coverage prediction via IRLA

the locations near by the refrigerator or behind the door). The pessimistic prediction points are located far from the emitter. This may be used as important evidence to further optimise the model.

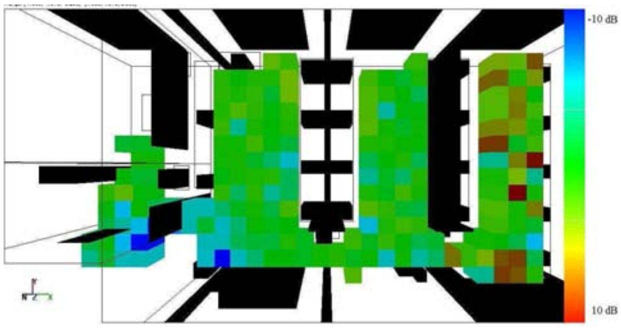

Fig. 3. Prediction errors (dB)

The IRLA model is extremely computational efficient since it is able to compute all possible rays between the the emitter and receivers. For 200 measurement locations, the simulation takes around 3 minutes on a standard PC (T9400, 4GB RAM) to compute the multipaths, which is 942, 424 rays. That is approximately 4, 712 rays per receiver location. In this aspect, IRLA is superior to other propagation models, especially ray-based models due to its unique efficient computation of rays. Standard ray-tracing algorithms suffer from high complexity, which usually limit the ray iterations.

Delay Spread (DS), Power Delay Profile (PDP) and Impulse Response (IR) are important characteristic of channel modelling. To investigate the performance of the IRLA model in indoor scenarios. Rays which have delay smaller than $150ns$ for point 'A' and 'B' are extracted, as displayed in Figures 4 and 5 respectively. It can be seen that apart from the direct ray, many indirect rays which travel in the next room even contribute to the final signals. This may not be computed due to limited ray iterations in standard ray tracing algorithms, which abandon weak rays.

A coverage prediction obtained via the IRLA model can be found in Figure 2. It is observed that the receiver power levels are in the range of -70 to -40 dBm.

Figures 6 and 7 display the omni-directional impulse response for point 'A' and 'B' respectively. Multipaths obtained

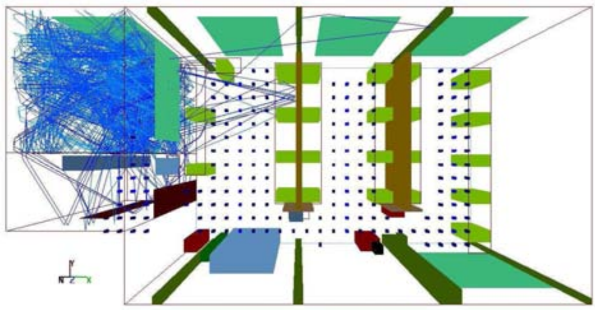

Fig. 4. Rays, point 'A', LOS, delay $<$ 150 ns

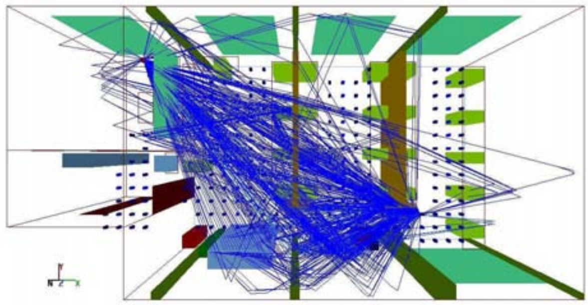

Fig. 5. Rays, point 'B', NLOS, delay $<$ 150 ns

are drawn with the delay and their azimuth angles of arrival. For the LOS case (point 'A'), it can be seen that paths with long delays (which travel in the next room also contribute to the signal strength), although a direct ray is possible. For the NLOS case (point 'B'), a bigger delay is usually observed.

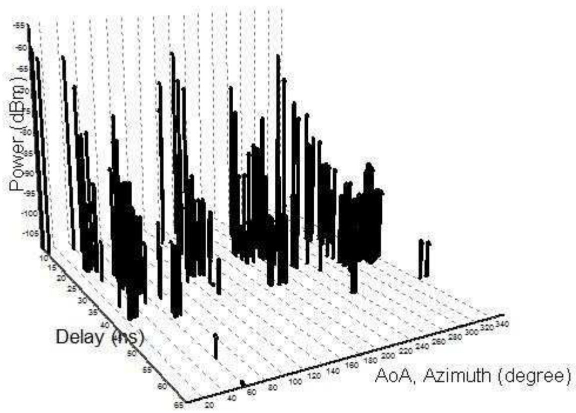

Fig. 6. Omni-directional impulse response (azimuth), point 'A', LOS

B. Reference Tools

To further validate IRLA, two referenced models are implemented and prediction results are obtained.

MR-FDPF [11] is a FDTD-like method but in the frequency domain. MR-FDPF has a lower complexity than FDTD because of its pre-processing and it directly solves the final Maxwell equations without time information. At

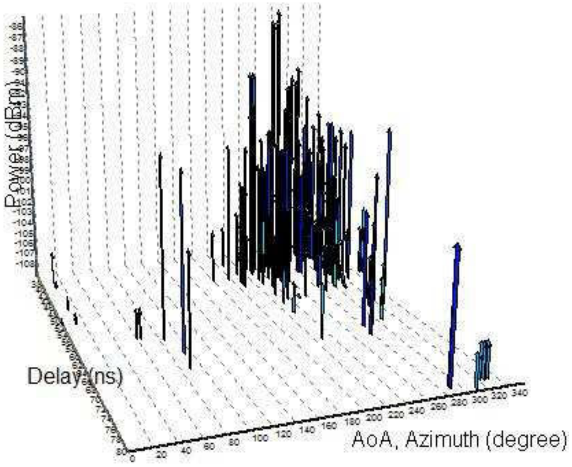

Fig. 7. Omni-directional impulse response (azimuth), point 'B', NLOS

this stage, 2-D MR-FDPF is usually tested due to a much larger computational complexity required when this model is applied in the 3-D cases. In order to use MR-FDPF to predict this indoor scenario, some assumptions have to be made. First a cut on receiver locations from full 3-D data is required. However, a 2-D scenario does not fully reflect the 3-D characteristics by approximation of one cut. For example, a table not blocking rays may be a reflected source, which is difficult to model in 2-D. Fortunately, by calibration, 2-D MR-FDPF can adjust the material properties so that the accuracy can be improved. For example, rays transmitted by a window do not attenuate much but this will be treated as a heavy-thick wall in this 2-D scenario used by MR-FDPF. By calibrating with measurements, this material is adjusted.

COST-231 Multi Wall [12], is an semi-empirical indoor model, which only accounts for the attenuations for walls and floors. Therefore, it does not compute reflection or diffraction rays. The only output from this model is the path loss/power prediction, which is an estimation based on the material properties and the number of transmitted walls/floors. This model is computational efficiency and it does not require pre-processing. The running time of the Multi Wall model is usually less than a few seconds. The prediction errors tend to increase with the number of transmitted walls or floors. e.g. the COST231 Multi Wall model generally produce pessimistic results when the receiver locations are far from the emitter.

C. Comparison and Recommendations

Table I compares the prediction performance obtained via IRLA, MR-FDPF and COST231 Multi Wall model.

It is observed that these models generally give a high agreement (cf. Figure 8) between prediction and measurement. In a full 3-D scenario, at least in this indoor scenario, 2-D MR-FDPF relies heavily on the calibration without which, this model tends to give large prediction errors due to inaccurate modelling of materials. The accuracy before calibration for

TABLE I
PERFORMANCE COMPARISON

	IRLA	MR-FDPF	Multi Wall
RMSE (dB)	3.5	3.5	5.6
Time (s)	< 60	< 5	< 1

MR-FDPF is around 8 dB whilst this is dramatically improved to around 3.5 dB due to calibration of the materials. For example, the emitter is placed on a table and the table should be removed from 2D cut, otherwise it will be treated as an obstacle in MR-FDPF model. On the standard PC (AMD 64+ Dual, 4GB), the preprocessing for MR-FDPF takes around 3 seconds and the computation time is less than 1 second, which is fast in a small 2-D scenario. However, due to its 2-D characteristics, some important ray phenomenal in 3-D are not well captured. For example, MR-FDPF treats the flows in only 2-D, as they only propagate in the 2-D plane. Rays bouncing by reflecting on the ceiling or floor are ignored. The accuracy obtained though MR-FDPF is 3.5 dB RMSE (0 mean error after calibration). The prediction via 2D MR-FDPF is designed for power level/path loss only, which does not compute the delay information.

IRLA for indoor, as presented in this paper, is fully applicable in 3D scenarios where this model is capable of capturing important 3-D dominant rays. Compared to MR-FDPF, IRLA does not require a preprocessing stage. However, since this is a full 3D model, all levels of receiver locations are computed which require longer computation time than 2-D MR-FDPF. The timing for IRLA, at least for this indoor scenario, is still within an acceptable range (less than 3 minutes) where it can be used to fully predict 3-D propagation mechanism such as PDP, DS. The accuracy before calibration via IRLA is around 6 dB by using standard parameters and this can be improved so that a similarly high accuracy can be obtained (3.5 dB RMSE). On the one hand, IRLA does not rely too much on exact materials. On the other hand, this is critical important to ensure a high accuracy for MR-FDPF model.

COST231-Multi Wall model [12], is extremely computational efficient and this model does not require a preprocessing either. In this scenario, this semi-empirical model obtains high accuracy, which is mainly because there are few walls to penetrate. It is easy to calibrate with the losses for each wall and floors. Therefore, an agreement can be observed. However, the performance of this model is limited due to its absence of capturing reflection and diffraction rays. For example, in a corridor where diffractions dominate, COST231-Multi Wall model will fail. The running time for this model is usually less than 1 second and accuracy obtained generally depends on the scenarios.

Based on the comparisons of these three indoor models, the recommendation of their usage can be given. COST231-Multi Wall is efficient and this model is suitable when an estimation of indoor coverage is required on an less complex building structure such as the scenario presented in this paper. MR-FDPF is accurate because it models the most radio wave prop-

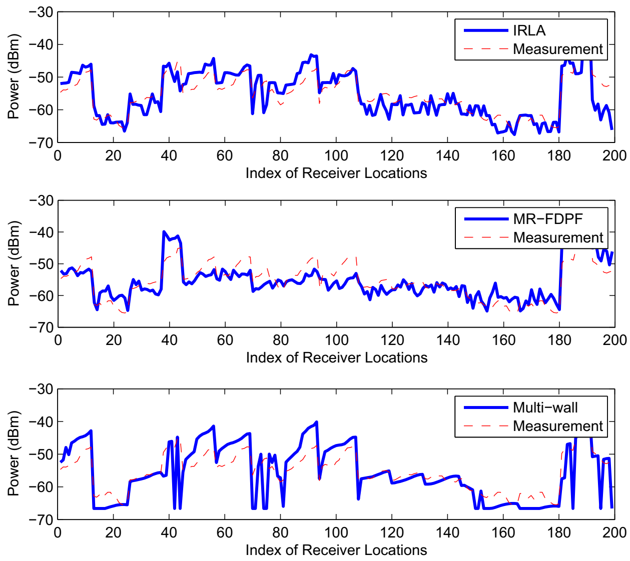

Fig. 8. Accuracy comparison

agation physics (a differential solver of Maxwell equations), its accuracy should be superior. However, as 3-D MR-FDPF is time and memory consuming and still under investigation, the 2-D MR-FDPF is only suitable for indoor structures where most propagation phenomena take place horizontally in the 2-D plane. This model is not suitable in multi-floor propagation simulation where a 3-D model is required. However, 2-D MR-FDPF is capable of obtaining a high accuracy on a floor after the calibration from measurements to correctly model the material properties. 3-D IRLA does not rely on calibration and it is useful in prediction for multi-floor indoor structures or complex, large indoor areas. If there are no measurements, IRLA is preferred because it can be used to find coverage gaps which may not be practically-feasible for 2D MR-FDPF and COST231 Multi Wall model.

V. Conclusion and Perspectives

This paper describes an extended ray launching model, IRLA, which is originally designed for outdoor scenario. A full indoor scenario (a typical UK office) is chosen to validate the performance of this model. Comparisons with two referenced models are investigated and recommendation of their usages are investigated.

Compared to other models, the advantages of the IRLA model are:

- It offers an accuracy similar to existing deterministic tools.
- The full 3D rays/prediction matrix are computed.
- It does not require preprocessing.
- It is fast compared to standard ray tracing methods.

Much work is still being undertaken in optimising IRLA for indoor scenarios. For example, further work includes the investigation of prediction errors in NLOS cases for some locations. It is also useful in validating the delay spread prediction via IRLA through measurements.

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References

[1] Y. Corre and Y. Lostanlen. Three-dimensional urban EM wave propagation model for radio network planning and optimization over large areas. *IEEE Transactions on Vehicular Technology*, 58, September 2009.

[2] Z. Lai, N. Bessis, G. De La Roche, H. Song, J. Zhang, and G. Clapworthy. An intelligent ray launching for urban propagation prediction. In *The Third European Conference On Antennas and Propagation*, pages 2867–2871, Berlin, Germany, March 2009.

[3] R. Mathar, M. Reyer, and M. Schmeink. A cube oriented ray launching algorithm for 3D urban field strength prediction. In *The IEEE International Conference on Communications ICC 2007*, Glasgow, UK, June 2007.

[4] ITU Recommendations. Propagation data and prediction methods for the planning of indoor radio communication systems and the radio local area networks in the frequency range 900 MHz to 100 GHz, 2001. ITU Recommendations.

[5] J.S. Seybold. *Introduction to RF propagation*. John Wiley & Sons Ltd, 2000.

[6] G. Wolfle, R. Wahl, P. Wertz, P. Wildbolz, and F. Landstorfer. Dominant path prediction model for indoor scenarios. In *German Microwave Conference (GeMIC)*, Germany, 2005.

[7] G. Wolfle, B.E. Gschwendtner, and F.M. Landstorfer. Intelligent ray tracing - a new approach for the field strength prediction in microcells. In *IEEE Vehicular Technology Conference*, pages 790–794, May 2007.

[8] V. Degli-Esposti, F. Fuschini, E. Vitucci, and G. Falciasecca. Speed-up techniques for ray tracing field prediction models. *IEEE Transactions on Antennas and Propagation*, 57:1469–1480, May 2009.

[9] P.N. Zakharov, R. Dudov, E.V. Mikhailov, A. Korolev, and A. Sukhorukov. Finite integration technique capabilities for indoor propagation prediction. In *2009 Loughborough Antennas & Propagation Conference*, Burleigh Court Conference Centre, Loughborough University, United Kingdom, November 2009.

[10] M. Klepal. *Novel Approach To Indoor Electromagnetic Wave Propagation Modeling*. PhD thesis, Czech Technical University In Prague, 2003.

[11] G. De La Roche, J. Gorce, and J. Zhang. Optimized implementation of the 3D MR-FDPF method for indoor radio propagation predictions. In *The Third European Conference On Antennas and Propagation*, Berlin, Germany, March 2009.

[12] European Cooperation in the Field of Scientific and Technical Research. Digital mobile radio towards future generation systems, COST231 final report. http://www.lx.it.pt/cost231/.

[13] Z. Lai, N. Bessis, P. Kuonen, G. De La Roche, J. Zhang, and G. Clapworthy. A performance evaluation of a grid-enabled object-oriented parallel outdoor ray launching for wireless network coverage prediction. In *The Fifth International Conference On Wireless and Mobile Communications*, pages 38–43, Cannes/La Bocca, French Riviera, France, August 2009.

[14] Z. Lai, N. Bessis, G. De La Roche, P. Kuonen, J. Zhang, and G. Clapworthy. A new approach to solve angular dispersion of discrete ray launching for urban scenarios. In *2009 Loughborough Antennas & Propagation Conference*, pages 133–136, Burleigh Court Conference Centre, Loughborough University, United Kingdom, November 2009.

[15] Z. Lai, N. Bessis, G. De La Roche, P. Kuonen, J. Zhang, and G. Clapworthy. The characterisation and human-body influence on indoor 3.525 GHz path loss measurement. In *Second International Workshop on Planning and Optimization of Wireless Communication Networks*, Sydney, Australia, April 2010.