Joint Ray Launching Method for Indoor to Outdoor Propagation Prediction Based on Ray Aggregation

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***Abstract*—A joint indoor to outdoor ray launching algorithm is proposed in this paper. Different resolutions are considered for indoor and outdoor simulations. Instead of using conventional sampling technique to extract rays from a finer resolution, a novel method, named Ray Aggregation, is applied to minimise the loss of accuracy while benefiting from the computational cost of a coarse resolution. Furthermore, this model will be demonstrated with two simulations based on the general 2.4 GHz 802.11n wireless local area network. Finally, the corresponding measurements will be presented to verify the accuracy of the proposed model.**

***Index Terms*—propagation, indoor to outdoor, coverage prediction**

I. INTRODUCTION

The growing demand for cellular data service is driving the small cell deployment in urban areas. The outdoor coverage of a public accessible femtocell that is installed indoors, needs to be evaluated by an accurate and efficient method. In this case, the indoor and outdoor simulations should be carried out under different resolutions e.g. 0.2m for indoor and 2m for outdoor.

The conventional sampling technique suffers from the linear loss according to the rate of sampling. However, the loss may not just be linear in the case of extracting rays from a finer resolution and re-launching in a coarse resolution, since the precision of ray launching method degrades while reducing the number of rays that are launched in a simulation.

The intelligent ray launching algorithm has demonstrated its ability of predicting the coverage in outdoor urban [1] and indoor office scenarios [2]. In [3], a hybrid indoor to outdoor propagation model is produced by combining the 3D Ray Launching algorithm for outdoor and the 2D Finite-Difference Time-Domain model for indoor. However, the hybrid model adopts a uniform resolution from indoor scenario and requires extra calculation [4] to compensate the vertical effect from emitter elevation. In this paper, a full 3D joint indoor to outdoor ray launching algorithm with mixed resolutions is presented.

II. SCENE MODELLING

A. Building Structure

First of all, the indoor and outdoor building models should be provided with certain level of detail. The indoor building structure needs to be properly modelled for each floor. The internal walls and external openings [5] (e.g. windows) are essential in predicting the outdoor coverage of an emitter that is placed indoors.

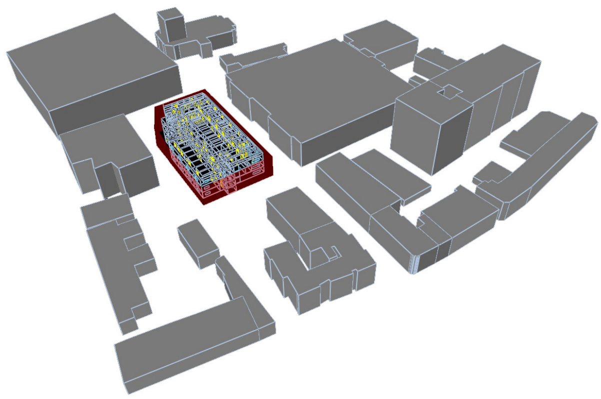


Fig. 1: Building Modelling

TABLE I: Scenario Size and Material in Use

	Indoor	Outdoor
Size	55×27×12 m	220×205×30 m
Material	Double Glazing Glass Plaster Board Medium Wood (Door)	Concrete Heavy

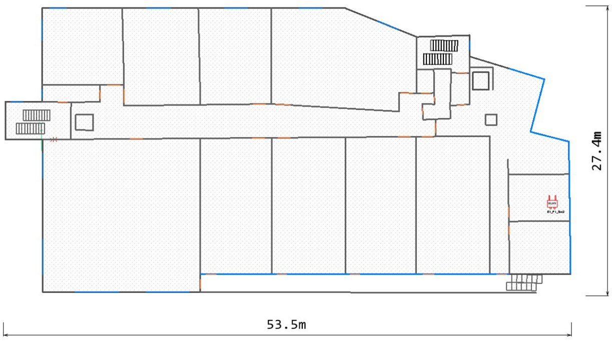
However, the outdoor neighbour buildings, in the given example, are obtained from the coarse Open Street Map (OSM) that are considered as 2.5D building model. Each of the outdoor buildings is modelled by a polygon and a height, which in most cases provide sufficient information for outdoor simulations if the material attenuation is well calibrated as to be discussed in Section V-B.

A 3D seamless indoor and outdoor building model is visualised in OpenGL as shown in Fig. 1.

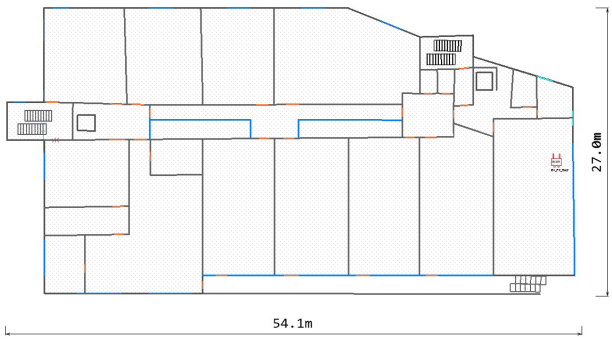
B. Material Modelling

The attenuation of building components is one of the major factors for the ray launching algorithm [1] to calculate the path loss of a ray that propagates away from the source location. Specifically, three kinds of attenuation are required by the ray launching algorithm including transmission (penetration), reflection and diffraction losses. Therefore, each of the building planes (e.g. walls and windows) needs to be assigned with a material that contains the above attenuations.

In the given indoor structure, the windows, doors and internal walls are set as double glazing glass, wood medium



(a) Ground floor 1.5m



(b) First floor 4.5m

Fig. 2: Indoor Building Model and Emitter Locations

TABLE II: Emitter Parameters

Deivce Model	TL-WR841N
Frequency	2.4 GHz
TX Power	< 20 dBm
Antenna Type	Omni-directional
TX Gain	5 dBi

and plaster board medium respectively. Each of the outdoor building planes is set as concrete heavy that has greater attenuation than the indoor internal walls. All the involved material types and the dimensions of scenarios have been summarised in Table I.

C. Equipment

The proposed joint indoor to outdoor ray launching algorithm is demonstrated by two experiments, both of which are implemented on the general 2.4 GHz 802.11n wireless local area network. Based on the official description, the wireless router TL-WR841N has dual omni-directional antennas with transmitting powers of less than 20 dBm and gains of 5 dBi (Table II). In addition, the two experiments have their emitters located at different elevations, 1.5m and 4.5m above the ground respectively as shown in Fig. 2a and 2b. Furthermore, as shown in Fig. 6a the emitter was placed at the north of the building in order to simulate a practical case that was to cover the resting area around the church (top right in the Fig. 6a).

III. Propagation and Ray Aggregation

The configuration of the ray launching algorithm is set to allow maximal 7 transmissions, 7 reflections and 4 diffractions. In addition, a path loss threshold of 175 dB prevents unnecessary calculation from rays that have no contribution to the coverage prediction.

The ray propagation is initiated indoors from the source location with a resolution of 20cm per cube. Afterwards, the rays emitting from the building are collected outdoors. In the given case, the semi-transparent red boundary (Fig. 1) indicates the surface where the emitted rays should be collected. If the rays across different floors are not within consideration due to the high cross-floor attenuation (usually over 30 dB [6]), then the collection surface may be cut down to cover the floor where the emitter is placed.

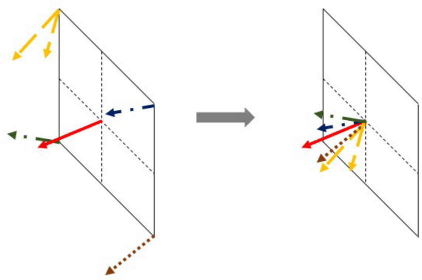


Fig. 3: Ray Aggregation

In order to launch the simulation outdoors at a sparser resolution while minimising the loss of accuracy, the rays from indoor simulation are aggregated instead of being sampled. As illustrated in Fig. 3, the surrounding rays are geometrically gathered at the location of the central ray other than being discarded. It should be noted that properties of each ray differ from each other, especially the heading direction, and there may be more than one ray (e.g. the yellow dashed rays in Fig. 3) at each node of the collection surface.

IV. Measurements

To verify the proposed model, one pair of measurements per experiment has been carried out inside and surrounding the Innovation Centre in Sheffield, UK. The 2.4 GHz transmitter for both experiments is described in Section II-C and its specification is summarised in Table II. In addition, the receiver being used to measure the received signal strength (RSSI) is the Dell® Wireless 1537 802.11n WiFi adapter with the iBuildNet® software.

The 4 measurements that are presented in this paper include the two at different floor elevations inside the building (Fig. 4a, 4b) and the two at the ground level around the building (Fig. 6a, 6a). In order to obtain a reliable RSSI at each measurement location, only the average of 5 samples was recorded with a sampling interval of 500 ms.

In terms of locations, the indoor measurements were taken placed along the main corridor that spans over the entire floor as shown in Fig. 4a and 4b. Moreover, the outdoor measurements were collected around the building from north to south and across all nearby streets. It should be noted that attempts were made to collect the RSSIs outside the south of the building, however, the sensitivity of the WiFi receiver (-90 dBm) limits the collection and invalidates the comparison beyond -90 dBm.

V. Results

A. Computational Cost

The two demonstrations are simulated on a PC with Intel® Core i5-3570K CPU and 8 GB RAM. The proposed joint ray launching algorithm takes an average of 1.5 minutes for indoor and around 5 minutes for outdoor. It is worth to mention that the ray aggregation is implemented during outdoor simulation, therefore the outdoor coverage prediction takes longer than usual. The results of the two coverage predictions are presented by their 2D horizontal cuts as shown in Fig. 4a, 4b for indoor and 6a, 6b for outdoor.

In comparison, the out of memory exception is thrown while attempting to predict the outdoor coverage at a resolution of 20 centimetres. Specifically, the preprocessing stage ceased when the memory consumption reached 4 Gigabytes with large memory support enabled, which may be explained by the performance comparison between different resolutions of the ray launching algorithm [8].

Furthermore, compared with the additional calculation [4] for the hybrid indoor to outdoor model [3], the height of emitter is also naturally taken into account due to the three dimensional rays from indoor simulations.

B. Calibration and Accuracy

The material calibration may be essential for deterministic models to carry out a realistic simulation [7]. The accuracy of ray optical methods varies with the precision of building structure, but it is more affected when the electrical properties of involved material are not sufficiently accurate. To overcome this, tabulated values are commonly adopted to compensate for accuracy. However, as indoor environments are usually so complex that sometimes an object is composed of several different unknown materials [7], properties of which may not be measured practically.

The ray launching algorithm in this paper uses the well known meta-heuristic approach, Simulated Annealing (SA), to calibrate the material properties for both the indoor and outdoor objects. The cost function of the optimisation is the Root Mean Square Error (RMSE) between the measured and simulated RSSIs.

After the calibrations with a total of 59 and 70 points for Experiment 1 and 2, the indoor/outdoor RMSEs reached 5.62/5.00 dB and 4.82/4.59 dB respectively. All the relevant data have been summarised in Table III. Moreover, the indoor and outdoor comparisons between measurements and simulations for each experiment are plotted respectively in Fig. 5a, 7a and Fig. 5b, 7b. By observing the RMSEs and their comparison plots, the outdoor simulations seem to be more accurate than indoor ones. It is therefore worth to mention that the indoor and outdoor material calibrations are independent of each other. Specifically, the indoor measurements are used to calibrate the properties of Double Glazing Glass, Plaster Board Medium and Wood Medium while the outdoor measurements are responsible for adjusting the Concrete Heavy only. Otherwise, bias may be yielded due to the fact that only one of the building in the outdoor scale has its complex internal structure presented in the calibration.

TABLE III: Summary of the RMSE and ME

Experiment 1		
Emitter Height	1.5m (Ground Floor)	
Scenario	Indoor	Outdoor
Resolution	20 cm	2 m
Num. Points	18	41
RMSE/ME	5.62 / -0.20 dB	5.00 / 0.26 dB

Experiment 2		
Emitter Height	4.5m (First Floor)	
Scenario	Indoor	Outdoor
Resolution	20 cm	2 m
Num. Points	27	43
RMSE / ME	4.82 / 0.47 dB	4.59 / -0.41 dB

VI. Conclusions and Perspectives

This paper proposed a 3D joint indoor to outdoor ray launching algorithm. The proposed model is described with two simulations that demonstrate its advantages of the low computational cost and the three dimensional simulation. Furthermore, two pairs of measurements have been presented and the accuracy of the model has been verified. In future, we would like to propose a simple model with a mechanism that allows multiple indoor to outdoor and outdoor to indoor transitions. For example, an outdoor to indoor simulation will be carried out based on the rays collected in any of the above simulations, which will assist to improve the indoor coverage prediction by the reflections and diffractions from nearby buildings, or to predict the interference being posed to surrounding buildings. Furthermore, we would like to verify other outputs such as delay spread and phase information for the proposed model.

Acknowledgement

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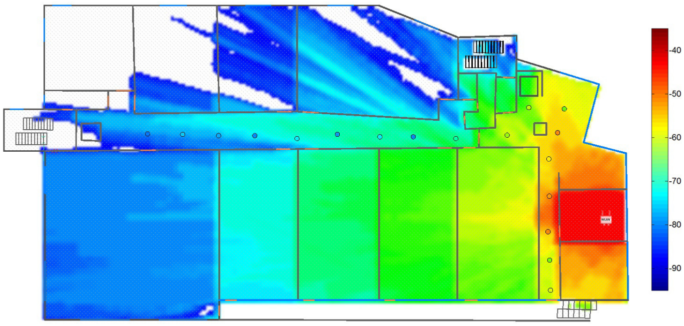
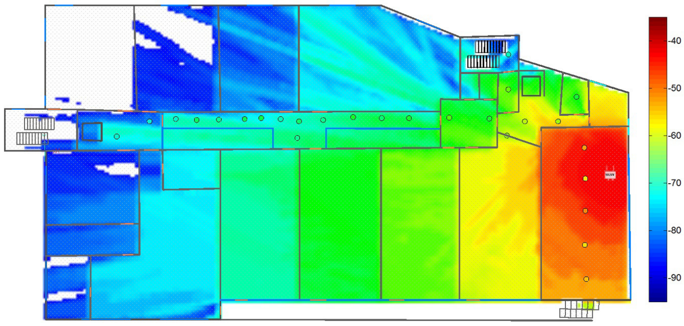
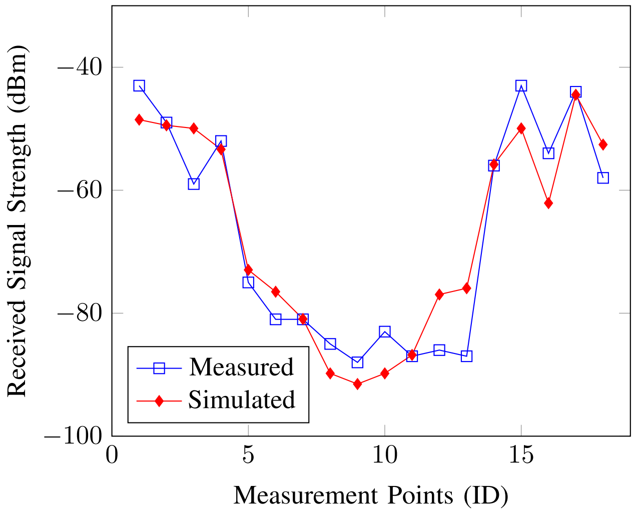


(a) Ground Floor (1.5m)

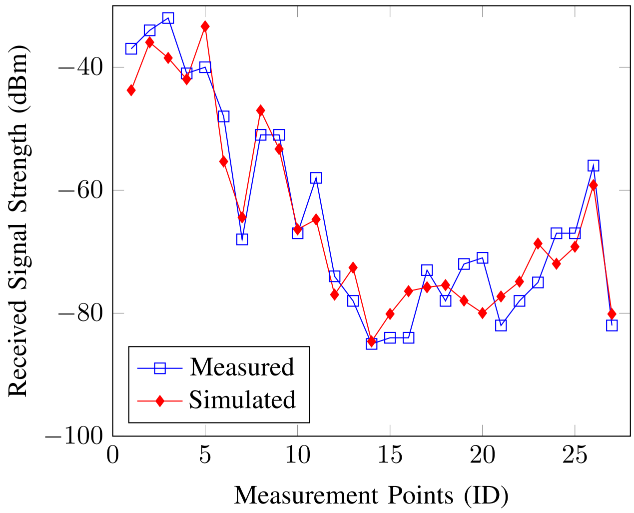


(b) First Floor (4.5m)

Fig. 4: Signal Coverage Prediction and Measurement Information (Indoor)



(a) Ground Floor (1.5m)



(b) First Floor (4.5m)

Fig. 5: Comparison between Measurement and Simulation (Indoor)

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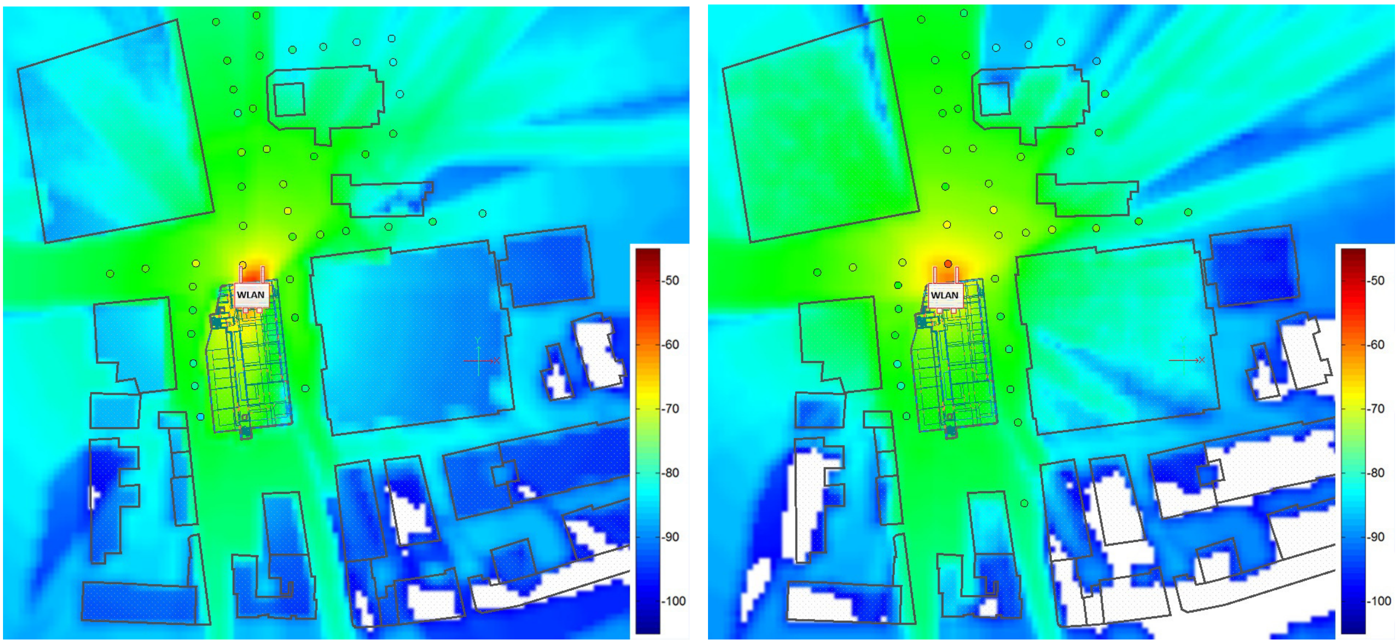
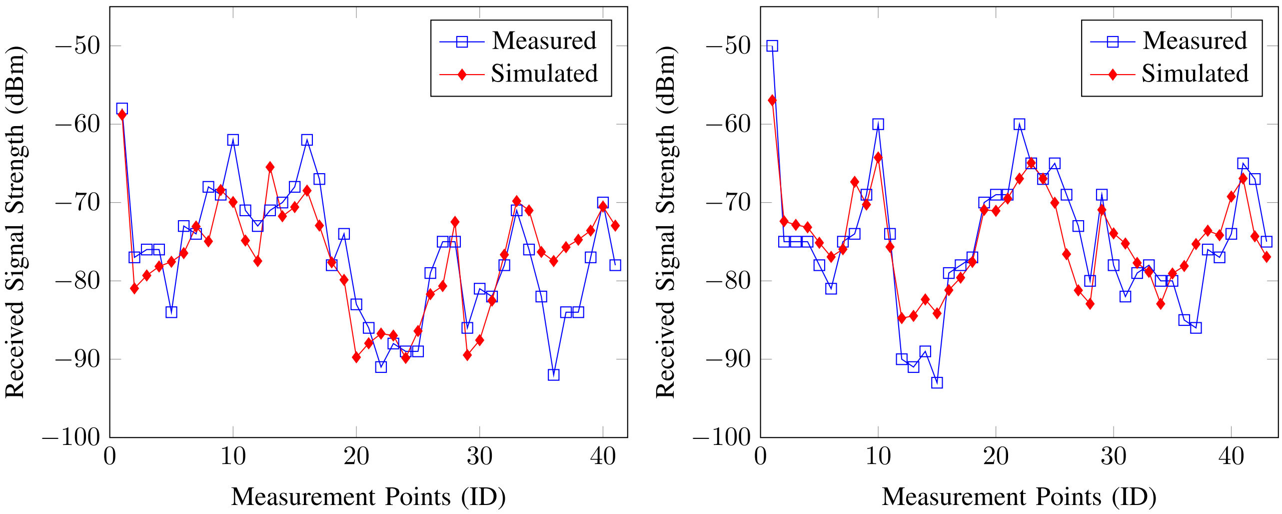


(a) Emitter at Ground Floor (1.5m)

(b) Emitter at First Floor (4.5m)

Fig. 6: Signal Coverage Prediction and Measurement Information (Outdoor Ground Level)



(a) Emitter at Ground Floor (1.5m)

(b) Emitter at First Floor (4.5m)

Fig. 7: Comparison between Measurement and Simulation (Outdoor Ground Level)