

# Effects of the Shape of Roofs on an Urban Propagation Modelling System at 2.4GHz

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## 1. Introduction

We have conducted a handset MIMO antenna measurement campaign using a realistic human phantom in an urban propagation environment [1], [2]. The key parameters for the campaign were as follows; a measurement frequency of 2.4 GHz with a bandwidth of 200MHz (100Mbps with BPSK); 8 elements of a base station (BS) and 4 elements of a mobile terminal (MS); and a propagation environment located in the downtown region of Aalborg city in Denmark, in order to accommodate a Microcell cellular MIMO.

In order to assess the performance of MIMO antennas, an evaluation of various radio propagation environments using ray-tracing techniques is being planned. Initially, highly sophisticated modelling of the city would have to be performed in order to enter accurate geometrical parameters into a computer model. This is a very laborious task, and requires a great investment in time. Thus, a simple way of modelling objects such as buildings and residential housing would be highly desirable to allow modelling of the whole of the test site using only easy-to-produce geometrical objects such as boxes and cylinders. Simple shapes such as these would also ensure that less computational time is required for the ray-tracing simulation than when their more complicated counterparts are used.

This paper presents the effects of the shape of roofs on urban propagation modelling at 2.4 GHz. The aim is to assess whether there is a need for accurate modelling of triangular-shaped roofs in terms of the performance evaluation of handset antennas in a Microcell cellular environment. It happens that triangular roofs are quite common in Aalborg city, and to this end, we have attempted comparative studies using ray-tracing simulations of the whole city by including either simple box-type buildings with flat roofs or more realistic buildings with triangular roofs. It will be shown from the results that a simple model with flat roofs can be used in place of a realistic model with triangular roofs, especially in areas that are in close proximity to the base station.

## 2. Experimental Setup

Fig. 1 illustrates an outdoor MIMO propagation test. In the experiment, a vertically-polarized four-element dipole array antenna with half-wavelength spacings was mounted on a car trailer for an MS antenna, which was driven at a speed of approximately 20 km/h. The MIMO transfer functions were collected by a channel sounder [3], [4], which was located inside the car. The space between the measurement samples was approximately 1.7 cm, corresponding to 0.14 wavelengths. The dipole array was located at a height of 1.52 m above the ground. The antenna array for the BS was mounted on a lifter positioned at height of 14.5 m. The BS array consisted of 8 elements located linearly. The array was divided into 2 sub-arrays. Each sub-array had 4 elements, with the spacing between the elements being 1 wavelength or 2 wavelengths.

In this paper, the propagation characteristics of a pair of antenna elements for the BS and the MS were evaluated. Each BS antenna element had a peak gain of 16.5 dBi, with half-power beamwidths of 6 degrees in the vertical plane and 85 degrees in the horizontal plane. A vertically-polarized wave was transmitted at 2.4 GHz, and the transmitted power of each element was 34 dBm. Fig. 2 depicts a test route in an urban area of Aalborg city in Denmark. The route was selected to obtain non line-of-sight (NLOS) situations where the heights of most of the surrounding buildings

were greater than 15 m. The route was approximately rectangular, with a length of about 140 m on the long side and 100 m on the short side. The propagation characteristics were measured along four sub-routes that ran in straight lines.

### 3. Simulation Condition

Table 1 summarizes the conditions for the ray-tracing simulations [5]. In the simulations, we only considered reflected and diffracted waves but ignored penetrated waves, since our main concern lies with fields outside buildings rather than those that occur inside. The resolution for the launch angles was set to 0.5 degrees, and the grid size (i.e. the reception area inside which a shooting ray is considered to be captured) was set to 5m on the receiving side. These parameters were chosen by considering the need to make a large-scale simulation with reasonable accuracy. For both the transmitting and receiving sides, single half-wavelength dipole antennas were assumed to be set at a height of 14.5m above the ground on the TX side and at 1.5m on the RX side, which corresponds to the experimental setup mentioned in the previous section. The transmitting power was set to 33dBm.

A key point of our study is to assess the effects of roof shapes in urban propagation modelling. Fig. 3 shows the modelling of buildings considering the shape of their roofs. In the figure, Fig. 3 (a) shows a realistic building with a triangular roof of height  $h_a$ , and Fig. 3 (b) shows a simple box-type building with a flat roof of height  $h_{\text{eff}}$ . Height  $h_{\text{eff}}$  means the effective building height that gives best-fitting characteristics in terms of propagation modelling of the test site, and can be calculated from the following equation;

$$h_{\text{eff}} = h_1 - \frac{1}{\sqrt{2}}(h_1 - h_2) \quad (1)$$

The above equation assumes that the height  $h_{\text{eff}}$  is defined such that model Fig. 3 (b) uses the same projection area for the building as that of model Fig. 3 (a). This analogy derives from the fact that the radar cross section (RCS) is determined by the projection area, meaning that similar levels of forward scattering can be expected between the two models. For a more accurate derivation, however, the height  $h_{\text{eff}}$  should be determined from the analysis of a single building taking into consideration the shadowing losses behind the building, and this will be left for further studies.

### 4. Results and Discussions

Fig. 4 shows perspective views in Aalborg city, comprising both realistic buildings with triangular roofs (Fig. 4 (a)) and simple box-type buildings with flat roofs (Fig. 4 (b)). In Fig. 4, the test route in Fig. 2 is illustrated by the red arrows surrounding the buildings. Fig. 5 shows the results of ray-tracing simulations that correspond to the two models shown in Fig. 4. The different signal levels are indicated by different colors, whereby red signifies a stronger signal and blue signifies a weaker signal. It can be seen from Fig. 5 that there are some discrepancies between Figs. 5 (a) and (b), such that the signal levels in Fig. 5 (b) appear smaller than those in Fig. 5 (a), particularly in the far distance from the base station. This may be attributed to the fact that a flat roof provides higher diffraction losses than a triangular roof. However, there is good agreement between the two models around the test route, where the distance between the TX and the RX is relatively small.

Fig. 6 shows the probability distribution function (PDF) and cumulative distribution function (CDF) of the received signals over the entire region of the simulation. As can be seen from the figures, the two models exhibit good agreement. From Fig. 6, the mean values of the received power are calculated to be -85.17 dBm for the realistic-building model, and -85.11 dBm for the simple box-type building model. As for the simulation time, the former model takes 10% less computational time than the latter model.

Fig. 7 shows a comparison between the simulated and measured results for received signals along the test route labelled III as indicated in Fig. 2. There are significant differences in level between the two graphs. A possible cause of these differences can be explained as follows; with regard to the measured results, Fig. 7 (b) shows the case when a 4-by-4 MIMO array with four half-wavelength dipole antennas is used for the RX side, and co-linear array antennas with a gain of 16.5 dBi are used for the TX side. Thus, Fig. 7 (b) shows the channel gain corresponding to each antenna combination, which includes the process gain of the channel sounder. In the simulation, however,

half-wavelength dipole antennas are used for both the RX and TX sides, and no correction is applied. Taking the above considerations into account, it can be said that the two results show a similar behaviour in their instantaneous variations.

It can be concluded from the above-mentioned results that a simple model with a flat roof can be used in place of a realistic model with a triangular roof when we attempt urban propagation modelling in an area in close proximity to the base station, say within several hundred meters.

## 5. Conclusion

This paper presents the effects of the shape of roofs on urban propagation modelling at 2.4 GHz. It is shown from the results that a simple modelling technique can be used, especially in an area in close proximity to the base station. Based on this conclusion, we will set forward the project to gather further knowledge about handset MIMO antennas with a higher channel capacity.

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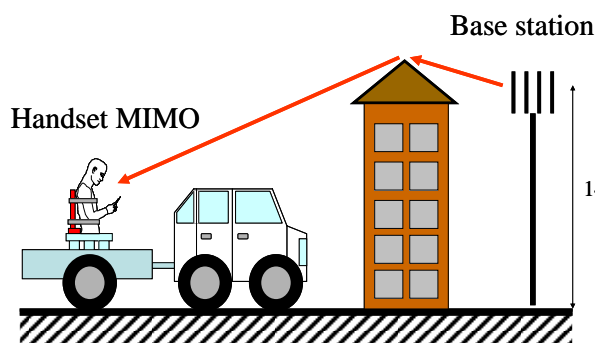


Fig. 1 Outdoor MIMO propagation test

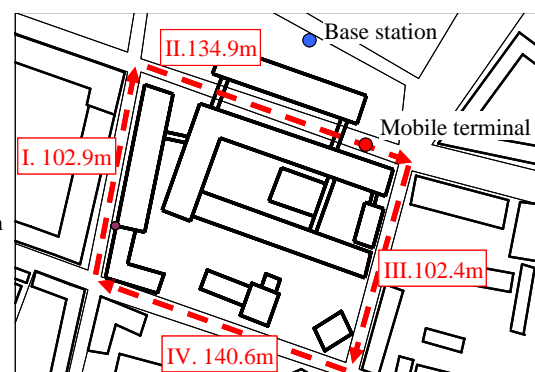


Fig. 2 Test route in an urban area

Table 1 Simulation condition

Frequency	2.4 GHz
Evaluation method	3 dimensional ray-launching method (Reflection : Valid, Diffraction : Valid, Penetration : Invalid)
TX	Antenna : Dipole, Transmit power = 33dBm, Height = 14.5m
RX	Antenna : Dipole, Height = 1.5m, Grid size = 5m

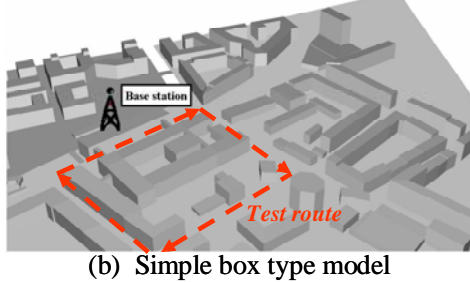
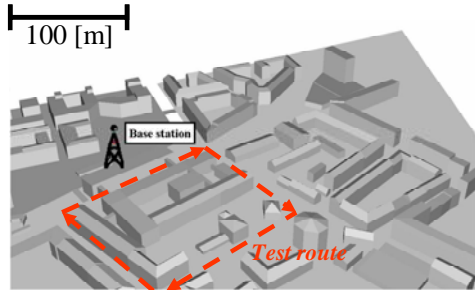
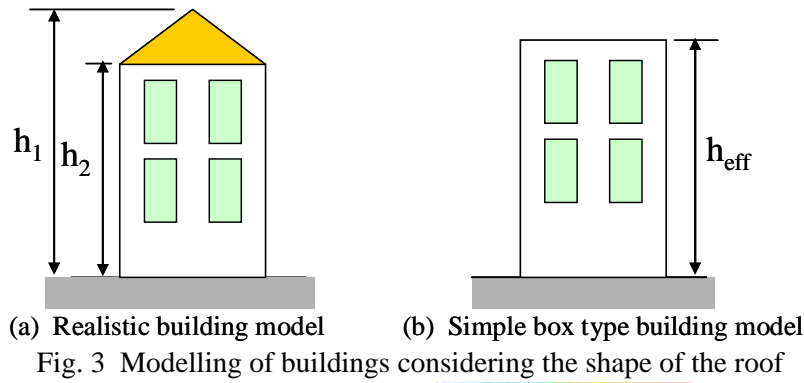


Fig. 4 Urban modelling in Aalborg city (the test route is indicated by the red lines)

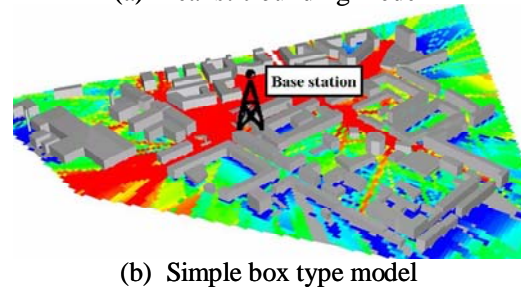
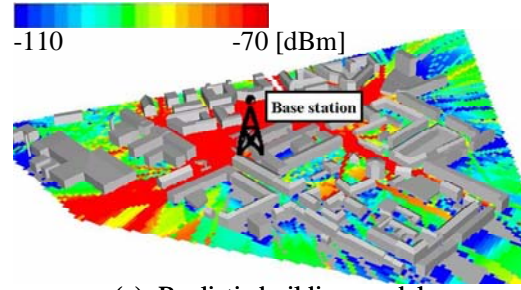


Fig. 5 Results of ray-tracing simulation

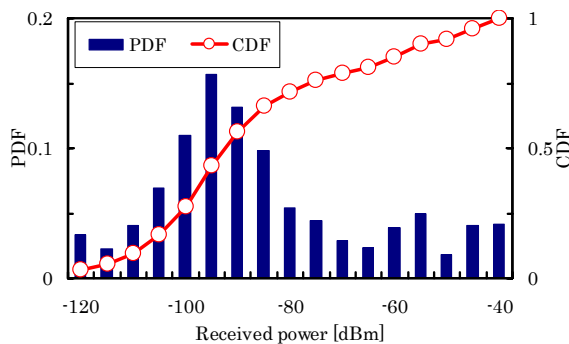
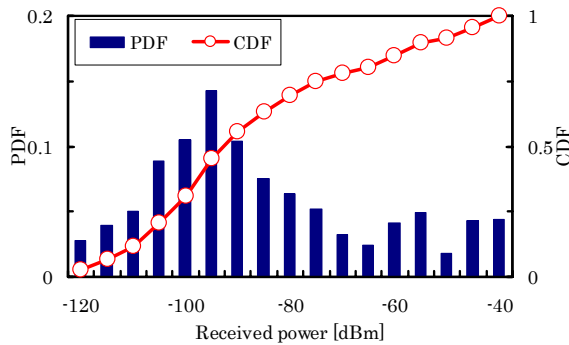


Fig. 6 PDF and CDF of the received signals

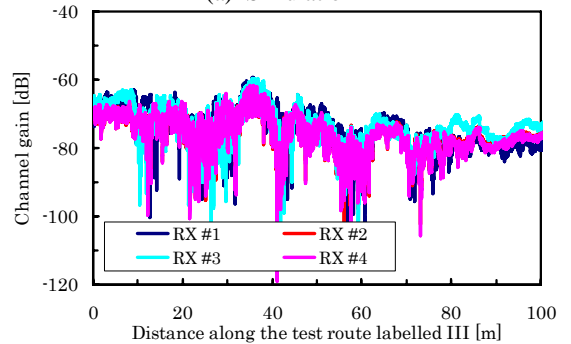
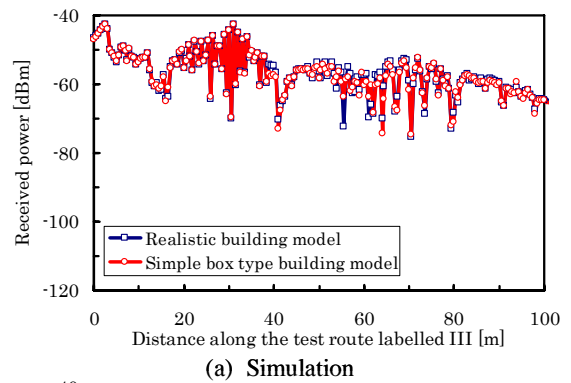


Fig. 7 Comparison between the simulated and measured results