Spatial Stability in Super Wideband Channel Responses

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Abstract

This paper examines the generally accepted multipath model of wideband radio channels. We use a simple multipath model based on paths of unlimited spatial extent, and compare it to a model that allows a finite spatial extent to the paths (that may result, for example, from shadowing). The comparison shows that the introduction of a finite spatial extent improves the accuracy of the model. Both models are fitted with parameters and compared to measurements from an indoor campaign. Our analysis is based on measurements in the 2-18 GHz band; we made static impulse response measurements with the receiving antenna at different positions along a one meter long linear axis.

Introduction

Multipath propagation is an established model for radio channels, supported by many works that compare channel measurements to model predictions (for examples see [4] and its references or [7, 1, 3, 8]). The physical explanation of multipath propagation is that radio waves emanating from a transmitting antenna are reflected, diffracted and scattered from different objects before reaching the receiver, the time of arrival of each path is determined by its physical length. The distinct paths can be detected if the system has a wide enough band to provide a time resolution on the order of the delay differences between them.

The multipath model is useful in explaining apparent variations of the channel with movement of the system terminals and reflecting objects. Each path forms part of the channel response as long as all its components, i.e. one that connects the transmitter to the first reflecting object and others that connect each reflecting object to the next and finally to the receiver, are free of obstruction. Most multipath models are designed for small areas of movement of the terminals, and thus assume that paths are valid or ‘visible’ for the entire area of interest. This paper examines the spatial stability aspect of the multipath model, in light of wideband (2-18 GHz) measurements that enable close inspection of the details of the propagation paths. In other words, we test the assumption that the multipath structure is stable over a significant range of receiver positions.

Measurements

Our setup is based on an Agilent N5230 network analyzer, connected to two omni-directional antennas (Electro-Metrics EM-6865) in the 2-18 GHz range, with suitable amplifiers. The receiver antenna was placed on a one meter long motorized positioner with millimeter accuracy. The transmitting antenna was placed on a cart that was moved to different locations in the building for different measurements, and was immobile during each measurement.

The measurements described in this paper were collected over a period of five months during 2006 and 2007 in the Ross Building in the Givat Ram Campus of the Hebrew University

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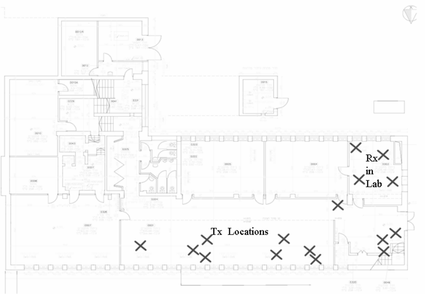

Figure 1: A sketch of the -2 floor of the Ross Building where measurements where taken. The receiver cart was located at different positions in the laboratory (top right room in the drawing) and the transmitter was located as indicated. Transmitter–receiver separation ranged from 2 to 23 meters.

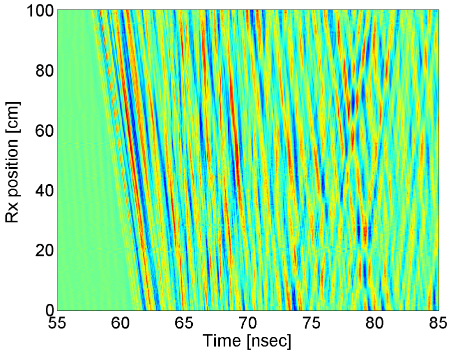

Figure 2: Measured NLOS impulse responses, shown in color versus the delay and the location of the receiving antenna. The colors show amplitude, blue shows negative values and red shows positive ones.

in Jerusalem, Israel. The structure is a conventional office building built during the 1970s, of reinforced concrete and concrete blocks. We kept the equipment in a single floor of the building, with the receiving antenna in a room and the transmitting antenna at different positions in an adjacent open-space area used as a computer room, as shown in Figure 1. Movement of people in the area of measurement occurred during some of the measurements, but we found that it only had a minor effect of the results.

Methods

Our work examines the suitability of the multipath model to line of sight (LOS) and non line of sight (NLOS) indoor radio propagation. We examine in particular the assumption that paths are stable over a one meter long movement of the receiver. We compare measurements taken over 18 pairs of transmitter-receiver locations in the building (Figure 1) to an approximation of the same measurements using two multipath models.

In essence, we compare an approximation that is based on a model with paths that cover the entire range of receiver positions, to a model where each path has a finite spatial extent and is thus ‘visible’ to the receiver over only a part of its positions. An example of a NLOS measurement with approximations of both types is shown in Figures 2, 3 and 4.

The algorithm that extracted the distinct diagonals from each measurement was based on the Radon Transform [2, 5, 6], that is used in various applications of image processing to extract linear features of images. The Radon Transform returns a two–dimensional description of an image input, the two dimensions of the transformed image represent the angle and the translation (shift) of straight lines of single pixel width that cover the original image from one edge to another. The Radon Transform uses a non–orthogonal basis as the diagonals it describes may overlap. Our algorithm uses the Radon Transform as a starting point for choosing a set of diagonals that describes the measurement. The main steps of the algorithm are described below:

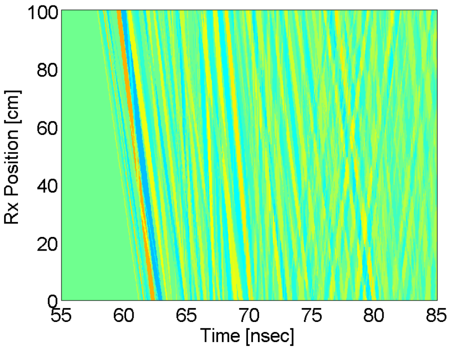

Figure 3: An approximation of the measurement from Figure 2, based on a multipath model with paths that are spatially unlimited. The color scale is identical to the scale of Figure 2. The MSE offered by this approximation is 0.71, the approximation contains 432 paths (some are outside the range of plotted delays).

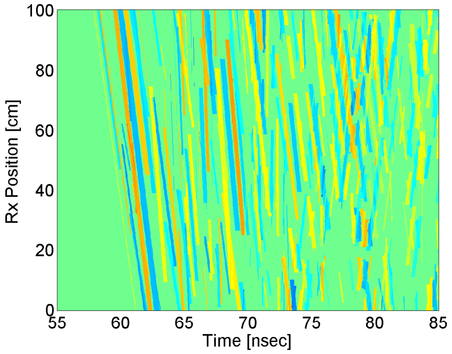

Figure 4: An approximation of the measurement from Figure 2, based on a model where paths have a limited spatial extent. The color scale is identical to the scale of Figure 2. The approximation contains 1294 paths, and the approximation MSE equals 0.63.

— Perform a Radon Transform of the input measurement.
— Choose the range(s) of significant angles, where energy is concentrated. These regions essentially represent directions of arrival of paths at the receiver.
— Collect the Radon output over adjacent thin diagonals, the new (thick) diagonals form an approximation of the original image, where each diagonal spans the entire image from edge to edge. The physical interpretation of the model is that paths are 'visible' to the receiver over its entire range of motion.
— Search over each diagonal to extract its significant sections. We allow up to four sections per diagonal. This second model is naturally more complex and it offers better accuracy when compared to measurements. The superiority of this second model, with finite area of stability per paths, is visible in the comparison of Figures 3 and 4 to the measurement in Figure 2.

Our algorithm used nine parameters that were set at slightly different values for LOS and for NLOS measurements. We do not claim that the choice of parameters was optimal and our methods are still under development. The figure of merit we used for assessing the accuracy of the channel models was the mean square error (MSE) averaged over receiver positions along its axis. The main sources of inaccuracy of the two models are the assumptions of a fixed pulse shape and of a constant amplitude, that simplify the models at the expense of their similarity to measurements.

Results

Our results show that NLOS measurements are matched with an average MSE of 0.71 by a multipath model with an unlimited spatial extent of the paths, where the average is taken over 14 measurements. The average energy of the approximation was 46% of the measured energy, the approximation included 349 paths on average. The parameters used for the path extraction algorithm were set using three measurements, two of them excluded from the test set used to generate the results presented here. The introduction of a limited spatial extent improves the matching of model to measurements by about 0.1 to an average MSE of 0.62 with an average number of 1559 sections of diagonals and an average approximation energy of 78% of the measured energy.

Line of sight measurements were matched with an average MSE of 0.77 by the model with unlimited paths with 2029 diagonals on average, that containted 27% of the measured energy. Averages were taken over 4 measurements. The introduction of a limited spatial extent did not improve significantly the average MSE, but the average energy contained in the model increased to 53% of the measurement energy, with an average of 195 sections of diagonals. The LOS measurements contained a strong direct path that is stable across receiver positions, followed by weaker paths.The introduction of a limited spatial extent to the paths has a minor effect of the MSE because of the stability of the direct path.

The reason for the spatial variation of the measurements is not clear, but a simple fading process where different paths interfere is not sufficient to explain our measurements. This insufficiency is concluded from the inferiority of the unlimited path model relative to the finite path model, and is apparent in Figures 2, 3 and 4.

References

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