ANGULAR SIGNAL DISTRIBUTION AND CROSS-POLARIZATION POWER RATIO SEEN BY A MOBILE RECEIVER AT 2.15 GHz

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INTRODUCTION

In mobile radio reception, signals typically arrive at the receiver antenna from a wide range of directions due to multipath propagation. This can be described by a direction-of-arrival (DoA) distribution of the propagation environment. If the DoA distribution is known, the Doppler spectrum and the autocorrelation function can be directly computed [1]. Furthermore, handset antenna performance can be evaluated by the concept of mean effective gain (MEG) [2], which is the ratio of the mean power received by the antenna to the total mean incident power. The DoA distributions for both vertically polarized (VP) and horizontally polarized (HP) waves and the cross-polarization power ratio (XPR) are needed in the evaluation of the MEG. Also the evaluation of pattern and polarization diversity techniques require the knowledge of DoA distributions of both polarizations. Therefore it is useful to know the form of the DoA distributions in different mobile communication environments.

Several mathematical models have been proposed to describe the DoA distribution of incoming signals seen by a mobile receiver [1-3]. The first and widely used model of Clarke [3] is a two-dimensional model where the DoA distribution is assumed to be uniform in the horizontal plane. However, it is known to be unrealistic especially in urban environments where high buildings give rise to multipath components from high elevation angles. A typical assumption of three-dimensional models is uniform distribution in azimuth while the elevation distribution is described by a suitable parametrized function. Reference [1] presents a three-dimensional model but gives no experimental data to verify or to tune the model. Taga [2] has proposed a Gaussian model in elevation and fitted the distribution parameters (mean and variance) to measured data. However, he only used four measured points of the elevation distribution, which is insufficient to verify the distribution. Few published results can be found on measured elevation distributions.

This paper presents elevation distributions and XPR values measured in four different environments: indoor microcell, urban microcell, suburban microcell, and suburban macrocell.

MEASUREMENTS

Measurement system and data processing

The measurement system used in these measurement campaigns is described in [4]. It consists of separate transmitter and receiver units synchronized by accurate rubidium standards to enable phase measurement. In the transmitter, a cyclic binary pseudo-noise sequence (M-sequence) is generated at 30 MHz chip frequency and transmitted using a fixed antenna. At the receiver unit, a complex radio channel sounder samples the received signals from 32 dual-polarized elements of a spherical array via a fast RF switch. In these measurements the receiver unit was moved along predefined measurement routes by a motorized trolley or a van and five snapshots of the channel were taken per each wavelength of each route.

The delays, DoAs, and complex amplitudes of both VP and HP components of the incoming waves at each snapshot were found by sequential delay-domain and DoA-domain processing at a post-processing stage. Delay-domain processing involves the correlation of the received signal of each antenna element with the sent M-sequence, which yields the complex impulse response, and finding the local maximums of the power delay profile (PDP). In DoA-domain processing, the DoAs and amplitudes of the waves arriving at a given PDP peak were found by a beamforming scheme [4]. Finally, the data at consecutive snapshots was combined to yield continuously evolving propagation paths. Paths with lifetimes less than one wavelength (five snapshots) were discarded. This “path combining” stage was carried out having channel simulation applications in mind, but it also gives more reliability to the results since spurious signals are probably rejected.

The delay resolution, DoA resolution, and cross-polarization discrimination of the measurement system and the data processing algorithm is approximately 30 ns, 40°, and 9 dB, respectively [4].

Description of the measured environments

The four measured environments will be called City indoor, City outdoor, HUT microcell, and Highway macrocell in the following. City indoor and City outdoor measurements were performed in a downtown shopping area in Helsinki. The fixed transmitter antenna was a modified GSM 1800 sector base station antenna. It was mounted approximately 8 m above ground and tilted so that the main beam pointed towards the line-of-sight (LOS) parts of the outdoor mobile routes. Transmitted polarization was, as well as in the other environments, vertical. Two indoor and two outdoor routes were measured. The first indoor route moved in an open lobby (6 m wide) and the second began in the same lobby but then moved into a narrow, 3 m wide corridor. The height of the ceiling was approximately 4 m in the lobby and 2.5 m in the corridor. Both outdoor routes began on an open square in LOS and then moved to non-line-of-sight (NLOS), the first into another square and the second into a 7 m wide alley. The height of the receiving spherical array was 1.65 m.

HUT microcell measurements were performed around the Department of Electrical and Communications Engineering of Helsinki University of Technology. The above-mentioned base station antenna was mounted on top of a 2 m high mast on the roof of a high voltage hall next to the department building, approximately 17 m above ground. This time the base station antenna was not tilted because coverage beyond the department building was desired. Six mobile routes were measured, five of which located on the yard between the buildings and one behind the department building. The distance from the routes to the closest wall varied from 2 m to 10 m and the height of the surrounding buildings varies from 10 m to 23 m. Again, the height of the receiving spherical array was 1.65 m. Compared to the City environment, dimensions of HUT microcell are larger, routes have more LOS parts, and highly elevated incident signals are found due to high buildings and high base station position.

In Highway macrocell measurements, an omnidirectional discone antenna was mounted on top of a water tower, approximately 50 m above ground. The receiver unit was placed inside a van and 21 short measurement runs were taken in the surrounding suburban environment, mostly on highways, and partly with LOS to the base station. The distance from the base station to the receiver varied from approximately 200 m to 2200 m.

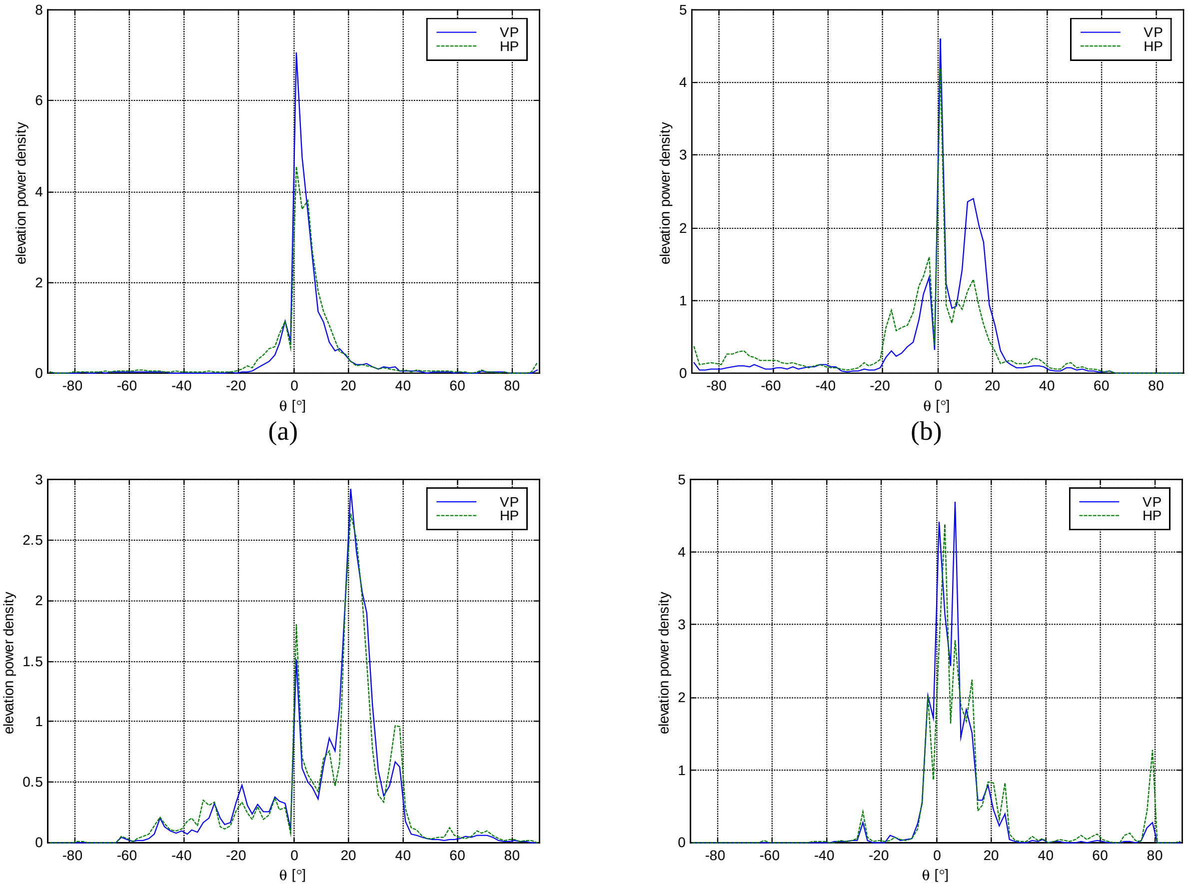
Due to a memory limitation of the system, longer measurement routes were divided into shorter, partly overlapping subruns. The total number of snapshots, NLOS snapshots, routes, and subruns measured in each environment is summarized in Table 1.

ANGULAR DISTRIBUTIONS AND XPR VALUES

The DoA power distribution is a function of the azimuth and elevation angles, which is normalized by the condition that its integral over the whole solid angle is equal to one. It was assumed that the distribution is uniform in azimuth, and an elevation power distribution $P(\theta)$ that satisfies the condition

Table 1. Measurement statistics and XPR values.

Environment	Snapshots	NLOS snapshots	Routes	Subruns	Total / NLOS XPR
City indoor	3328	3328	2	26	6.3 dB / 6.3 dB
City outdoor	4864	2816	2	38	5.4 dB / 3.4 dB
HUT microcell	6867	2205	6	109	7.4 dB / 8.2 dB
Highway macrocell	620	not specified	20	20	8.9 dB / —



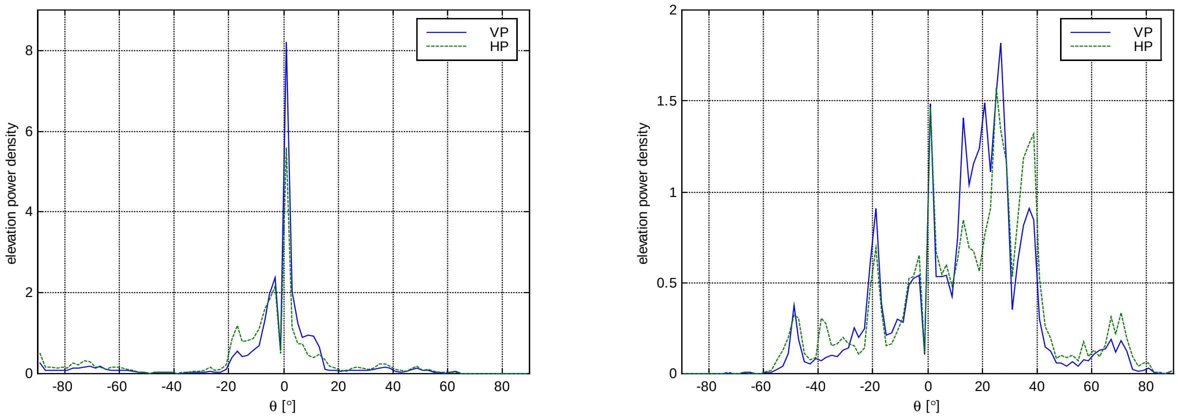
(a) (b) (c) (d)

Fig. 1. Measured elevation distributions in (a) City indoor, (b) City outdoor, (c) HUT microcell, and (d) Highway macrocell environments.

$$\int_{-\pi/2}^{\pi/2} P(\theta)\cos\theta \, d\theta = 1 \tag{1}$$

was calculated from the processed measurement data. The elevation power distribution at each measurement subrun was computed by summing the incident powers at each discrete elevation angle value of the grid used in beamforming (from -89° to 89° by 2° increments) and by normalizing by the sum of the incident powers. Actually it is the product $P(\theta)\cos\theta$ that is found this way since the size of the solid angle from which the data is collected changes as the elevation angle changes. The total distribution in a given environment was then approximated as the average of the subrun distributions. These distributions were calculated separately for VP and HP incident waves. The results are shown in Fig. 1. It can be seen that the elevation power distribution depends strongly on the propagation environment. For example, HUT macrocell distribution is notably broader than the others, with a peak as high as at 37° due to rooftop diffractions. LOS propagation peaks can be seen at 13°, 21°, and 7° in City outdoor, HUT macrocell, and Highway macrocell distributions, respectively. These peaks are clearly stronger in VP distributions, except in HUT macrocell, where the orientation (no tilting) and location (15 m from the edge of the roof) of the base station antenna may explain the high proportion of horizontal polarization in the LOS direction. For comparison, the elevation power distributions of NLOS parts of the City outdoor and HUT microcell environments are shown in Fig. 2. A common feature of all the distributions is a peak at 1° caused by horizontally traveling waves.

In addition to the DoA distributions of both polarizations, the XPR has to be known to completely describe the signal environment. It is defined as [2]



(a) (b)

Fig. 2. Measured elevation distributions in NLOS and (a) City outdoor and (b) HUT microcell environments.

$$XPR = P_V \, / \, P_H \, , \tag{2}$$

where P_V and P_H are the mean incident powers of VP and HP incident waves, respectively. The XPR of each environment was approximated by calculating the ratio (2) for each subrun and then taking the average of these values. The results are shown in Table 1, where also the XPR values of the NLOS parts of City indoor and HUT microcell are given. As expected, lower XPR values are found in densely built environments where a lot of scattering occurs. In City outdoor environment, the XPR is lower in NLOS, but in HUT microcell it is somewhat surprisingly higher in NLOS. This may be explained by the above-mentioned orientation and location of the base station, which causes a large HP component to the LOS path.

CONCLUSIONS

Based on these measurement results it can be concluded that the elevation power distribution varies heavily depending on propagation conditions such as building height and material, base station location and tilting etc. VP and HP distributions were found to be quite similar, the most obvious difference being the stronger LOS peaks in the VP distribution. Although some of the measured distributions are far from smooth functions, it is expected that smoother distributions are obtained by gathering more data. If an analytical elevation distribution model is desired, it should be able to describe the following features: asymmetricity about 0°, varying elevation spread, and several peaks at least if LOS propagation is present. Probably a family of functions, as proposed in [1], is needed to properly describe all circumstances.

The assumption of uniform azimuth distribution is not fully satisfied by the measured data. This may be due to insufficient data and/or nonrandom measurement routes. However, it may also be a characteristic feature of some propagation environments. For example, in a corridor the mobile receiver as well as the radio signal typically travels along the corridor. In these cases a complete three-dimensional DoA distribution model should be used in antenna performance evaluations.

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