Elevation Analysis for Urban Microcell Outdoor Measurements at 2.3 GHz

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Abstract—This paper presents the elevation of departure analysis for the urban microcell radio channel measurements at 2.3 GHz center frequency. The measurements were conducted with EB Propsound CS™ for 30 x 16 antenna configuration for the transmitter (Tx) antenna heights of 5 m and 10 m in Oulu city center, Finland. The Tx antenna elements were arranged in the plus shape and nine antenna elements were placed with linear spacing in the vertical dimension providing high elevation resolution and an accurate elevation angle estimate for the departure angles. The measurements indicate that the Laplacian distribution can be used for modelling the elevation spread of departure (ESD) for the higher Tx antenna height and a significant difference in ESDs between the line-of-sight (LOS) and the non-line-of-sight (NLOS) propagation environment. The ESD with respect to distance was observed to follow the negative exponential model and the linear model in the LOS propagation environment and the NLOS propagation environment, respectively.

I. INTRODUCTION

Two dimensional (2D) channel models, e.g., WINNER II [1] and International Telecommunication Union radiocommunication sector (ITU-R) channel model [2], have been accurate enough in the fourth generation (4G) wireless communication studies. The effect of radio wave propagation in the elevation domain was assumed to be negligible in these models. However, the wireless communication traffic is expected to grow explosively in the next few years and more advanced channel models are needed for the fifth generation (5G) mobile and wireless communication systems. To meet this demand, the higher frequencies and wider bandwidths should be utilized. Furthermore, the resources of the current spectrum should be exploited maximally. Therefore, an accurate three-dimensional (3D) multiple-input-multiple-output (MIMO) geometry based stochastic channel model (GSCM) is needed for the elevation domain beamforming and spatial multiplexing.

The analysis of radio wave propagation in the elevation domain has gained a lot of interest in the past few years. Several measurement campaigns have been carried out and the angular characteristics in elevation domain have been investigated, e.g., in [3], [4]. The 3D extension of ITU-R channel model was proposed in [5]. However, according to the best knowledge of the author’s the majority of the existing work in the analysis of elevation domain has been focused on the macrocell environment and only a few works, e.g., [6], [7] have been focused on the analysis of elevation dimension in microcell. In [8], the elevation angle parameters are reported for urban microcell (UMi) but the elevation resolution is limited by the measurement data, i.e., the analysis in the elevation domain, especially at the base station (BS), is based on measurements where the number of antenna elements in the vertical domain is small.

This motivated us to perform radio channel measurements in a microcell environment. This paper concentrates on the analysis of the elevation angles of departure (EoD) and the elevation spread of departure (ESD). In order to achieve an accurate elevation resolution at the transmitter (Tx), i.e., BS, nine antenna elements were placed with linear spacing in the vertical dimension. Therefore, this paper provides more accurate elevation angle estimates for the propagated paths against the majority of the existing measurement results.

The rest of this paper is organized as follows. In Section II, the measurement equipment and environment are described. Section III presents the theory of elevation domain analysis and the measurement results. Finally, the conclusions are drawn in Section IV.

II. MEASUREMENT EQUIPMENT AND ENVIRONMENT

The measurements were conducted with EB Propsound CS™ [9] at the center frequency of 2.3 GHz. An uniformly spaced linear antenna array (ULA) was used as the Tx antenna and it was installed in an articulated crane in order to vary the Tx antenna height. The ULA consists of 15 dual polarized elements (30 feeds) and the elements of antenna array are arranged in the plus shape (Fig.1a). The Tx antenna heights were 5 meters and 10 meters above the street level in the measurements. An omnidirectional antenna array (ODA) was used as the receiver (Rx) antenna (Fig.1b) and it was installed on the roof of a car at the height of 2.5 m above the street level.

The measurement device uses direct sequence spread spectrum (DSSS) technique for channel sounding. The impulse responses (IRs) of channel samples are obtained by correlating the received signal with the spreading code used in transmission. Sounding in the spatial domain is achieved by switching through the multiple antennas in the time domain. The antenna elements are switched through in a such way that the channel response remains constant within antenna switching period.
The antenna switching period should be shorter than channel coherence time. This sets the limitation to the useable antenna configuration for urban measurements where several moving scatterers are present. Therefore, the lowest ring of dual polarized patches in the azimuth domain, i.e., 16 ports were selected from the Rx antenna array for the measurements. This also indicates that the elevation spread of arrival (ESA) cannot be analyzed. The measurement settings are presented in the Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Bandwidth [MHz]</td>
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</tr>
<tr>
<td>Transmission power [dBm]</td>
<td>23</td>
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<tr>
<td>Antenna configuration [x]</td>
<td>30 x 16</td>
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<tr>
<td>Code length [chips]</td>
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<td>Measurable delay [µs]</td>
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<tr>
<td>Array scan time [ms]</td>
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<td>Channel coherence time [ms]</td>
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<tr>
<td>Snapshot duration [ms]</td>
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</table>

The GPS positions of the Rx were recorded in order to calculate the distance between the Tx and the Rx. In addition, GPS data was recorded by a navigator and a vector network analyzer for cross-checking the Rx positions in the data analysis phase. The measurements were performed at Oulu city center. The Rx was immobile during the data recordings. Several spots including line-of-sight (LOS) and non-line-of-sight (NLOS) propagation conditions were recorded. The measurement routes are presented in Fig. 2.

### III. Data Analysis and Measurement Results

The data analysis is divided into four group based on Tx antenna height and propagation environment, i.e., the data analysis is done independently for both Tx antenna heights and LOS and NLOS scenarios. The angular estimates and the powers of each individual paths were obtained by initialization and search improved SAGE (ISIS) algorithm [10].

#### A. EoD Distributions

The Laplacian distribution used for fitting the observed EoDs is presented as

\[
I_{EoD}(\theta) = \frac{1}{\sqrt{2\pi} \sigma_{EoD}} \exp\left(-\frac{\sqrt{2}(\theta_m - \mu_{EoD})}{\sigma_{EoD}}\right),
\]

where \( \theta_m \) is the EoD of the \( m \)th path and \( \mu_{EoD}, \sigma_{EoD} \) are the mean and standard deviation of the Laplacian distribution, respectively. The mean of EoD is normalized to zero degree and the probability density function (PDF) for EoD is presented in Fig. 3. The Laplacian distribution fits fine for the observed EoDs in the NLOS scenario. In the LOS scenario, a small offset between the measured EoDs and the Laplacian distribution can be observed.

#### B. ESD Analysis

The ESD for each measured time instant is calculated as described in 3rd Generation Partnership Project spatial channel model (3GPP SCM) specification [11] from the EoDs and the path power values as

\[
ESD = \min_{\Delta} \sigma_{AS}(\Delta) = \sqrt{\frac{\sum_{m=1}^{M} (\theta_m(\Delta) - \mu_{\theta}(\Delta))^2 : P_m}{\sum_{m=1}^{M} P_m}},
\]

where \( \Delta \) is a discrete grid for minimization, \( \theta_m(\Delta) = \theta_m + (\Delta) \), \( P_m \) is the power of the \( m \)th path and \( \mu_{\theta}(\Delta) \) is the mean of elevation angular power of departure calculated as

\[
\mu_{\theta}(\Delta) = \frac{\sum_{m=1}^{M} \theta_m(\Delta) : P_m}{\sum_{m=1}^{M} P_m}.
\]

The cumulative density function (CDF) for the ESD is presented in Fig. 4. The difference between the LOS and...
Fig. 3. PDF of EoD (a) LOS, Tx height 5 m (b) LOS, Tx height 10 m (c) NLOS, Tx height 5 m (d) NLOS, Tx height 10 m.

Fig. 4. CDF of ESD.

Fig. 5. ESD versus link distance, LOS and Tx height 5 m.

The NLOS scenario is clearly seen from the Fig. 4. The contribution of direct path in the LOS propagation condition is significantly higher than the contribution of multipath components (MPCs), which leads to smaller ESD in the LOS scenario. In the NLOS scenario, the ESD differs remarkably between the two Tx antenna heights. The reason for this is the fact that the stronger MPCs are detected from the ground reflection with lower Tx antenna height than the higher Tx antenna case.

C. ESD Distance Dependency Models

In this subsection, the ESD dependency on distance is investigated. The 3GPP model for the distance dependency of ESD [12] is plotted as the reference in Figs. 5–8. The ESD with respect to the distance between the Tx and the Rx for the LOS scenario are presented in Figs. 5–6. It can be seen that when the distance increases, the ESD decreases exponentially. Therefore, the exponential model is used for modelling the distance dependency of ESD in the LOS scenario and it is presented as

$$ESD_{LOS}(d) = A_{LOS} \cdot \exp(-B_{LOS}(d)) + \gamma,$$

where $A_{LOS}$ and $B_{LOS}$ are the coefficients of exponential model in the LOS scenario, $d$ is the distance between the Tx and the Rx and $\gamma$ is the standard deviation between the model and the measured ESDs. In order to extract out the angular estimates using ISIS algorithm, approximately 15 dB dynamic range is needed, i.e., the difference between the highest peak and noise level in the IR should be at least 15 dB. There is a small mound with the height of three meters approximately 150 meters away from the Tx, which caused a remarkable attenuation in the received power when the Tx antenna height was 5 meters. Therefore, the results for the Tx antenna height of 5 meters are presented only for distance range from 50 meters to 170 meters.

The ESD with respect to the link distance for NLOS scenarios are presented in Figs. 7–8. A linear polynomial fit is used for the distance dependency of ESD in the NLOS scenarios and it is presented as

$$ESD_{NLOS}(d) = A_{NLOS} + B_{NLOS}(d) + \gamma,$$

where $A_{NLOS}$ and $B_{NLOS}$ are the coefficients of linear function obtained by using the least square (LS) method. Some offset between the model and measured ESD is observed. This is partly caused by an insufficient number of measurement spots and the lack of dynamic range in the NLOS measurements.

D. Cross-correlation Analysis

The spatial correlations of channel parameters are important in the system level simulations. In order to create correlations...
between links at the system level, the large scale parameters have to be generated with correlation properties [1]. The cross-correlation coefficient is calculated as [1]

$$\rho_{xy} = \frac{C_{xy}}{\sqrt{C_{xx}C_{yy}}}$$  \hspace{1cm} (6)

where $C_{xy}$ is the cross-covariance of parameters $x$ and $y$ and $C_{xx}$ indicates auto-covariance. The results of cross-correlation coefficients and the statistics of elevation analysis are summarized in Table II, where the mean and the standard deviation of ESD are denoted as $\mu_{ESD}$ and $\sigma_{ESD}$, respectively. Furthermore, the table II shows the results for $\mu_{ESD}$ and $\sigma_{ESD}$ reported in [8] and the cross-correlation parameters reported in [12].

According to the obtained results, the mean of ESD decreases, when the Tx antenna high increases. The $\sigma_{ESD}$ is higher in the NLOS scenario than the LOS scenario. This can be also seen from Fig. 3 and Fig. 4. The reason for this is that the contribution of MPCs is weaker in the LOS scenario than the NLOS scenario. Some difference in $\mu_{ESD}$ can be noticed between the calculated results and the parameters reported in [8]. In the LOS scenario, the obtained results indicate a smaller $\mu_{ESD}$ in comparison to the parameters reported in [8]. On the other hand, the $\mu_{ESD}$ obtained for NLOS scenario is higher than in [8]. Furthermore, the observed $\sigma_{ESD}$ is higher in comparison to the parameters reported in [8]. This is caused by the higher elevation resolution in our measurements.

Some interesting observations concerning cross-correlation coefficients can be noticed from the Table II. The cross-correlation between the ESD and the azimuth spread of departure (ASD) in the LOS scenario is almost unity, indicating that the ESD and the ASD are almost fully correlated. On the other hand, the cross-correlation between the ESD and the azimuth spread of arrival (ASA) is mainly negative, indicating when the ESD increases the ASA decreases. The cross-correlation coefficients between the ESD and delay spread (DS) are almost the same in the obtained results and the parameters reported in [12].

IV. CONCLUSIONS

The radio channel measurements were carried out with 30 x 16 antenna configuration in an urban microcell environment at the center frequency of 2.3 GHz for two transmit antenna heights. An elevation domain analysis was performed for the departure angle estimates. The results show that the departure angles in the elevation domain can be modelled by the Laplacian distribution. The elevation spread of departure was decreased when the transmitter antenna high was increased. A significantly higher elevation spread of departure was observed in the non-line-of-sight scenario than the line-of-sight scenario. The link distance dependency of the elevation spread of departure was observed to follow exponential function and linear function in the line-of-sight and the non-line-of-sight case, respectively.

V. ACKNOWLEDGMENT

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<th>Parameter</th>
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<th>Statistic</th>
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REFERENCES