Clusterization of Measured DoA Data in an Urban Macrocellular Environment

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I. INTRODUCTION

In urban propagation environments, radio waves are assumed to arrive at receiving devices in several separate clusters, each of them arriving from different directions and with different delays. Our study was to extract the clusters from measured data, to locate the cluster sources to the surrounding environment and to determine key parameters describing the clusters.

Several continuous routes in micro- and macrocellular environments were measured in downtown Helsinki, Finland, using a wideband channel sounder and a spherical antenna array. After applying beam forming to the measured data the angle of arrival, delay, amplitude, phase, and polarization state were obtained for each instantaneous incident wave along the measured route. The routes were 100 - 400 m long. One of those routes is studied in this paper.

To understand the physical propagation channel in more details, the measured direction-of-arrival (DoA) data were clusterized. Then each cluster was considered and analysed separately. The clusterization was done by manual inspection, utilizing both angular and delay space.

II. MEASUREMENT AND EQUIPMENT

The measurement system consists of a fixed transmitter, which transmits known PN-code with a single base station antenna using vertical polarization, and a receiving mobile. The carrier frequency of the transmitter was 2.154 GHz, chip frequency 30 MHz, and transmitted power 40 dBm. In the receiver I- and Q-channels are sampled separately with 120 MHz sampling frequency and stored for post-processing. The used spherical antenna is an antenna array which consists of 32 dual polarized antenna elements. The elements are arranged to shape of a sphere to cover the whole 4π solid angle in space. Since dual polarized elements were used, the polarization states of the received waves can be determined.

During measurements the receiver was moved along a continuous route with a constant speed of 1 m/s. A snapshot, set of impulse responses which consists of impulse responses of each feed of the receiving array, was measured approximately 5 times per moved wavelength. All the measured impulse responses were stored to hard disks during the movement to allow a continuous real time measurement. Direction of arrival of each incident wave was calculated in post-processing stage from the recorded complex impulse responses by beam forming. Both elevation and azimuth angles were determined. Also amplitude, delay, polarization state and phase were obtained for each wave. The spatial resolution is 40° within a single delay tap, delay resolution 33 ns and the cross polarization discrimination 17 dB. The RMS error of the incidence angle measurement is approximately 1° [2]. The S/N-ratio of the measured impulse responses was 25 to 30 dB.

One small macrocellular route is considered within this paper. The route is 120 m long (4400 snapshots), and distance from to the base station (BS) is 400 m. The BS height was 25 m and height of the buildings surrounding the mobile station (MS) was also approximately 25 m. The MS height was 1.6 m.

III. CLUSTERIZATION

In this paper clusters are assumed to be rather large structures that scatter the propagating radio waves. Thus at the receiving end these clusters appear as strong and stable signal sources which can be traced and separated through the measured route.

Any limits for the size of a cluster, in angular or delay space, were not defined. Instead, all received paths which
seemed to belong in a certain cluster were included.

The cluster extraction from the DoA data was done by manual inspection, utilizing both angular and delay space. The areas in direction and delay space which look like part of certain cluster were combined until the the cluster was as complete as possible. The procedure was repeated until there was no clearly separable clusters left in the DoA data. In total 14 clusters were extracted from the considered measurement route.

To locate the cluster sources, a cosine function was fitted to the azimuth arrival angles of each extracted cluster's centers. Since one cluster may consist of several paths in one snapshot, the cluster center was calculated as a power weighted mean of the azimuth angles of the paths. When the receiver is moved along a straight route, the azimuth directions of arrival from one source position follow a trigonometrical function along the route. Therefore by fitting a cosine function to the azimuth arrival angles, the position of the cluster source can be estimated from the coefficients of the function. For clusters whose azimuthal direction is close to the direction of movement along the measured route, the accuracy is low since the azimuth DoA changes only little over the route. For clusters beside the route the accuracy should be adequate.

The map of the measured environment and locations of the detected cluster sources are presented in Figure 1. The small numbers are cluster numbers, which later on are used to refer to a certain cluster. Numbered comments about the clusters: (1) long delayed paths from the building ahead (2) this cluster may be a direct reflection from nearby wall and thus the real cluster source is around the building corner opposite side of the road (3) the cluster seems to be far away according to the DoA along the route, but the delay is too short. It is more likely scattering from the rooftop level of the opposite building.

The original DoA data and DoA data after extracting the clusters are presented in Figures 2 and 3. In the figures angle 0° points towards the direction of motion. The azimuth angles grow clockwise, -90° points left and 90° right.

The total received wideband power and the residual power after extracting the clusters are presented in Figure 4. In average the residual power is 9.0 dB below the total power.

![Figure 1. Map of the environment, measured mobile route (dotted line), BS location (circle), and detected cluster sources (stars).](image1)

![Figure 2. Azimuth plot of the original DoA data.](image2)

![Figure 3. Azimuth plot of the DoA data after extracting the clusters.](image3)

![Figure 4. Total received power and power after extracting the clusters.](image4)

### IV. Results

To measure the significance of the clusters, the average proportion of power contributed by each of the clusters were calculated. The total received power of each snapshot was
normalized to one and the instantaneous proportions were averaged.

The standard deviation between the direction of previously located cluster source and the measured instantaneous azimuthal direction of the cluster was calculated for each of the clusters. The power weighted mean of the azimuth angles of the paths inside a single snapshot was used to represent the instantaneous measured direction.

The cross-polarization ratios (XPR) were calculated for the clusters to see if there is significant depolarization. The transmitted polarization was vertical.

Since a cluster itself may consist of several multipath components, the distributions of received signal strength were also studied. The received narrowband power of each cluster was normalized to the local mean by removing a sliding average value over 10 wavelengths. Thus considering only fast fading. The instantaneous amplitude was assumed to follow rician distribution and parameters which yield the best fit to the distribution were estimated. A high K factor means that the cluster consists of one dominating component while low or zero (-∞ in [dB]) implies that the amplitude is rayleigh distributed and there are no dominating component.

From propagation delay the length of the propagation path can be estimated. Note however that the propagation delay changes along the measured route. To calculate the propagation delay over the whole measured route, the instantaneous propagation delays were averaged.

The numerical results are presented in Table 1. From the mean proportions of power it can be seen that three most significant clusters contribute almost 60% of the total power, while most of the clusters contribute only few percents or even less. In average 19% of the received instantaneous power remains outside the clustering. Since all of the clusters are not visible through the whole route, the range of snapshots the cluster was visible or detected should be taken into account when considering the proportions of power.

The standard deviation varies between 4° and 11°, while the mean of the standard deviations is 7.6°. The value reflects the view angle of the cluster source seen from the receiver. However, few degrees of the deviation can be explained as well by the inaccuracy of the positioning of the receiving antenna during the measurement. The movement through the measured route was done by pulling the antenna on a trolley. Even the movement was done carefully, some variation in the direction is always present. Also the beam forming code itself may introduce some uncertainty when several waves are arriving within the beamwidth of the receiving array.

Depolarization inside the clusters is small, most of the XPR values are between 10 and 20 dB. One clear exeption is found from cluster 11, in which most of the power is received at horizontal polarization, having an XPR value of -3.5 dB.

The K-factors obtained from the rician fit vary from 2 dB to 21 dB, but for most of the clusters the K-factor is over 10 DB. It was also noted that the K-factor of the residual power is very low, thus it is following the Rayleigh distribution.

The propagation delay varies from 1.28 μs to 4.77 μs. These correspond to propagation path lenghts from 384 m to 1430 m, respectively.

### Table 1. Numerical results from the clusters.

<table>
<thead>
<tr>
<th># of cluster</th>
<th>Visbility [snapshot]</th>
<th>Proportion of power [%]</th>
<th>Std [°]</th>
<th>XPR [dB]</th>
<th>K [dB]</th>
<th>Propag. delay [μs]</th>
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<tr>
<td>1</td>
<td>1-4400</td>
<td>4.9</td>
<td>4.6</td>
<td>10.7</td>
<td>13.4</td>
<td>4.77</td>
</tr>
<tr>
<td>2</td>
<td>450-4400</td>
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<td>9.4</td>
<td>14.7</td>
<td>21.1</td>
<td>3.80</td>
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<tr>
<td>3</td>
<td>250-4400</td>
<td>0.4</td>
<td>5.1</td>
<td>9.2</td>
<td>18.5</td>
<td>3.30</td>
</tr>
<tr>
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<td>300-4400</td>
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<td>7.7</td>
<td>16.4</td>
<td>12.0</td>
<td>2.79</td>
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<tr>
<td>5</td>
<td>1-2500</td>
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<td>6.3</td>
<td>11.1</td>
<td>17.8</td>
<td>2.94</td>
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<td>6.4</td>
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<td>2.1</td>
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<td>8.9</td>
<td>10.1</td>
<td>18.9</td>
<td>1.66</td>
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<td>1-4400</td>
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<td>5.2</td>
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<td>12.2</td>
<td>1.56</td>
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<tr>
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<td>4.6</td>
<td>8.6</td>
<td>15.9</td>
<td>1.28</td>
</tr>
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<td>7.4</td>
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<td>15.2</td>
<td>1.33</td>
</tr>
<tr>
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<td>6.6</td>
<td>11.7</td>
<td>5.0</td>
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<tr>
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<td>11.3</td>
<td>11.3</td>
<td>9.9</td>
<td>1.90</td>
</tr>
<tr>
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<td>3.2</td>
<td>10.9</td>
<td>16.0</td>
<td>7.4</td>
<td>1.77</td>
</tr>
<tr>
<td>Residual</td>
<td></td>
<td>-</td>
<td>18.9</td>
<td>-</td>
<td>-</td>
<td>-84.8</td>
</tr>
</tbody>
</table>

V. Descriptions of the clusters

Since the clusters were separated and few describing parameters were calculated, some assumptions on their origin and propagation phenomena can be drawn. Below each of the 14 clusters are considered separately.

1. Long delay and arriving straight from front. Seems to be scattered from the large building ahead.
2. Similar to 1st cluster.
3. Similar to 1st cluster.
4. Source at the building corner ahead. Relatively long delay, but high XPR. Maybe the polarization is preserved due to specular reflections from building walls, but the propagation path has been longer than for most of the other clusters. Thus the signal path may go around the building in front, instead of the shortest way along street canyons or over rooftops.
5. Arriving directly from behind, scattering or diffraction from the building corner behind.
6. Roughly the same sourcepoint as for 4), but with shorter delay and very low K-factor. The amplitude is almost Rayleigh distributed. Assumed to be propagation along street canyons scattered to the measured route through the building corner opposite side of the road.
7. Scattering from round tower at the roof of the building. In azimuth the DoA increases from 0° to 55°, fades, and then again from 85° to 180°. The tower is on the same side as the TX.

8. Scattering from tower like construction on the building opposite side of the road. The tower rises slightly above the average building height.

9. Most significant of the extracted clusters. The peak in the total received power between snapshots 1500-2500 is generated by this cluster, see Fig 4. According to the cosine fit, the cluster source would be far away from the measured route. However the propagation delay of the cluster is approximately same as for the 8th cluster, which is coming from the opposite building. Thus also the origin of this cluster has to be in the same range. In the middle of the measured route the 8th and 9th cluster actually cross each others in both DoA and delay domain. Explanation for the cluster is assumed to be distributed scattering from the rooftop structures of the opposite building.

10. Cluster with the shortest delay. It is received over rooftop of the building at a corner of a small plaza beside the measured route.

11. The XPR of the cluster is -3.5 dB, which makes it very special compared to the others. The cluster is received with short delay and the elevation angle is rising fast from 30° to 70°. It is visible only for the first 1250 snapshot from the beginning of the route. The estimated cluster source is near the source of 7th cluster, which is a tower in a building corner. This cluster is reflection from the round metallic roof of the tower, similar heavy depolarization is observed also from other round metallic objects [3].

12. Similar to 10th cluster, but with longer delay.

13. The source is located inside a building, which does not seem reasonable. Any reliable assumption could not be drawn from the information available. It is possible however that the cluster is related to the strong 9th cluster, maybe through reflections from surrounding walls. The cluster appears after passing the plaza on other side of the road and sources of 8th and 9th cluster at the opposite side.

14. Possibly a specular reflection from the nearest wall. Applying the image source technique utilized in ray tracing to the wall would reposition the cluster source near the 4th and 6th cluster. Also the propagation delay is close to 6th cluster.

The residual power still represents 19% of the received power. There may still be several cluster that could be extracted from the data if the S/N-ratio of the measurement was higher or the angular and delay resolution was better. Yet still there will always be left clusters whose lifespan is short, scattering from the ground and objects near the MS, reflections from walls etc. For those this kind of clusterization approach is not suitable.

VI. CONCLUSION

All together 14 clusters were extracted from the measured DoA data and the source points of the clusters could be located to the surrounding environment with reasonable assumptions. The extracted clusters explain most of the received power, in average the residual power is 9 dB below total received power. All the clusters have long lifespan of 25% or more of the measured snapshots. This corresponds to 30 m or more along the measured route.

Three strongest clusters contributed nearly 60% of the received power, while most of the extracted clusters only few percents or less. All the three were also visible through the whole measured route. 19% of the received power remains outside the clustering.

The results show that the corners of the buildings and building structures above the average building height dominate the local propagation environment. Some of the clusters showed unexpected behavior or phenomena such as heavy depolarization and very strong scattering from the opposite building rooftop.

REFERENCES

