Multipath Cluster Polarization Characteristics of a Small Urban MIMO Macrocell

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Abstract—This paper presents clusterwise polarization characteristics taken from an estimated MIMO channel of a small urban macrocell at 4.5 GHz. Polarization path gain, cross-polarization ratio, and co-polarization ratio characteristics as influenced by channel parameters such as delay, azimuth and elevation angle of arrival were investigated. The results showed that polarization characteristics were almost independent of the azimuth angle of arrival and delay, whereas some correlation was found between the cross-polarization ratio and the elevation angle of arrival. The results also confirmed a log-normal cross-polarization ratio.

I. INTRODUCTION

Multiple-input–multiple-output (MIMO) wireless systems have attracted a lot of attention as a key technology to achieve high data rates [1], [2]. However, using only spatial diversity has disadvantages in terms of the size limitations especially at the mobile terminal. In this regard, the adoption of dual-polarized arrays has been proposed to enable polarization diversity as well [3], [4]. Moreover, since advantages of MIMO systems are exploited in multipath-rich environments, knowing the multipath channel including the effect of depolarization through the channel plays a key role in realistic system design. Given the above, polarimetric measurement results have been presented (e.g. [5]–[8]). However, how the polarization components depend on other channel parameters has not yet been thoroughly explored. In this paper, relations between polarization characteristics of an estimated MIMO channel and other channel parameters are presented. In particular, the polarization path gain and polarization ratio are examined. The estimated channel was derived from a small urban macrocell at 4.5 GHz and it is based on the double-directional channel model [9]. Multipath cluster parameters are the primary consideration of the analysis since their polarization behavior is also seen as an effect on the interaction of multipaths with scatterers in the environment. The rest of the document is organized as follows. Section II describes the measurement scenario and the equipment used, followed by brief description of the channel estimation and clusterization performed. In Section III the results are presented and analyzed and afterwards conclusions are drawn in Section IV.

II. MEASUREMENT

A. Channel Sounder and Environment

Channel sounding was performed using the RUSK channel sounder. Important specifications of this sounder are placed in Table I. The antenna arrays were carefully calibrated in an anechoic chamber. The sounder has a switched-array architecture, which uses fast switches at both ends of the channel. Reference clocks at both base station (BS) and mobile station (MS) ensure timing and switching synchronization throughout the measurement.

Figure 1 shows the small urban macrocell environment that was considered. The BS antenna was placed on the highest building in the measurement area, where the average building height around it was less than half its height. For the MS positions, they were placed along the street. Details of the measurement setup are shown in Table II.

B. Parameter Estimation and Multipath Clusterization

The complex polarimetric path weights ($\gamma_{VH}$, $\gamma_{HH}$, $\gamma_{HV}$, $\gamma_{VV}$), diffuse components, delay ($\tau$), azimuth ($\phi$) and co-elevation ($\theta$) angle of departure (AoD) and angle of arrival (AoA) were estimated by a gradient-based maximum likelihood multidimensional parameter estimation approach [11]. After parameter estimation, automatic clustering was done jointly in all the spatial and temporal dimensions. For the sake

| TABLE I RUSK-FUJITSU WIDEBAND MIMO CHANNEL SOUNDER [10] |
|---------------------|---------------------|
| Carrier frequency | 4.5 GHz |
| Bandwidth | 120 MHz |
| BS antenna array | Uniform rectangular array |
| 2 x 4 x 2 elements (row x col. x pol.) | |
| BS patch element | 3-dB VP beamwidth: 101°/89° |
| 3-dB HP beamwidth: 86°/94° |
| Main lobe gain: > 5 dBi |
| XPD: 13-15 dB | |
| MS antenna array | Stacked uniform circular array |
| 2 x 24 x 2 elements (row x col. x pol.) | |
| V & H polarized patch antennas | |
| MS patch element | 3-dB VP beamwidth: 122°/86° |
| 3-dB HP beamwidth: 61°/89° | |
| Main lobe gain: > 4 dBi |
| XPD: 10-14 dB | |
| Transmit signal | Wideband multitone |
| Max. delay setting | 3.2 µs |
| No. of MIMO channels | 1536 |

a V-plane  b H-plane  c VP-port / HP-port
TABLE II
SMALL URBAN MACROCELL SCENARIO

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS height</td>
<td>∼85 m</td>
</tr>
<tr>
<td>MS height</td>
<td>∼1.80 m</td>
</tr>
<tr>
<td>BS-MS distance</td>
<td>∼230 m - 400 m</td>
</tr>
<tr>
<td>Structure type</td>
<td>residential and industrial</td>
</tr>
<tr>
<td>Distance between MS positions</td>
<td>20 m</td>
</tr>
<tr>
<td>MS status</td>
<td>static; moving (slow walk)</td>
</tr>
<tr>
<td>Measurement condition</td>
<td>after midnight; clear spring weather</td>
</tr>
</tbody>
</table>

Fig. 1. Layout of the measurement scenario.

of brevity, details of the clustering algorithm are not presented here. Interested readers are referred to [12], [13]. Only static multipath estimates were used in clustering since the goal was to examine clusters due to multipath mechanisms. So paths that represent the line of sight (LoS) were removed using the single path estimate. In the analysis which follows, the average of the clustered path parameters were used.

III. RESULTS AND DISCUSSIONS

The results of the analysis are described in terms of polarization path gain, the polarization ratios, and the behavior of polarization ratios as influenced by the delay, azimuth AoA and elevation AoA.

A. Polarization Path Gain

For each polarization pair, the cluster path gain against distance between BS and MS is plotted in Fig. 2 together with their best-fit curves obtained by linear least squares. The fitted path gains in dB could be expressed as follows.

\[ P_{VV} = -22.55 \log_{10}(d) - 4.88 \quad (1) \]

\[ P_{HH} = -27.57 \log_{10}(d) + 8.21 \quad (2) \]

\[ P_{VH} = -25.81 \log_{10}(d) - 1.14 \quad (3) \]

\[ P_{HV} = -28.28 \log_{10}(d) + 5.12 \quad (4) \]

It was observed that the path gain of HH polarization pairs decay faster than that of VV polarization pairs. These co-polarized path gains were 4.65 dB higher than the cross-polarized ones. Quite similar observations are reported in [14] and [15] for different macrocell scenarios. In particular for indoor scenarios, [5] and [16] report that the HH path gain decays faster than the VV path gain. In [14], co-polarized pairs have been observed to be 4 to 10 dB higher than cross-polarized ones, whereas [15] observes a median value in this range.

B. Cluster Polarization Ratios

The cross-polarization ratio (XPR) indicates how much the polarization of the paths changes, whereas the co-polarization ratio (CPR) shows the degree of vertical polarization with respect to the horizontal polarization. The cluster XPRs and CPR were computed respectively as follows.

\[ XPR_{BS}^{SV} = 10 \log_{10} \left( \frac{\sum_{i \in C_k} |\gamma_{SV,i}|^2}{\sum_{i \in C_k} |\gamma_{SV,i}|^2} \right) \quad (5) \]

\[ XPR_{BS}^{SH} = 10 \log_{10} \left( \frac{\sum_{i \in C_k} |\gamma_{SH,i}|^2}{\sum_{i \in C_k} |\gamma_{SV,i}|^2} \right) \quad (6) \]
\[ \text{XPR}_{V}^{\text{MS}} = 10 \log_{10} \left( \frac{\sum_{l \in C_k} |\gamma_{VV,l}|^2}{\sum_{l \in C_k} |\gamma_{HV,l}|^2} \right) \]  

(7)

\[ \text{XPR}_{H}^{\text{MS}} = 10 \log_{10} \left( \frac{\sum_{l \in C_k} |\gamma_{HH,l}|^2}{\sum_{l \in C_k} |\gamma_{VH,l}|^2} \right) \]  

(8)

\[ \text{CPR} = 10 \log_{10} \left( \frac{\sum_{l \in C_k} |\gamma_{VV,l}|^2}{\sum_{l \in C_k} |\gamma_{HH,l}|^2} \right) \]  

(9)

In the notation in (5)-(8), XPR\textsuperscript{MS}\textsubscript{V} for example, is the XPR at the MS for paths \( l \) in the \( k \)-th cluster \( C_k \) that originated with \( V \) polarization, with the channel assumed to be reciprocal. Figure 3(a) shows a comparison of the cluster polarization ratios. Low CPRs were noted to be due to prevalence of horizontal scatterers in the environment. For the cluster XPRs, they could be considered as log-normally distributed as seen in their log-normal probability plots in Fig. 3(b)–3(e). As could be observed in Fig. 3(f), the CPR may not be log-normally distributed due to the 15% deviation in the tail.

C. Influence of Delay and Directions on Polarization Ratios

Figure 4 shows the individual effect of \( \theta^{\text{AoA}} \), \( \phi^{\text{AoA}} \) and \( \tau \) on XPR. It was observed that the influence of \( \theta^{\text{AoA}} \) on vertically transmitted components was stronger than their horizontal counterparts, with most of the concentration occurring from 40°–140°. Similar results have been obtained in [17], [18]. For \( \phi^{\text{AoA}} \) and \( \tau \), no significant effects were observed, which has been seen in [17] and [19] as well, where polarization is currently being considered independent of \( \phi \) and \( \tau \) for non-LoS (NLoS) macrocell environments. In the same way, the effect of the same parameters on CPR are presented in Fig. 5. Figure 6 and 7 show the inspection for the random behavior of the residuals. It was observed that general trends of residuals were similar for both XPR (Fig. 4) and CPR (Fig. 5), however, comparison with other results is limited.

Quantifying the linearity relationship among the parameters in Figs. 4 and 5 were done by calculating their correlation coefficients, which are listed in Table III. It should be noted that the correlation coefficient indicates only the ordinal relation. So to examine the correlation among the parameters closely, it would be difficult to give general observations.

IV. CONCLUSION

Multipath cluster polarization characteristics of a small urban macrocell at 4.5 GHz has been presented in this paper. The results indicate that cluster XPRs are log-normally distributed, which was not found to be true for the CPR due to the scenario. With respect to distance, HH polarization path gains were observed to decay faster than their VV counterparts. In the same way, both co-polarized gains were about 4.65 dB higher than cross-polarized gains. The analysis of the behavior of polarization ratios with respect to delay, and to direction shows that they are affected by elevation AoA, whereas delay and azimuth AoA do not show any significant impact. Consistencies with other published measurements have been observed as well, nonetheless there are differences. Generalizations should be explained from the environment structure, propagation mechanism, and the inclusion of other related measurement results should be done in the future.

ACKNOWLEDGMENT

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REFERENCES


Fig. 3. Probability plots of the polarization ratios.
Fig. 4. Influence of $\theta^{\text{AoA}}$, $\phi^{\text{AoA}}$ and $\tau$ on XPR with their best-fit lines.

Fig. 5. Influence of $\theta^{\text{AoA}}$, $\phi^{\text{AoA}}$ and $\tau$ on CPR with their best-fit lines.
Fig. 6. Normality check on the fitted XPR residuals.

Fig. 7. Normality check on the fitted CPR residuals.