Modelling of the Angle of Arrival Scattering Using the Von Mises Function for Compatibility Analysis

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Abstract— In this paper, the evaluation of the modeling capabilities of scattering angle for compatibility analysis is presented. We present an empirical power azimuth spectrum (PAS) model based on the von Mises distribution. This model allows a varied shape of AOA distribution. For different propagation scenarios, the fit of the von Mises model to empirical PAS is presented in figures. Results of measurements taken from the open literature are used as reference data. Authors present brief characteristics of measurement scenarios. Accuracy assessment of the fit of the proposed model and empirical data is shown by graphs and numerical calculations.

1. INTRODUCTION

A designing and building of sector antenna systems in the modern wireless communication systems require an analysis of a cross-sectors electromagnetic compatibility. This is due to the occurrence of the angular dispersion of the received signal. It is result of the multipath phenomena. This problem is particularly important in the urban environment.

To analyse the angle of arrival (AOA) are used two model types: the probability density function (PDF) of AOA and the power azimuth spectrum (PAS). PDF of AOA models are theoretical. In contrast, PAS models are practical, because the PAS characteristics are determined on the basis of measurements. PAS and PDF of AOA models can be divided into two main groups, i.e., theoretical geometric and empirical models. The empirical models, e.g., the Gaussian and Laplacian models, use the well-known functions (distributions) for modelling the statistical properties of AOA. For such models, physical interpretation is difficult, however, these functions fit well PAS characteristics obtained in the real environment.

This paper presents an empirical model based on the von Mises distribution. This model allows a varied shape of AOA distribution. The fit of the von Mises model to empirical PAS is presented in figures. Results of measurements taken from the open literature are used as reference data. Authors present brief characteristics of measurement scenarios. Accuracy assessment of the fit of the proposed model and empirical data is shown. The least-square error (LSE) and the rms angle spread are used as evaluation criteria.

The rms delay spread is used to classify the type of propagation environment. This parameter can be determined based on the power delay profile (PDP) or the power delay spectrum (PDS). Obtained results show that the proposed model can be applied to the channel modelling for the various scenarios and propagation conditions.

2. THE VON MISES DISTRIBUTION

The von Mises PDF for the azimuth AOA, $f(\theta)$, is given by [1]

$$f(\theta)=\frac{\exp\left(\kappa\cos\left(\theta-\theta_0\right)\right)}{2\pi I_0(\kappa)}\quad \text{for}\theta\in\left(-\pi,\pi\right\rangle \tag{1}$$

where $I_0(\kappa)$ is the zero-order modified Bessel function, $\theta_0 \in (-\pi, \pi\rangle$ accounts for the mean direction of AOA, and κ determines the width of AOA distribution. In Fig. 1, the graphs of von Mises PDF is presented for different values of κ.

As we can see, if model parameter equal to zero then this distribution is uniform that is often used for modelling of the local isotropic scattering. If the von Mises parameter tends to infinity then distribution has the high concentration and small variance like the Dirac delta. These properties are the basis for the adaptation of the model to different propagation environments. The accuracy assessment of PDF of AOA by von Mises distribution is determined on basis of measurement results for different scenarios. Since, this assessment is based on PASs comparison so von Mises distribution must be converted to PAS. Note that [2]

$$P(\theta)=P_0\cdot f(\theta) \tag{2}$$

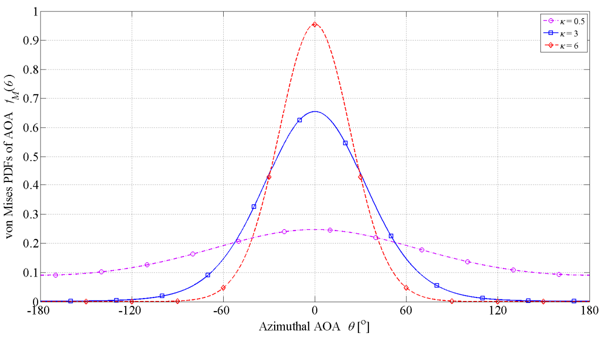

Figure 1: Von Mises PDF for different values of κ.

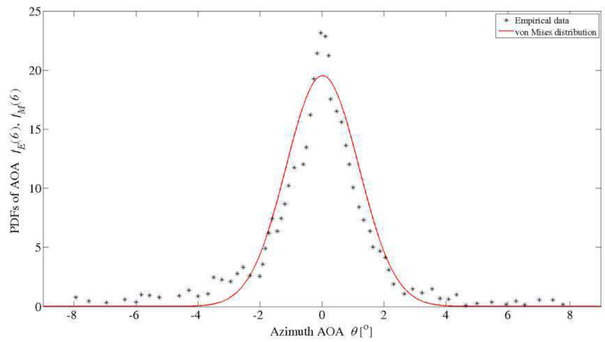

Figure 2: Von Mises model and empirical PAS – Bristol RA [3].

where P_0 total power of received signal.

Therefore, in logarithmic scale, we can describe PAS as

$$P_{\mathrm{dB}}(\theta)\ [\mathrm{dB}] = 10\log_{10}\frac{P(\theta)}{\max\left(P(\theta)\right)} = 10\log_{10}\frac{f(\theta)}{\max\left(f(\theta)\right)} \tag{3}$$

The error approximation assessment for empirical PAS and von Mises model is based on above expression.

3. MEASUREMENT SCENARIOS

The results of the PAS measurement that are presented in [3–6], are the basis for approximation error assessment of von Mises model for variation of propagation environments.

3.1. Scenario 1 (Sc1) [3]

The rural measurement campaign took place near Bristol in UK. This measurement place is classified as rural area (RA). The received antenna was mounted on base station (BS) tower at a height of 27 m. It ensures line-of-sight (LOS) propagation conditions. The received antenna was built with the eight-element phased antenna array. At the array output, the eight branch signals were sampled with interval equal 0.923 µs. These samples were stored on a hard disk for off-line processing. Time of recording a single measurement sequence required 4.6 ms. Transmitting antenna was an omnidirectional antenna that was mounted on the mobile station (MS). The frequency carrier and structure of the sounding signal were designed according to the DCS1800 standard. The average distance between MS and BS was 5000 m.

3.2. Scenario 2 (Sc2) [4]

The urban measurement campaign was conducted in Aarhus (Denmark). The propagation environment is characterized by an irregular street grid and buildings ranging from four to six floors. This measurement place is classified as typical urban area (TU). The measurement system was designed for uplink transmission. The BS was equipped with an eight-element uniform linear antenna array that was mounted on at a height of 32 m (12 m above average rooftop level). At the array output, the eight branch signals were sampled with interval equal 0.122 µs and recorded for further off-line processing. The signal transmitting source with an omnidirectional antenna was mounted on a car. The measurement carried out along six different routes having an average length of 2 km. The sounding signal operated at a carrier frequency of 1.8 GHz. Its bandwidth was comparable to the bandwidth used by selected wide-band Code-Division Multiple Access (CDMA) third-generation cellular system. In most cases, the propagation conditions were no line-of-sight (NLOS). The average distance between MS and BS is 1500 m.

3.3. Scenario 3 (Sc3) [4]

The measurement campaign was conducted in Stockholm (Sweden). This area is characterized as a TU with developed infrastructure. The same testbed, measurement methodology and parameters were used as in a case of the scenario 2. About difference between these two scenarios decides the height of the received antenna location. In this case, the BS antenna was mounted 21 m above ground level, which corresponds to the average rooftop level of the surrounding buildings.

3.4. Scenario 4 (Sc4) [5] and 5 (Sc5) [6]

The measurements were carried out in urban area with a high degree of urbanization. This measurement place is located in Aalborg (Denmark). The propagation environment is characterized by irregular street layout and mostly 3–5 story buildings with only a few higher buildings. It is classified as a TU area. Measurement system was designed for uplink transmission. The BS was equipped with an eight-element uniform linear antenna array that was mounted on at a height of 41 m. The signal transmitting source with an omnidirectional antenna was mounted on a car (MS). The frequency carrier (1.8 GHz) and structure of the sounding signal were designed according to the GSM standard. So, its bandwidth was comparable to the bandwidth (200 kHz) used by GSM two-generation cellular system. Measurements were carried out along four test routes, where the average distance from BS is 2.1 km. For scenario 4 and 5, the measurement campaigns were conducted in the same propagation environment. The diversity of these scenarios due to different measurement routs.

4. COMPARISON OF THE VON MISES MODEL AND EMPIRICAL RESULTS

Adaptation of von Mises model to empirical data is made possible by the parameter of the model. The selection criterion of κ value is minimize *LSE*. In Figs. 2–6, the graphical comparisons of

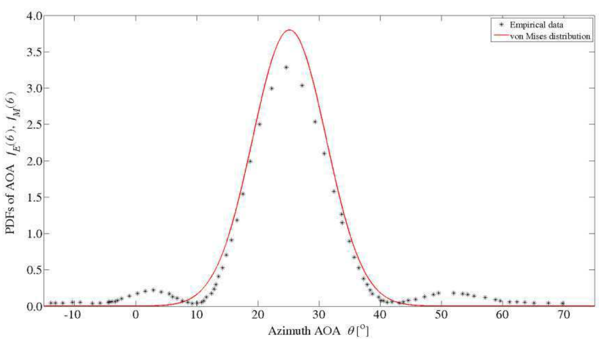

Figure 3: Von Mises model and empirical PAS — Aarhus TU [4].

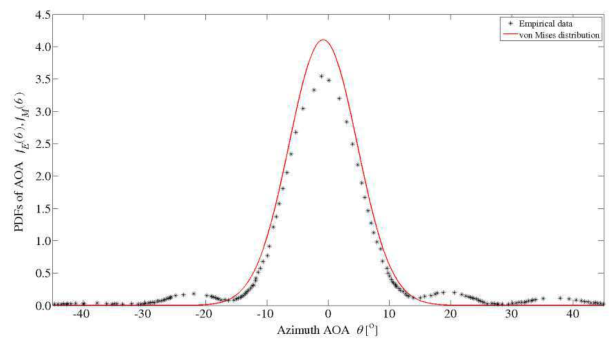

Figure 4: Von Mises model and empirical PAS — Stockholm TU [4].

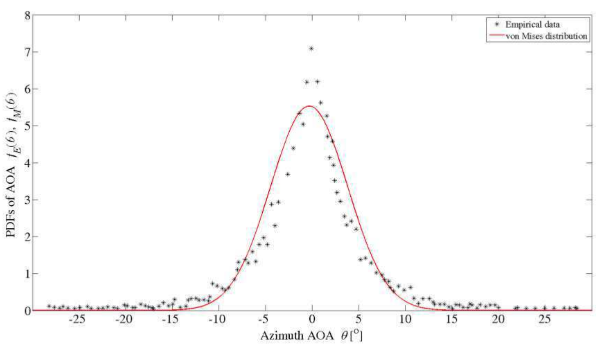

Figure 5: Von Mises model and empirical PAS — Aalborg TU [5].

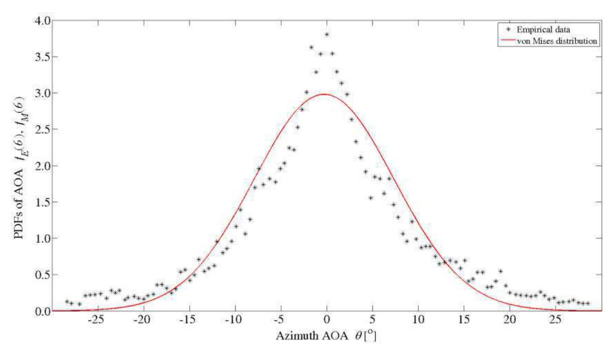

Figure 6: Von Mises model and empirical PAS — Aalborg TU [6].

Table 1: The results of numerical calculation for measurement scenarios.

	Sc1	Sc2	Sc3	Sc4	Sc5
σ_τ [µs]	0.0932	0.3221	0.6285	1.2337	1.2337
σ_θ [°]	2.089	6.428	9.445	9.782	10.169
$\sigma_{\theta M}$ [°]	1.173	4.162	7.679	5.604	6.045
LSE	3,228008	0,189050	0,083797	0,018543	0,019532
κ [1]	2398.4	192.5	56.0	106.1	90.9

where: σ_τ, σ_θ — rms delay and angle spread, respectively for measurement,
$\sigma_{\theta M}$ — rms angle spread for von Mises model,
κ — optimum value of von Mises model parameter.

empirical results and von Mises model with κ optimum value are presented.

For each measurement scenarios, the results of numerical calculations are presented in Table 1.

As we can see, von Mises model of PAS provides faithful reproduction of the scattering angle of reception signal. The approximation error of the angle spread does not exceed a few degrees. The article connected with the topic of this article are [7–11].

5. CONCLUSIONS

In this paper, the evaluation of the modeling capabilities of scattering angle for compatibility analysis is presented. Obtained results show that von Mises model of PAS reproduces probabilistic AOA properties. The choice of the model parameter value makes it possible to adopt the model to different environmental propagation conditions. This fact provides the versatility of von Mises model. It gives a basis to assess the interference level which arrives at receiver from the cells served by neighboring base stations.

REFERENCES

1. Abdi, A., J. A. Barger, and M. Kaveh, "A parametric model for the distribution of the angle of arrival and the associated correlation function and power spectrum at the mobile station," *IEEE Transactions on Vehicular Technology*, Vol. 51, No. 3, 425–434, May 2002.
2. Ziółkowski, C., "Statistical model of the angular power distribution for wireless multipath environments," *IET Microwaves, Antennas & Propagation*, Vol. 9, No. 3, 281–289, Feb. 2015.
3. Pedersen, K. I., P. E. Mogensen, and B. H. Fleury, "Power azimuth spectrum in outdoor environments," *Electronics Letters*, Vol. 33, No. 18, 1583–1584, Aug. 1997.
4. Pedersen, K. I., P. E. Mogensen, and B. H. Fleury, "A stochastic model of the temporal and azimuthal dispersion seen at the base station in outdoor propagation environments," *IEEE Transactions on Vehicular Technology*, Vol. 49, No. 2, 437–447, Mar. 2000.
5. Mogensen, P. E., K. I. Pedersen, P. Leth-Espensen, B. H. Fleury, F. Frederiksen, K. Olesen, and S. L. Larsen, "Preliminary measurement results from an adaptive antenna array testbed for GSM/UMTS," *IEEE VTC-1997 47th IEEE Vehicular Technology Conference*, Vol. 3, 1592–1596, Phoenix, AZ, USA, 1997.
6. Fleury, B. H., M. Tschudin, R. Heddergott, D. Dahlhaus, and K. I. Pedersen, "Channel parameter estimation in mobile radio environments using the SAGE algorithm," *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 3, 434–450, Mar. 1999.
7. Kubacki, R., R. Przesmycki, and J. Ferenc, "Własnosci elektromagnetyczne nanokrystalicznego proszku stopu Fe-Si-B-Cu-Nb w zakresie mikrofalowym," *Przeglad Elektrotechniczny (Electrical Review)*, 92–95, ISSN 0033-2097, NR 12b/2011.
8. Przesmycki, R., "Measurement and analysis of compromising emanation for laser printer," *PIERS Proceedings*, 2661–2665, Guangzhou, China, Aug. 25–28, 2014.
9. Przesmycki, R. and P. Skokowski, "Dual band microstrip antenna," *PIERS Proceedings*, 2641–2645, Guangzhou, China, Aug. 25–28, 2014.
10. Bugaj, M., "Measurements of wall attenuation in closed spaces inside a building," *PIERS Proceedings*, 2681–2686, Guangzhou, China, Aug. 25–28, 2014.
11. Bugaj, M., "Attenuation measurements of materials used in construction of buildings," *PIERS Proceedings*, 2671–2675, Guangzhou, China, Aug. 25–28, 2014.