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Influence of the propagation environment on statistical properties of bearing

***Abstract**. The paper relates to issue of the radio direction finding. The impact of the propagation environment on the angle dispersion of the received signal is presented. This analysis is based on the measurements that are shown in open literature. The empirical results are the basis to determine the mutual relationship between the rms angle spread and rms delay spread. The Laplacian function is used to describe the statistical properties of received signal angle. For this function, the optimal fit to type of propagation environment is determined based on the relationship between the rms delay spread and the function parameter. As the match criterion of this function, the least-square error is used. The resulting statistics makes it possible to assess of the impact of the propagation environment on accuracy of the radio direction finding procedures.*

***Streszczenie.** Artykuł poświęcony jest problematyce namierzania radiowego. Bazując na wynikach pomiarów prezentowanych w literaturze, przedstawiono w nim analizę wpływu właściwości transmisyjnych środowiska na rozrzut kąta odbioru sygnałów. Na podstawie wyników pomiarów wyznaczona została wzajemna relacja pomiędzy rozproszeniem kąta dotarcia sygnału do odbiornika a wartością skuteczną rozmycia opóźnienia sygnału. Do opisu właściwości statystycznych kąta odbioru sygnału wykorzystana została funkcja Laplace'a. Optymalne dopasowanie tej funkcji do typu środowiska propagacji zostało wyznaczone na podstawie związku jej parametru z rms opóźnienia. Jako kryterium dopasowania wykorzystano błąd średniokwadratowy. Uzyskana statystyka daje możliwość oceny wpływu środowiska na dokładność realizacji procedury namierzania. (**Wpływ środowiska propagacji na statystyczne właściwości namiaru**).*

Keywords: radio direction finding, multipath environment, channel dispersion, angle spread.
Słowa kluczowe: namierzanie radiowe, środowisko wielodrogowe, dyspersja kanału, rozmycie kąta odbioru sygnału.

Introduction

The degree of environment urbanization has a significant impact on statistical properties of received signal. The probabilistic properties of received signal angle are particularly important. These are basis for the procedures of determining position of radio wave emission sources. Numerous measurement results show that the increase of the urbanization degree causes the increase of the angular dispersion of received signal power. The reason of this effect is the increase of propagation multipath intensity that is characteristic for the environment with dense buildings. Additionally, for most cases in urban areas, the radio connections are realized in non-line-of-sight (NLOS) propagation conditions. This fact reinforces the impact of propagation multipath on increase of the received signal angle dispersion.

The angular dispersion of power causes a significant increase of the errors in radio direction finding procedure. It limits the use of this method for location of radio waves emission sources in urban areas. Therefore, mapping of the statistical properties of the reception angle has significant importance for the evaluation of the error in radio direction finding procedures. For description of these properties, the power azimuth spectrum (PAS) characteristic and probability density function (PDF) of angle of arrival (AOA) are used. The first of these characteristics has practical importance, because it is directly determined on the basis of the measurements [1-4]. Whereas, PDF of AOA is theoretical nature, because it is the result of spatial analysis of propagation phenomena that are based on the geometrical propagation models (GPMs) [5-8]. The essence of the geometric modeling consists in the adoption of assumptions which define the spatial distribution and/or shape of scattering area. Such adopted geometric structure is the basis for PDF of AOA analysis. The fundamental deficiency of this approach to the problem is lack of opportunities of practical verification of shape and size of scattering area. The second method of the angle distribution evaluation involves using the selected function to approximate the measurement data. In [1], the use of the Laplacian function to approximate measurement data is presented, whereas the approximation accuracy for the Laplacian and Gaussian functions is compared in [2]. Analysis of the obtained results is a premise for the use of the Laplacian function to approximate PAS. In this case, the main problem is the determination of the relationship between Laplacian function parameter and transmission properties of propagation environment.

In this paper, the relationship between Laplacian function parameter and rms delay spread is determined on the basis of the selected measurement scenarios. The selection criterion of measurement scenarios have been necessary data that describe the power spread in time and angle domain. The use of the Laplacian function makes it possible to model the dispersion of the bearing as a function of type environment. It is a practical importance for evaluation of errors in the radio direction finding procedure.

Descriptions of measurement scenarios

The results of PAS measurement that are presented in [1-4], are the basis for assessment of the environment impact on the direction finding error. The measurement scenarios and presented results indicate diversity of types analyzed propagation environments. Thanks to this, the obtained results make it possible to assess the impact of the terrain infrastructure on accuracy of direction finding procedure.

Scenario 1 [2]

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.

Scenario 2 [1]

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. 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 NLOS. The average distance between MS and BS is 1500 m.

Scenario 3 [1]

The measurement campaign was conducted in Stockholm (Sweden). This area is characterized as 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, BS antenna was mounted 21 m above ground level, which corresponds to the average rooftop level of the surrounding buildings.

Scenario 4 [3] and 5 [4]

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 TU, Measurement system was designed for uplink transmission. BS antenna consists of 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 second-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.

Analysis of measurement results

Evaluation of the propagation properties of environment is based on the characteristics that describe signal power dispersion in both the time, power delay spectrum (PDS), and the angle, PAS. The classification of propagation environments enable the measures that are defined by these characteristics. For these measures, the basis is the square root of second order central moment. In time domain, it is rms delay spread, σ_τ , and in angle domain, it is rms angle spread, σ_θ [9]

(1)
$$\sigma_\tau = \sqrt{\frac{\int_0^\infty \tau^2 P(\tau)\mathrm{d}\tau}{\int_0^\infty P(\tau)\mathrm{d}\tau} - \left(\frac{\int_0^\infty \tau P(\tau)\mathrm{d}\tau}{\int_0^\infty P(\tau)\mathrm{d}\tau}\right)^2}$$

(2)
$$\sigma_\theta = \sqrt{\frac{\int_{-180^\circ}^{180^\circ} \theta^2 P(\theta)\mathrm{d}\theta}{\int_{-180^\circ}^{180^\circ} P(\theta)\mathrm{d}\theta} - \left(\frac{\int_{-180^\circ}^{180^\circ} \theta P(\theta)\mathrm{d}\theta}{\int_{-180^\circ}^{180^\circ} P(\theta)\mathrm{d}\theta}\right)^2}$$

where $P(\tau)$ and $P(\theta)$ denote PDS and PAS, respectively.

For classification of the propagation environment type is primarily applied the first parameter. For all analyzed measurement scenarios, σ_τ and σ_θ are determined based on PDS and PAS, respectively. For individual measurement scenarios, the numerical calculation results of these parameters are presented in Table 1.

Table 1. σ_τ and σ_θ for the analysed measurement scenarios

Scenario	σ_τ [µs]	σ_θ [°]
1 [2]	0.10	1.85
2 [1]	0.29	6.79
3 [1]	0.59	9.79
4 [3]	1.13	19.01
5 [4]	1.13	24.40

The obtained results show that with the increase of σ_τ , the value of σ_θ increases. This means that the dispersion of the received signal angle increases with the increase of the environment urbanization degree. In environment with a complex infrastructure, this effect is the reason for a significant increase of errors in radio direction finding procedures. Therefore, the statistical properties of received signal angle are important in the accuracy analysis that determines the correctness assessment of the direction finding empirical results.

Approximation of the angular dispersion of power

The Laplacian function is one of the basic functions which is used to approximation of PAS

(3)
$$P(\theta) = P_0 C_L \frac{\lambda}{2}\exp(-\lambda|\theta|) \quad \text{for} \quad \theta \in \left(-180^\circ, 180^\circ\right\rangle$$

where $\lambda \geq 0$ is function parameter which the value depends on the propagation environment properties, P_0 is the average power of received signal, and C_L it is a constant which comes from normalization condition

(4)
$$\int_{-180^\circ}^{180^\circ} C_L \frac{\lambda}{2}\exp(-\lambda|\theta|)\mathrm{d}\theta = 1$$

The examples of the measurement data approximation by the Laplacian function are shown in [1] and [2]. In these papers, the presented results concern only to the selected measurement scenarios. This paper extends the analysis of the use of Laplacian function to approximate PAS. In this case, more measurement scenarios for differential propagation environments are considered.

The problem of the measurement result modeling consists in such selection of λ value that provides the best fit of the model to the empirical data. In this paper, the match criterion is the minimization of the least-squares error (LSE)

(5)
$$LSE = \frac{1}{360^\circ}\int_{-180^\circ}^{180^\circ} \left(P(\theta) - P_E(\theta)\right)^2 \mathrm{d}\theta$$

where $P(\theta)$ is PAS model, $P_E(\theta)$ is empirical PAS.

For analyzed measurement scenarios, empirical PAS and fitting Laplacian function with optimally chosen λ values are presented in Figs. 1-5.

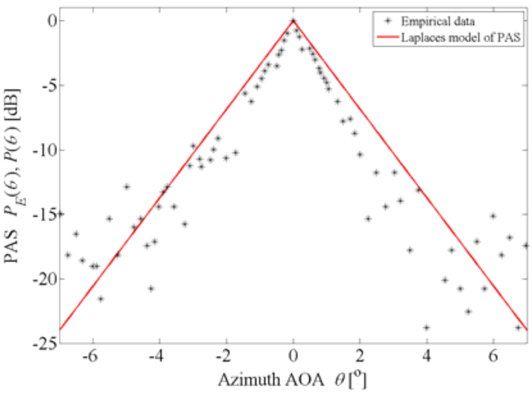

Fig.1. Empirical PAS and fitting Laplacian function for scenario 1 [2]

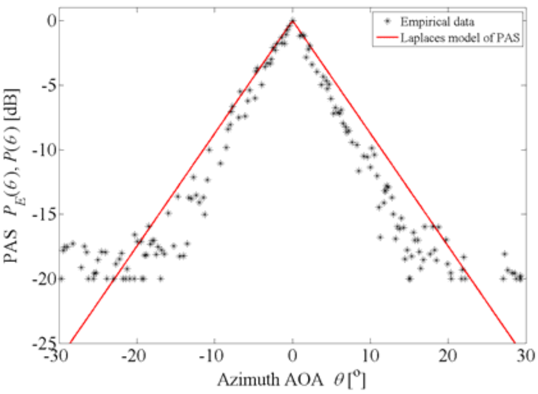

Fig.2. Empirical PAS and fitting Laplacian function for scenario 2 [1]

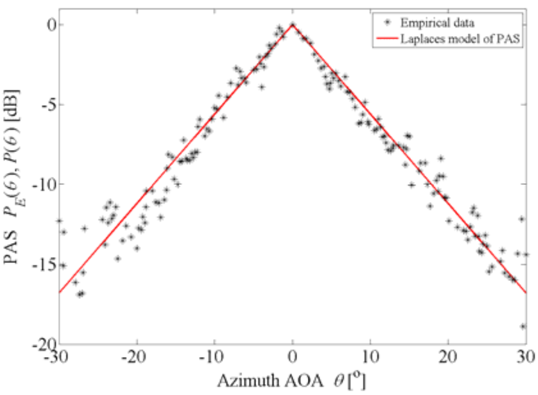

Fig.3. Empirical PAS and fitting Laplacian function for scenario 3 [1]

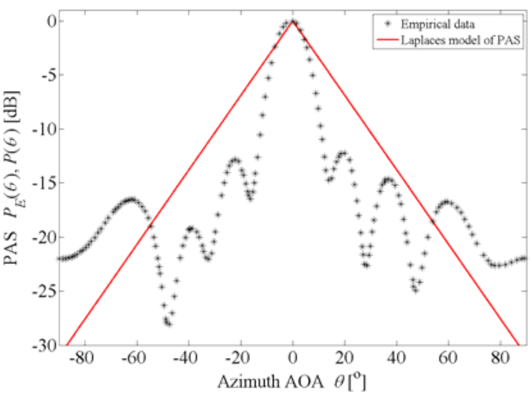

Fig.4. Empirical PAS and fitting Laplacian function for scenario 4 [3]

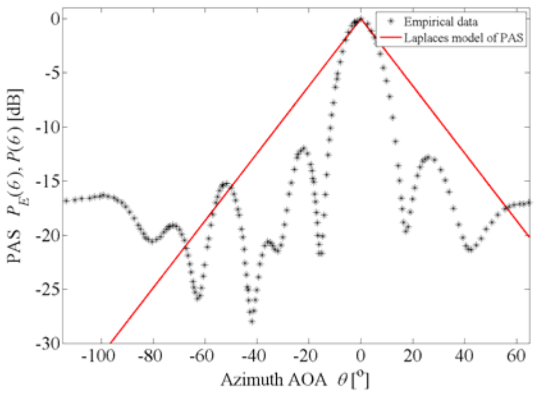

Fig.5. Empirical PAS and fitting Laplacian function for scenario 5 [4]

The presented graphs show that Laplacian function provides an approximation of the data measured in the different propagation conditions. It means that this function can be used for statistical evaluation of the angular dispersion of received power.

For individual measurement scenarios, the rms delay spread, σ_τ, is determined on the basis of the fitting Laplacian function. In Table 2, σ_τ, optimally λ vales and the corresponding σ_L values are presented.

Table 2. σ_τ, λ, and σ_L for the analysed measurement scenarios

Scenario	σ_τ [μs]	λ [1/°]	σ_L [°]
1 [2]	0.10	0.7895	1.79
2 [1]	0.29	0.2014	7.02
3 [1]	0.59	0.1289	10.97
4 [3]	1.13	0.0794	17.81
5 [4]	1.13	0.0716	19.75

The calculation results of σ_θ and σ_L that are included in Table 1 and Table 2, allow to evaluate the accuracy of the empirical data mapping by Laplacian function. The comparison of the obtained results shows that the analyzed model provides the mapping of the angular spread of power with a relatively small error. The results that are included in Table 2, shows the relationship between σ_L and σ_τ. The linear approximation of this relationship is determined on the basis of the least square method [10]

(6) $$\sigma_L(\sigma_\tau) = 15.59 \cdot \sigma_\tau + 1.37$$

But, for Laplacian function is

(7) $$\sigma_L^2 = \frac{\int_{-180^\circ}^{180^\circ} \theta^2 P(\theta) d\theta}{\int_{-180^\circ}^{180^\circ} P(\theta) d\theta} = \frac{\int_{-180^\circ}^{180^\circ} \theta^2 \exp(-\lambda|\theta|) d\theta}{\int_{-180^\circ}^{180^\circ} \exp(-\lambda|\theta|) d\theta} = \frac{\frac{2}{\lambda^2} - \exp(-180^\circ \cdot \lambda) \cdot \left(\frac{2}{\lambda^2} + \frac{360^\circ}{\lambda} + (180^\circ)^2 \right)}{1 - \exp(-180^\circ \cdot \lambda)}$$

In practice, the above expression simplifies to the form

(8) $$\sigma_L^2 \cong \frac{2}{\lambda^2}$$

Taking into account (6), λ fit to the type of propagation environment can be described as follows

(9) $$\lambda(\sigma_\tau) = \frac{\sqrt{2}}{15.59 \cdot \sigma_\tau + 1.37}$$

In Fig.6, the graph of above expression is presented. Additionally, the ranges of the specific types of propagation environments are marked in this figure.

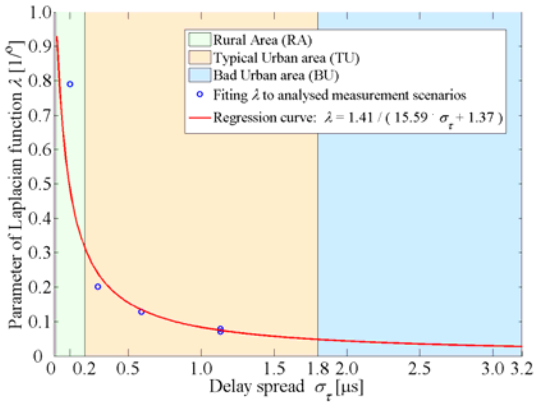

Fig.6. λ as a function of the propagation environment type

The graph shows, that λ changes dynamically in the range of RA type, and on the border ranges between RA and TU. This means a great diversity of the propagation conditions in RAs. Therefore, in this case, the accuracy of σ_τ calculation is important for a correct evaluation of the angular dispersion of received signal.

The obtained relationship enables the use of Laplacian function to statistical evaluation of the angular dispersion of power. This is the basis for the accuracy analysis of the direction finding procedures in TUs.

Conclusion

The results of the angular dispersion of power as a function of propagation environment properties are presented in this paper. This analysis is performed on the basis of the measurement data contained in open literature. The results of this analysis show that the increase of the urbanization degree causes a significant increase in errors of the direction finding procedure. In this paper, presented the relationship between σ_L and σ_τ is the basis for the adaptation of the Laplacian function to modeling statistical properties of the angular dispersion of received power. This makes it possible to carry out a statistical evaluation of the direction finding procedures for urbanization areas.

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