Regular paper

Modeling spatial aspects of mobile channel for low antenna height environments

Mohammed T. Simsim, Noor M. Khan, and Predrag B. Rapajic

Abstract— It is essential to have deep understanding of the mobile radio channel in particular for radio communication modeling and advanced technology system design. Models for the mobile radio channel are vital for the study of smart antenna systems, both for the design of algorithms, system-testing purposes, and for network planning. This paper provides an intensive study of the spatial characteristics of the mobile channel for low antenna height cellular environments, i.e., picocells and microcells, assuming Gaussian distributed scatterers. We investigate previous work on the angle of arrival (AoA) statistics for Gaussian distributed scatterers and make appropriate comments. Further, we employ the recently proposed eccentro-scattering physical channel model, as a generalized model, to derive the probability density function (pdf) of AoA of the multipaths at base station (BS) assuming Gaussian distributed scatterers around both BS and mobile station (MS). We found that the pdf of AoA at BS is directly affected by the standard deviation of the scatterers' density and the size of the scattering disc. The derived formulas, in closed form, can be used further for performance assessment of smart antennas and beamwidth design purposes.

Keywords— Gaussian distributions, geometric modeling, multipath channels, scattering.

1. Introduction

During the last few years, there has been a great interest in the research to enhance the capacity of the mobile radio channel to meet the increasing demand of large data rate transmissions. Towards this goal, more attention was given to the spatial domain of the radio propagation channel in order to employ it more efficiently. While conventional transceivers use temporal and spectral signal processing, modern transceivers need to exploit the spatial dimension, as well. Smart antenna technology was proposed as a promising technical solution that utilizes the spatial parameters of the radio propagation channel to enhance the performance [1, 2].

In order to exploit the spatial dimension efficiently, reliable channel models are required which would lead to the design of effective signal processing schemes. Wireless signal has unpredictable behavior due to multipath fading, which confronts the effective exploitation of the mobile radio channel. Complete knowledge of the multipaths would bring about great improvements in wireless communication services in terms of capacity and performance.

Radio environments have extremely different geographical and electrical features, which in turn lead to different propagation mechanisms. However, similar propagation mechanisms have been characterized into three main categories based on the cell type, i.e., picocell, microcell, and macrocell environments. Yet, there would still be some variability within these categories due to differences in antenna heights of base station (BS) and mobile station (MS), average height of the surrounding buildings, distance between BS and MS, total number of users, distances between users, etc.

The idea of generic channel modeling and the description of its parameters based on some measurements has been presented in [3, 4]. It may take few more years to obtain the correct parameters for such generic models from rigorous measurement campaigns [4]. Even though, many geometry-based physical channel models have been proposed in the literature [5–15] but still the discussion is open to adopt set of values as the actual parameters for different cellular environments [4].

Previously proposed geometry-based physical channel models are specific for modeling particular cellular environments. For instance, circular scattering models (CSM) were proposed to model the scattering environment in macrocells [9–11] and elliptical scattering model (ESM) was proposed to model the scattering environment in picocells and microcells [11, 12]. The distribution of scatterers within the scattering area is considered to be either uniform or Gaussian. In uniformly distributed scattering region, scatterers are assumed to have constant density throughout the scattering area, which simplifies the analysis and manipulation. Whereas for Gaussian distributed scatterers, the majority of scattering points are situated close to MS and the density of scattering points decreases as the distance from MS increases. This is a more practical approach to model real situations.

Considering the proximity of a model to a particular environment, the previous models are very specific to their environments either with respect to the shape of the scattering disc [9–12] or with respect to the standard deviation of the Gaussian distributed scatterers around MS [13]. An elliptical model was proposed in [14], which could be used as a circular one as well with change in eccentricity of the ellipse, for uniformly distributed scatterers, only. Even though, the model was able to explain the radio wave propagation phenomenon in macrocell and quasi-macrocell environments but did not deliver enough information to model picocell and microcell environments where both MS and BS fall inside the scattering region. This is due to the fact that, in picocell and microcell environments, the antenna heights, of transmitter and receiver, are lower as compared to those in macrocell and quasi-macrocell environments. Therefore, multipath scattering is assumed near BS and MS.

Gaussian scatter density model (GSDM) was proposed in [13] to be applied to every type of cellular environment by changing the standard deviation of the scatterers around MS, only. Thus, to model a picocell environment using GSDM, the standard deviation of the scatterers around MS is increased in order to encompass BS inside the scattering area. This way, BS is supposed to be inside the scattering region but it falls at its edge, hence the density of scatterers around BS would be much less than that around MS, which is not always the case especially in picocell environments. Usually in picocells, scatterers exist in the vicinity of BS as much as around MS. Moreover, a comparison is presented in [13] among GSDM, CSM, and ESM to show the superiority of GSDM. It is worth noting that GSDM assumes Gaussian distribution for the scatterers around MS without confining the scatterers in a scattering disc while CSM and ESM assume uniform distribution of the scatterers confined in scattering discs, which may include MS only (for CSM), or both MS and BS (for ESM). Therefore, this comparison makes no clear distinction between the shape of the scattering disc and the distribution of scatterers within that disc.

A generalized physical channel model has been recently proposed in [16] that can be used to model all types of cellular environments, i.e., picocell, microcell, macrocell, uniform scattering, Gaussian scattering, bounded scatterers, unbounded scatterers with appropriate choice of few model parameters. This provides a unified approach to model all cellular environments. The proposed eccentro-scattering model can be easily used to derive the probability density function (pdf) of angle of arrival (AoA) of the multipaths at BS and/or MS.

Here, we employ the eccentro-scattering physical channel model [16] to derive the pdf of AoA of the multipaths at BS from Gaussian distributed scattering regions around MS and BS for picocell and microcell environments while we carry similar work for macrocell environment in another paper. The derived formulas for the pdf of AoA in closed form are useful for analytical and simulation purposes.

The angular distribution of the received multipath components is very useful in systems employing spatial filtering, e.g., smart antennas, to determine the performance of radio link [12]. Even thought, it is possible to obtain the pdf of AoA from measured data or from site-specific propagation prediction techniques, however this type of data may not be always available. Therefore, statistical models are helpful to characterize the AoA of the multipaths. Furthermore, being a generalized model yields more flexibility, since it is easy to imitate several environments/situations by changing the model parameters.

Angle of arrival statistics are helpful in the performance and capacity enhancement of multiple input multiple output (MIMO) systems. Spatial division multiple access (SDMA) is a special case of MIMO systems intended for multiuser detection in which BS antenna coefficients are optimized, adaptively, for radiating maximum energy towards the desired user keeping it orthogonal to all other users in spatial domain. So, the pdf of AoA becomes an important factor in designing beamwidth and incidence angle for SDMA case.

Our contributions in this paper are as follows:

- We inspect previous work [9, 13, 15, 17] on the scatterers' density and AoA statistics for Gaussian distributed scatterers and make appropriate comments and comparisons.
- We exploit the recently proposed eccentro-scattering physical channel model to derive the pdf of AoA of the multipath signals at BS in closed form for Gaussian distributed scatterers around both BS and MS. That is, the model assumes Gaussian distributed scatterers around MS in addition to another Gaussian distributed scatterers around BS, each with different standard deviation, in order to provide more flexibility in the design and to simulate the real situations more closely. Being able to independently change the standard deviations of these two Gaussian functions means that we can have a model of Gaussian distributed scatterers around MS only, e.g., GSDM, or a model of Gaussian distributed scatterers around BS only as special cases. Whereas the general case corresponds to the model of Gaussian distributed scatterers around both BS and MS where increasing (or decreasing) the corresponding standard deviation indicates less (or more) scattering density in the vicinity of the respective antenna.
- We consider Gaussian distributed scatterers confined in a scattering disc and investigate the advantages of this technique.

The rest of the paper is organized as follows: in Section 2 we present the physical channel model and describe its parameters, Section 3 presents the derivation of the pdf of AoA of the multipaths at BS and Section 4 concludes the paper.

2. Channel model

2.1. General remarks

Wave propagation path changes in different environments according to scatterers' density and distance between BS and MS depending on the maximum delay spread. The propagated radio signal experiences shorter delays in picocell and microcell environments as compared to macrocell environment. The word "scattering" is not only

used for diffuse scattering but even for those processes that are strictly speaking "'specular reflections" [3].
In picocell environment, BS and MS are few meters away from each other and are surrounded by local scatterers (Fig. 1a). The antenna heights are relatively low and multipath scattering is assumed near BS as likely as around MS. This situation mainly occurs in indoor wireless communication, i.e., offices and factory/hall, and it may include street crossings under some circumstances.

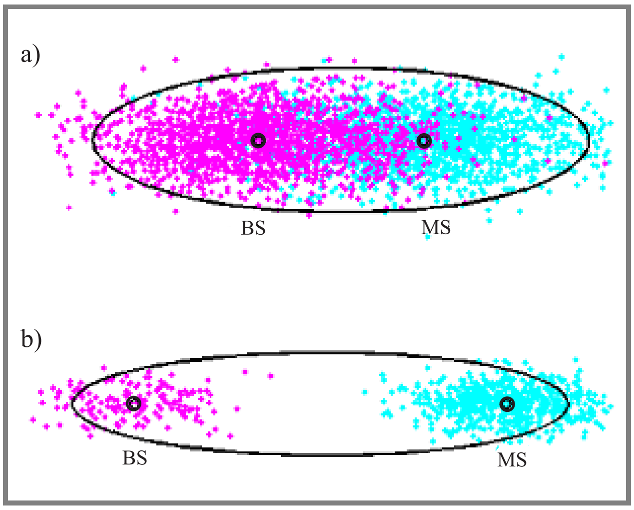

Fig. 1. Picocell (a) and microcell (b) environments.

In microcell environment, the distance between BS and MS is greater than that in picocell environment (typically in the order of a few hundred meters [3]). Here also antenna heights are relatively low, however BS usually has less scattering points in its vicinity as compared to MS (Fig. 1b). This situation corresponds, in general, to streets and open areas such as shopping malls, busy roads, and downtown areas.
Our study is based on the following assumptions.

- Scatterers are enclosed in an elliptical scattering disc whose eccentricity can be altered according to the maximum delay spread and the distance between BS and MS. Considering unbounded scattering regions may simplify the derivation but it is not practical since multipaths with longer delays experience greater path loss and therefore have relatively low power as compared to those with shorter delays [12, 17]. The scattering disc, which is referred to as "the eccentro-scattering disc" [16], can simulate both circular and elliptical models with corresponding choice of eccentricity.

- Scatterers are Gaussian distributed within the scattering disc. We investigate the relation between the standard deviation of the distribution of scatterers and the pdf of AoA of the multipath signals at BS.

- Multipath signals received at the antenna are plane waves coming from the horizon, i.e., only azimuthal coordinate is considered.

- Received signal at the antenna undergoes no more than one reflection by scatterers when traveling between transmitter and receiver. Placing a scattering object at the last re-radiation and approximating the preceding scattering as a stochastic process can retain some of the properties of multiple bounces while providing for a much simpler model [18]. Practically, we are considering only the distribution of scatterers contributing to the last reradiation while the preceding multiple-bounce can be modeled as a stochastic process which has lognormal shadowing with Nakagami fading [19]. This assumption, in conjunction with the first assumption, means that we are considering all scatterers giving rise to a single bounce multipath signal arriving at the receiving antenna up to $\tau_{\max}$. Hence, $\tau_{\max}$ is the maximum allowed delay spread, i.e., the time difference between first and last signal arrivals at the receiving antenna with signal power exceeding some threshold value defined by the system designer.

- Each scatterer is assumed to be an omnidirectional re-radiating element with equal scattering coefficients and uniform random phases.

- Effective antenna pattern is omnidirectional. Practically, the derived formulas for the pdf of AoA should be used in conjunction with the actual antenna radiation pattern.

2.2. Model description

The elliptical diagram shown in Fig. 2 represents the eccentro-scattering model for picocell and microcell environments. In the figure, C is the center of the ellipse with foci B (BS) and M (MS) separated by a distance D and with semi-major and semi-minor axes a and b, respectively. The line segments r_b and r_m satisfy

$$r_b + r_m = 2a \, . \tag{1}$$

Local scatterers exist in the vicinity of BS and MS in picocell and microcell environments, as mentioned before. Therefore both BS and MS are placed inside the elliptical scattering disc. Based on the eccentro-scattering model,

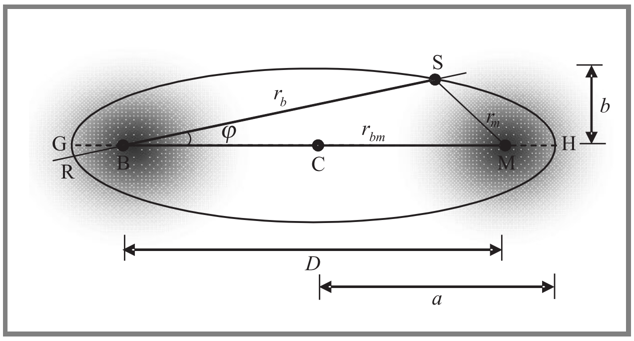

Fig. 2. Eccentro-scattering model for picocells and microcells.

BS and MS are located at the focal points of the eccentro-scattering disc.

Exemplary values of the model parameters are listed in Table 1. The values in the table are merely typical ones while more specific values may differ greatly from those on the table. For example, the delay spread in corridor (picocells) may exceed 0.1 μs in some cases due to the variety of antennas, measurement techniques, measurement locations, and different assumptions made by the working groups. However, we have based our numbers on values given in [1, 3]. The standard deviations of the Gaussian distributed scatterers have been taken from [13, 17].

Table 1
Typical values of the parameters of eccentro-scattering model for picocell and microcell environments

Environment	Picocell	Microcell
Maximum delay spread ($\tau_{\max}$) [μs]	≤ 0.1	0.3
Angle spread ($2\phi_{\max}$) [degrees]	360	120
Distance between BS and MS (D) [m]	$1 < D < 30$	$50 < D < 500$
Semi-major axis (a) [m]	$15 < a < 65$	$45 < a < 545$
Eccentricity (e)	$0 < e < 1$	$0.33 < e < 1$
Standard deviations (σ_b, σ_m) of scatterers around BS and MS	$\sigma_b = \sigma_m$ $ae \leq \sigma_m \leq 2ae$	$\sigma_b \geq \sigma_m$ $0.4ae \leq \sigma_m \leq 0.68ae$

Using radio signal propagation theory, the relationship among maximum delay spread, $\tau_{\max}$, total path traveled, $r_b + r_m$, and speed of light, c, can be written as

$$r_b + r_m = c\tau_{\max}\,. \tag{2}$$

From Eqs. (1) and (2), the semi-major axis of the eccentro-scattering disc, a, in Fig. 2 is

$$a = \frac{c\tau_{\max}}{2}\,. \tag{3}$$

The eccentricity, e, aspect ratio, k, and semi-minor axis, b, of the eccentro-scattering disc in Fig. 2 are:

$$e = \frac{D}{2a}\,, \tag{4}$$

$$k = \frac{b}{a} = \sqrt{1-e^2}\,, \tag{5}$$

$$b = \frac{1}{2}\sqrt{4a^2 - D^2}\,. \tag{6}$$

A Gaussian model of the spatial pdf of the scatterers around MS and BS can be written as in Eqs. (7) and (8), respectively,

$$p_{X_s,Y_s}(x_S,y_S) = \frac{1}{2\pi\sigma_m^2}\exp\left[-\frac{\left|(x_S-x_M)^2+(y_S-y_M)^2\right|}{2\sigma_m^2}\right], \tag{7}$$

$$p_{X_s,Y_s}(x_S,y_S) = \frac{1}{2\pi\sigma_b^2}\exp\left[-\frac{\left|x_S^2+y_S^2\right|}{2\sigma_b^2}\right]. \tag{8}$$

Or in polar coordinates, Eqs. (7) and (8) can be written as in Eqs. (9) and (10), respectively [20],

$$p_{R_b,\Phi_m}(r_b,\varphi) = \begin{cases} \dfrac{\|r_b\|}{2\pi\sigma_m^2}\exp\left[-\dfrac{\|r_b - r_{bm}\|^2}{2\sigma_m^2}\right], & r_b > 0 \\ 0, & \text{elsewhere} \end{cases} \tag{9}$$

$$p_{R_b,\Phi_b}(r_b,\varphi) = \begin{cases} \dfrac{\|r_b\|}{2\pi\sigma_b^2}\exp\left[-\dfrac{\|r_b\|^2}{2\sigma_b^2}\right], & r_b > 0 \\ 0, & \text{elsewhere} \end{cases} \tag{10}$$

where σ_m and σ_b are the standard deviations of the distribution of scatterers around MS and BS, respectively. The angle φ is the angle with the horizontal (in our case the AoA of the multipaths at BS from a scattering point S), and r_b and r_{bm} are the position vectors of the scattering point S and MS, respectively, with respect to BS, as shown in Fig. 2. The angle 0° corresponds to the angle towards MS, i.e., direction of line of sight (LoS). The spatial pdf of the scatterers around MS in polar coordinates presented in [9, 15] is deficient in r_b factor, which is the Jacobian of the transformation from Cartesian coordinate system to polar coordinate system.

3. Probability density function of the angle of arrival

Considering Eq. (9) and the geometry in Fig. 2, the density of scattering points around MS can be described by the bivariate Gaussian distribution as follows:

$$p_{R_b,\Phi_m}(r_b,\varphi) = \begin{cases} \dfrac{r_b}{2\pi\sigma_m^2}\exp\left[-\dfrac{r_b^2+D^2-2r_bD\cos\varphi}{2\sigma_m^2}\right], & r_b > 0 \\ 0, & \text{elsewhere} \end{cases}. \tag{11}$$

In a similar way, the density of scattering points around BS can be defined as

$$p_{R_b,\Phi_b}(r_b,\varphi) = \begin{cases} \dfrac{r_b}{2\pi\sigma_b^2}\exp\left[-\dfrac{r_b^2}{2\sigma_b^2}\right], & r_b > 0 \\ 0, & \text{elsewhere} \end{cases}. \tag{12}$$

For microcell environment, the maximum AoA, $\varphi_{\max}$, has been found to be 60° [1] and the density of scatterers around MS is greater than that around BS. Whereas, for picocell environment, the maximum AoA,$\varphi_{\max}$,, is 180° [1] and the density of scatterers around MS is almost equal to that around BS. The distance between BS and MS, D, is larger in case of microcells than picocells.

The area bounded by the sector BSH in Fig. 2 is a function of the angle φ, with angles between 0 and $\varphi_{\max}$.

Considering Eqs. (11) and (12) and the geometry in Fig. 2, the cumulative distribution functions (CDF) of the scattering points around MS and BS would be respectively defined as

$$P_{\Phi_m}(\varphi) = \int_{-\varphi_{\max}}^{\varphi} \int_{0}^{r_{b1}} \frac{r_b}{2\pi\sigma_m^2} \exp\left(\frac{-r_b^2 - D^2 + 2r_b D\cos\eta}{2\sigma_m^2}\right) dr_b\, d\eta \tag{13}$$

and

$$P_{\Phi_b}(\varphi) = \int_{-\varphi_{\max}}^{\varphi} \int_{0}^{r_{b1}} \frac{r_b}{2\pi\sigma_b^2} \exp\left(\frac{-r_b^2}{2\sigma_b^2}\right) dr_b\, d\eta\,, \tag{14}$$

where r_b is the positive root of the equation defining the disc in Fig. 2 in polar coordinates, i.e.,

$$r_b^2\left(\frac{\cos^2\varphi}{a^2} + \frac{\sin^2\varphi}{b^2}\right) - r_b\left(\frac{D\cos\varphi}{a^2}\right) + \frac{D^2}{4a^2} = 1\,. \tag{15}$$

Solving Eq. (15) for r_b results in the following two solutions:

$$r_{b1,b2} = \frac{4a^2 - D^2}{2(\pm 2a - D\cos\varphi)}\,. \tag{16}$$

Since the received signal at the antenna has interacted with only one single scatterer in the channel, as assumed earlier, then the AoA of the multipaths from scatterers around BS and MS are two disjoint events. Hence, the pdf of AoA of the multipaths from all scattering points within the eccentro-scattering disc, $p_\Phi(\varphi)$, would be basically the addition of the derivatives of Eqs. (13) and (14) with respect to φ, i.e.,

$$\begin{aligned} p_\phi(\varphi) &= \frac{1}{2}\Big(p_{\Phi_m}(\varphi) + p_{\Phi_b}(\varphi)\Big) \\ &= \frac{1}{2}\left(\frac{d}{d\varphi}P_{\Phi_m}(\varphi) + \frac{d}{d\varphi}P_{\Phi_b}(\varphi)\right)\,, \end{aligned} \tag{17}$$

therefore

$$\begin{aligned} p_\Phi(\varphi) &= \int_0^{r_{b1}} \frac{r_b}{2\pi\sigma_m^2} \exp\left(\frac{-r_b^2 - D^2 + 2r_b D\cos\varphi}{2\sigma_m^2}\right) dr_b \\ &+ \int_0^{r_{b1}} \frac{r_b}{2\pi\sigma_b^2} \exp\left(\frac{-r_b^2}{2\sigma_b^2}\right) dr_b\,. \end{aligned} \tag{18}$$

Substituting the value of r_{b1} from Eq. (16) into Eq. (18), we get the pdf of AoA of the multipaths at BS from Gaussian distributed scatterers around BS and MS confined in an eccentro-scattering disc as in Eq. (19):

where Δ is a normalizing constant such that $\int_0^{2\pi} p_\Phi(\varphi)d\varphi=1$, and $\mathrm{erf}(x)$ is the well known error function defined as $\mathrm{erf}(x) = \int_0^x \exp(-t^2)dt$.

The work in [15] derived the pdf of AoA of the multipath signals at BS considering scattering points that are Gaussian distributed around MS, only, and within the angular beamwidth of a directional antenna. But no geometrical shape of the scattering disc was defined. The only effect of using directional antenna at BS is to reject AoAs falling outside the beamwidth, while it does not alter the distribution of AoA at BS.

As mentioned earlier, maximum delay spread of the multipaths, $\tau_{\max}$, has a significant effect on the pdf of AoA at BS. Figures 3 and 4 show that the pdf of AoA at BS derived using the eccentro-scattering model depends on the size of the scattering disc, which in turn depends on $\tau_{\max}$, while this is not the case for the corresponding pdf derived using unbounded scatterers [13, 15, 17]. It was mentioned in [13] that "in the Gaussian AoA model, the distribution of arriving waves in azimuth is assumed to be Gaussian without specific mention of the scatter density required to produce it". But it was already stated earlier in [21] that "if the bell-shaped spatial Gaussian model

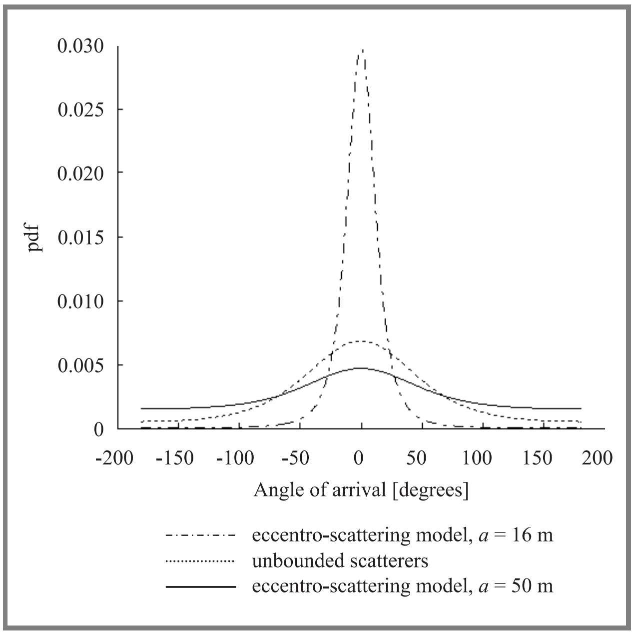

Fig. 3. Probability density function of AoA for picocell environment with $D = 30$ m, $\sigma_b = \sigma_m = D/2$ using eccentro-scattering model and unbounded scattering region.

$$p_\Phi(\varphi) = \frac{\Delta}{4\pi}\left\{\begin{aligned} &1 + \exp\left(-\frac{2a^2e^2}{\sigma_m^2}\right) - \exp\left(-\frac{a^2(1+e^2-2e\cos\varphi)^2}{2\sigma_m^2(1-e\cos\varphi)^2}\right) + \frac{\sqrt{2\pi}ae\cos\varphi}{\sigma_m}\exp\left(-\frac{2a^2e^2\sin^2\varphi}{\sigma_m^2}\right) \\ &\left[\mathrm{erf}\left(\frac{\sqrt{2}ae\cos\varphi}{\sigma_m}\right) + \mathrm{erf}\left(\frac{a(1-2e\cos\varphi+e^2\cos 2\varphi)}{\sqrt{2}\sigma_m(1-e\cos\varphi)}\right)\right] - \exp\left(-\frac{a^2(1-e^2)^2}{2\sigma_b^2(1-e\cos\varphi)^2}\right) \end{aligned}\right\}, \tag{19}$$

for the distribution of scatterers round the mobile is assumed then the angular distribution seen form BS is also Gaussian". In fact, if we consider unbounded scatterers or multipaths from infinitely far distant scatterers, we get exactly bell-shaped Gaussian pdf of AoA of the multipath signals at BS. But if we consider Gaussian distributed scatterers confined in some disc, e.g., eccentro-scattering disc, still the pdf of AoA would be Gaussian distributed while its tails depend on the size of the disc, the distance between BS and MS, and the standard deviation of the scattering points around MS and BS under the zooming effect (Figs. 3 and 4).

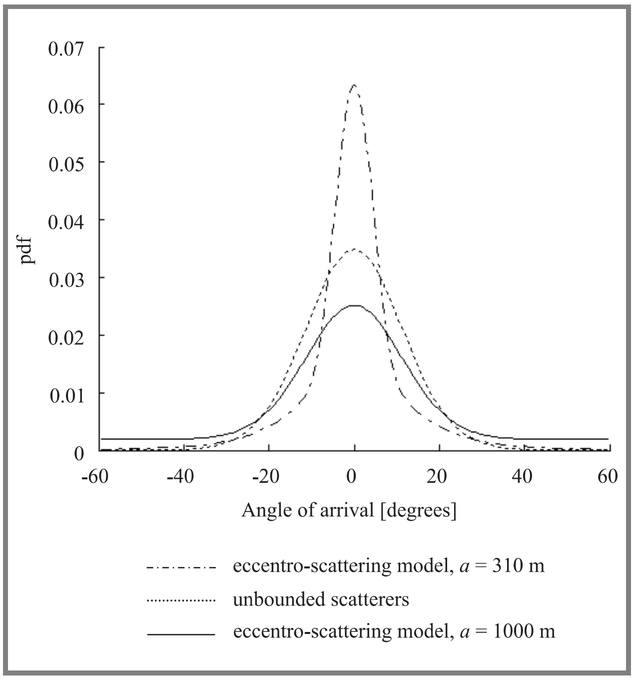

Fig. 4. Probability density function of AoA for microcell environment with $D = 600$ m, $\sigma_b = 0.34D$, $\sigma_m = 0.2D$ using eccentro-scattering model and unbounded scattering region.

If we consider $\sigma_m = \infty$ and $\sigma_b = 0$ in Eq. (19), the pdf of AoA of the multipath signals at BS approaches a uniform distribution. Whereas, if we consider $a = 4 \times \sigma_m$ and $\sigma_b = 0$, Eq. (19) approaches the result found by Janaswamy [13] for unbounded Gaussian distributed scatterers around MS only. This is because at $a = 4 \times \sigma_m$, the eccentro-scattering disc would confine almost all (99.99%) of the scattering points. Whereas, practically, a must be smaller than $4 \times \sigma_m$.

As shown in Fig. 5, the pdf of AoA of the multipath signals at BS derived using the eccentro-scattering model depends on the value of a provided that $a \leq 4 \times \sigma_m$. Therefore, it is more realistic to bound the scatterers inside some scattering disc according to terrain conditions, i.e., eccentro-scattering disc.

Similarly, if we consider $\sigma_m \geq 5 \times a$ and $\sigma_b = 0$, Eq. (19) approaches the results found originally by Liberti [12] and derived again in a compact form by Ertel [11] for bounded uniformly distributed scatterers confined in an elliptical scattering disc.

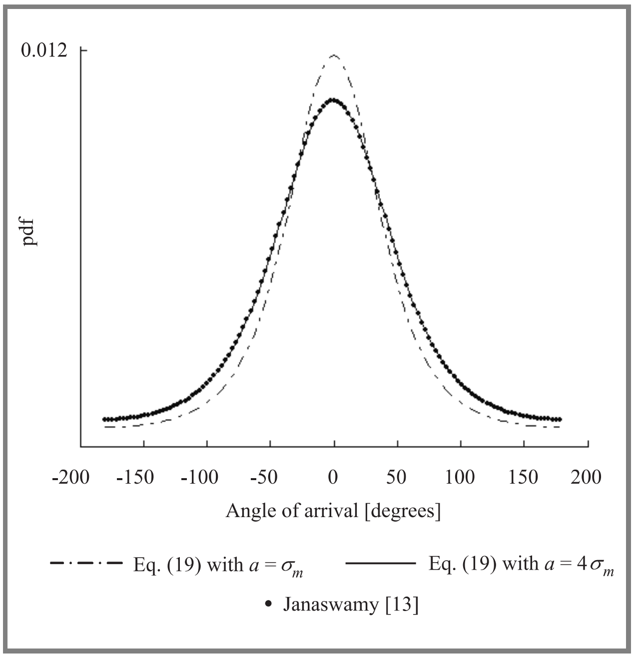

Fig. 5. Effect of increasing a on the pdf of AoA, $\sigma_b = 0$.

Figure 6 shows the effect of using large values for σ_m on the pdf of AoA of the multipaths at BS. We note that Gaussian distributed scatterers confined in an eccentro-scattering disc with large values of σ_m approach uniformly distributed scatterers confined in the disc.

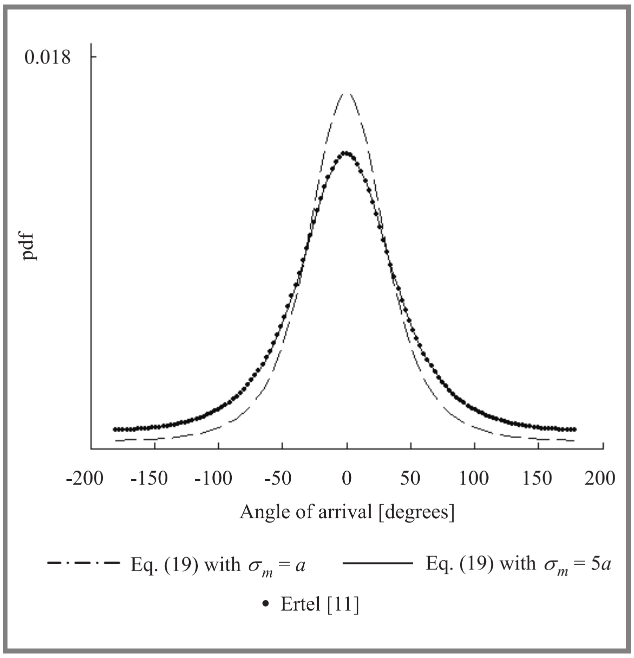

Fig. 6. Effect of increasing σ_m on the pdf of AoA, $\sigma_b = 0$.

In [22], Lapalcian distribution of angular variance 25.5° was proposed as the best fit for indoor measurements, but it was observed that the tails were actually heavier than predicted by Laplacian distribution. The model proposed by Spencer captured the behavior of 90% of arrivals while the eccentro-scattering model represents a better fit (more than 98%). The tail behavior predicted in the proposed models and that observed in the measured data are examined by looking at the distribution on log scale as shown in Fig. 7. Furthermore, the Laplacian function lacks a theoretical explanation [23].

In Figs. 8 and 9, simulation and theoretical results are presented using different values of σ_b and σ_m for typical picocell and microcell environments. In picocell environment, the effect of the standard deviation of scatterers is not so evident because BS and MS are usually located very close to each other while in microcell environment this effect is obvious because BS and MS are relatively far from each other and the scattering disc gets larger values of eccentricity, e, close to 1.

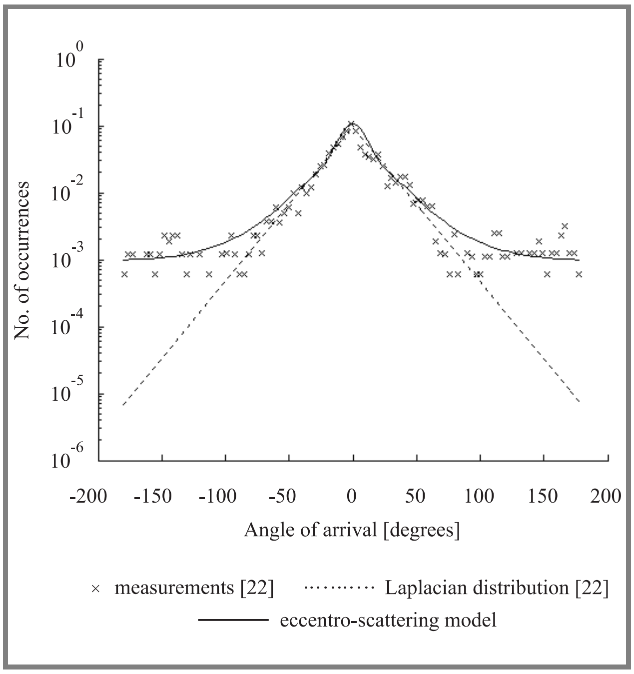

Fig. 7. Comparison of the pdf of AoA for eccentro-scattering model ($a = 36$ m, $D = 64$ m, and $\sigma_m = \sigma_b = 18$), Laplacian distribution ($\sigma = 25.5°$) [22], and measurements [22].

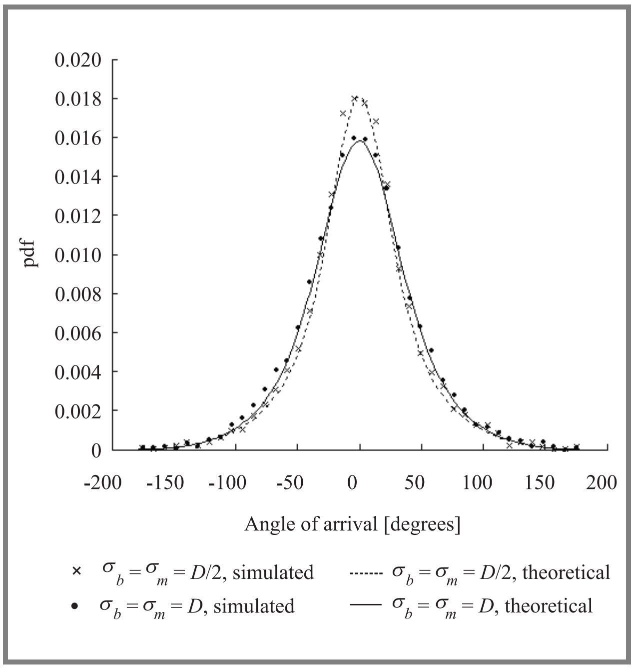

Fig. 8. Simulated and theoretical pdf of AoA for picocells with $D = 30$ m, $a = 25$ m using different values for $\sigma_b = \sigma_m$.

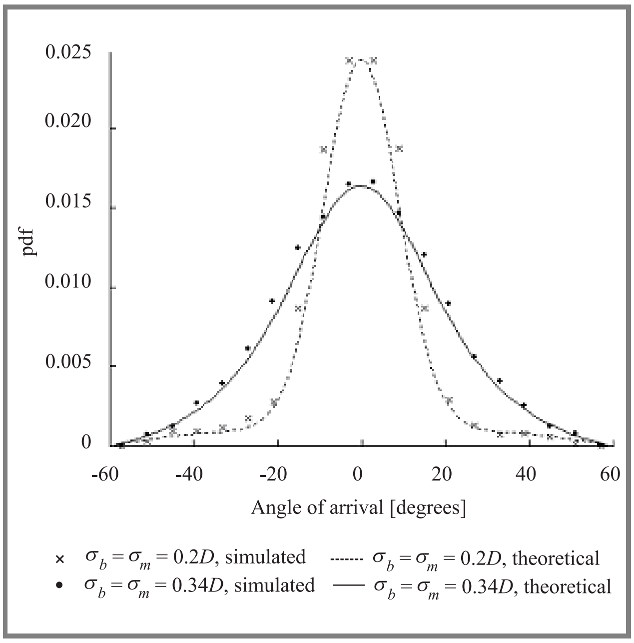

Fig. 9. Simulated and theoretical pdf of AoA for microcells with $D = 300$ m, $a = 180$ m using different values for $\sigma_b = \sigma_m$.

These results illustrate the accuracy and generality of the eccentro-scattering model.

4. Conclusions

In this paper we have presented an intensive study of the spatial statistics of the mobile channel for picocell and microcell environments assuming Gaussian distributed scatterers around both base station (BS) and mobile station (MS) and have made appropriate comments on previous work. We have made clear distinction between the shape of the scattering disc and the distribution of scatterers within that disc. This is important to understand several approaches used in physical channel modeling.

We have exploited the eccentro-scattering physical channel model, assuming Gaussian distributed scatterers around BS and MS, to derive the probability density function (pdf) of angle of arrival of the multipath signals at BS by simple ray-tracing approach. Our model consisted of two Gaussian functions for the distribution of scatterers around BS

and MS whereas previous Gaussian scattering models considered only one Gaussian function around MS only.
The model is very useful in simulating several propagation scenarios for wireless communication systems. Equation (19) presents the formula for the pdf of AoA of the multipath signals at BS in closed form, which can be used further for beamwidth design purposes of multi antenna systems used in low antenna height environments especially in spatial division multiple access (SDMA) and wireless local area networks (WLANs). Simulated and theoretical results for such low antenna height environments have been presented which show very good proximity. Furthermore, the proposed model and the derived results are helpful in high data rate services such as wireless personal area networks (WPANs) and wireless broadband PAN (WB-PANs), which need accurate physical channel models to combat fading effects for enhanced quality of service (QoS) requirement.

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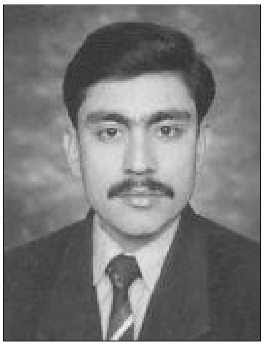
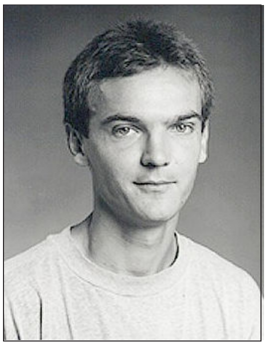
Mohammed T. Simsim was born in Makkah, Saudi Arabia, in 1975. He received the B.Sc. degree in electrical and computer engineering from UMM AL-QURA University, Makkah, Saudi Arabia, in 1998. He served in the Presidency of Civil Aviation (PCA) and UMM AL-QURA University, Saudi Arabia, from 1998 to 2001. In 2002, he received the M.Sc. degree in electrical engineering from Colorado State University (CSU), Fort Collins, CO, USA. In 2003, he joined the University of New South Wales (UNSW), Sydney, Australia, for Ph.D. studies. His research mainly focuses on physical channel modeling and its applications in cellular mobile communications.

e-mail: msimsim@student.unsw.edu.au
School of Electrical Engineering
and Telecommunications
University of New South Wales (UNSW)
Sydney, 2052, Australia



Noor M. Khan was born in Pakistan in 1973. He received the B.Sc. degree in electrical engineering from University of Engineering and Technology (UET), Lahore, Pakistan, in 1998. He held several positions in WorldCall Communications, National Institute of Science and Technical Education (NISTE), Islamabad and Pakistan Telecommunication Company Limited (PTCL) from 1998 to 2002. In 2002, he joined University of New South Wales (UNSW), Sydney, Australia, for Ph.D. studies. His research interests are channel estimation, adaptive multiuser detection, and physical channel modeling for mobile communications.
noor@unsw.edu.au
School of Electrical Engineering
and Telecommunications
University of New South Wales (UNSW)
Sydney, 2052, Australia



Predrag B. Rapajic received the B.E degree from the University of Banja Luka, Yugoslavia, in 1982, and the M.E. degree from The University of Belgrade, Belgrade, Yugoslavia, in 1988. He received the Ph.D. degree from The University of Sydney, Sydney, Australia, in 1994. In 1996, he was appointed Head of the Communications Group, Motorola Australian Research Center. Since 2005, Professor Rapajic has been working at Medway School of Engineering, University of Greenwich, UK. His research interests include adaptive multiuser detection, equalization, error control coding, mobile communication systems and multiuser information theory.
e-mail: p.rapajic@unsw.edu.au
School of Electrical Engineering
and Telecommunications
University of New South Wales (UNSW)
Sydney, 2052, Australia