Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
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Source(s)	**Shuangquan Wang, Xiaodong Wang** NEC Laboratories America, Inc. Email: {shuangquan, wangx}@nec-labs.com Mohammad.Madihian@necam.com **Mohammad Madihian** NEC Corporation of America
Re:	Call for Comments on Draft 802.16m Evaluation Methodology Document
Abstract	In this contribution, a flexible Doppler behavior model is proposed. The model is obtained by approximating both the directional antenna pattern and the angular distribution of non-isotropic scattering environments by a mixture of von Mises distributions. The proposed model has the closed-form expressions for both spatial/temporal correlations and spectrums, a feature highly desired in real-time correlation-based simulations. It also includes the classical Jakes' model as a special case. In addition, the existing Rayleigh faders can be still used with only slight modifications.
Purpose	For discussion and approval by TGm
Notice	
Release	
Patent Policy	

A Flexible Doppler Behavior Model

Shuangquan Wang, Xiaodong Wang
NEC Laboratories America, Inc.
Mohammad Madihian
NEC Corporation of America

1. Introduction

The Doppler behavior depends on the power azimuth spectrum (PAS) [8], which includes the combined effects of both *antenna patterns* and *physical propagation environments*.[1] In the current Draft 802.16m Evaluation Methodology Document [1], the Laplace distribution is used to characterize the PAS in the correlation-based method. In WINNER model [11], the wrapped Gaussian is used to model *physical propagation environments*. In addition, the uniform PAS is recommended as an option to reduce the simulation run time (i.e., the classical Jakes' bathtub-shaped spectrum is used to characterize the Doppler behavior), which, in most cases, assumes isotropic scattering environments and omni directional antennas [2], i.e., the power density is constant over the azimuth angle, (-π, π].

However, it has been argued [3][5], and experimentally demonstrated [4][5] that the scattering encountered in many environments is non-isotropic. Some typical non-isotropic scattering environments are shown in Fig. 1 [6], and Fig. 4 of [12] (elliptical scattering model).

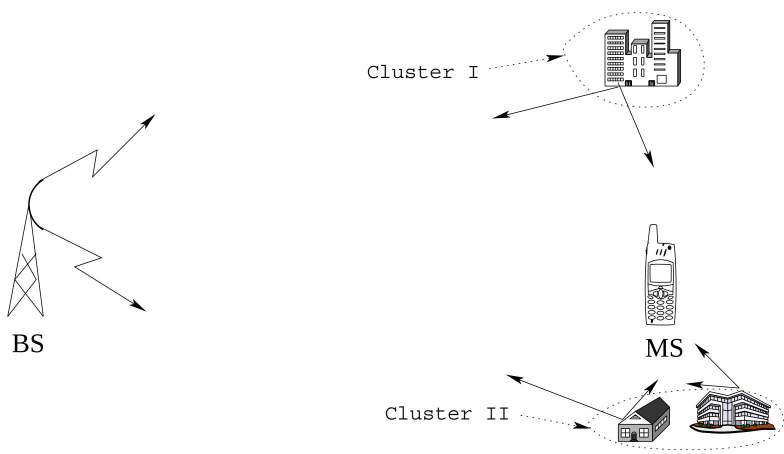


Fig. 1: A typical non-isotropic scattering environment

In addition, the directional antenna will make the received power density non-uniform even in the isotropic scattering environment. One example of the antenna pattern of a direction antenna is shown in Fig. 2 [1].

[1] In the following text, we use "antenna pattern" for the effect of the antenna radiation pattern, "angular distribution" for the effect of the physical radio propagation scattering environment in the tap/path level, and "PAS" for the combined effect of both antenna pattern and angular distribution in the tap/path level.

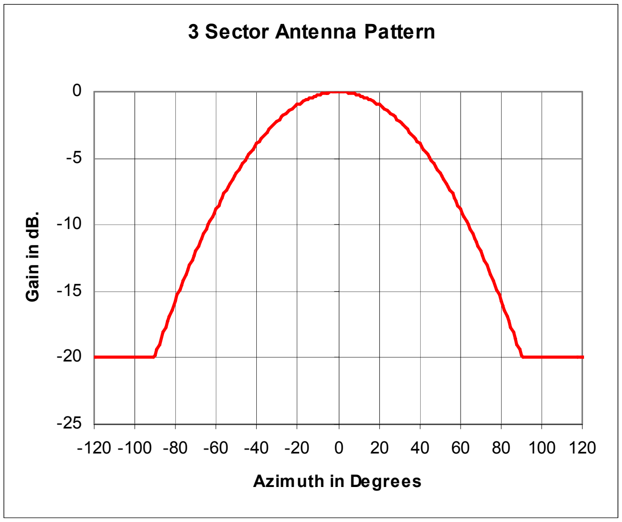


Fig. 2: Antenna pattern for 3-sector cells at BS side

Moreover, as bandwidth increases, the Doppler characteristics will not have the classic "bathtub" shape, as stated in [1].

Based on the above description, we observed the following potential problems in the current draft, which may affect the future evaluations of considered techniques.

- In Jakes' model, the maximum Doppler frequency, f_m, fully dictates the channel dynamics. It implies that the larger the f_m, the faster the channel varies, i.e., the shorter the coherence time. However, in the non-uniform PAS scenario, large f_m's do not imply the fast variation of the channel. For example, as shown in Fig. 4, the coherence time of the real-world scenario is much longer than that predicted by the Jakes' model. This may have important impacts on the feedback signaling design.
- In the ray-based method, the defined antenna pattern (r.f. Fig. 2) and wrapped Gaussian angular distribution (r.f. [11]) will not lead to the Laplace PAS, which is assumed in the correlation-based method. Obviously, this will introduce some inconsistence between two implementation methods.

To remedy the above problems, a flexible Doppler spectrum model is proposed in this contribution. We use $h_{m_r,m_t,l}(t)$ to represent the time-varying channel coefficient of the lth path between the m_tth Tx antenna and m_rth Rx antenna, which includes the LOS (line-of-sight) component. We assume the Rician factor to be $K_{m_r,m_t,l}$ and the path power to be $P_{m_r,m_t,l}$, then $h_{m_r,m_t,l}(t)$ can be written as

$$h_{m_r,m_t,l}(t) = \sqrt{\frac{K_{m_r,m_t,l}P_{m_r,m_t,l}}{K_{m_r,m_t,l}+1}}e^{j\varphi_{m_r,m_t,l}} + \sqrt{\frac{P_{m_r,m_t,l}}{K_{m_r,m_t,l}+1}}g_{m_r,m_t,l}(t)\,, \quad (1)$$

where $\varphi_{m_r,m_t,l}$ is the phase of the LOS component, and $g_{m_r,m_t,l}(t)$ is a circular complex Gaussian random process with unit power. Since the LOS component (the first item in (1)) is not random and very easy to generate, we consider the Doppler behavior of $g_{m_r,m_t,l}(t)$ only in this contribution. To simplify the notation, we drop off the subscript $_{m_r,m_t,l}$ in $g_{m_r,m_t,l}(t)$. Note that all the incidence angles are relative to the mobile moving direction in this contribution.

2. PAS Model

As stated in the introduction, the Doppler behavior depends on the PAS model. In the current draft [1], the Laplace distribution is used to characterize the PAS. Except for the possible problems described in the above, furthermore, it has the following limitations.

a. It can not be reduced to the uniform distribution.
b. It takes the value over (-∞, ∞) instead of (-π, π]. Therefore, it may lack the physical meaning of the underlying angles.
c. It will not give the closed-form expressions for both spatial and temporal correlations of the channel. To calculate the *spatial* correlation value, we need to resort the numerical integration. As stated in [1], the integration depends on the mean angle of arrival (AoA) and angle of departure (AoD), which makes the channel generation difficult in real time.

If the wrapped Gaussian distribution from the WINNER model is used in the correlation-based method, the above a and c still apply.

The von Mises distribution (also known as the circular normal distribution) plays a prominent role in statistical modeling and analysis of angular variables [7]. Compared to the Laplace distribution, the von Mises has the following advantages.

a. It includes the uniform distribution as a special case.
b. It takes the value over (-π, π] naturally.
c. It provides closed-form and mathematically-tractable expressions for the channel correlation function and its spectrum, which is highly desired in the real-time correlation-based simulation. In addition, since it includes the uniform distribution, the correlation and spectrum includes the Jakes' model as a special case. It implies that we can include the Jakes' spectrum as an option by changing the underlying parameters only.

We assume the unnormalized PAS to be $q(\theta), \theta \in (-\pi, \pi]$, which includes the combined effect of antenna pattern and angular distribution. The total power of the NLOS component associated with the *l*th path between the m_tth Tx antenna and m_rth Rx antenna is $\frac{P_{m_r,m_t,l}}{K_{m_r,m_t,l}+1} = \int_{-\pi}^{\pi} q(\theta) d\theta$. Therefore, the normalized PAS is given by $p(\theta) = q(\theta) / \int_{-\pi}^{\pi} q(\theta) d\theta$, which is a probability density function (PDF) of the azimuth angle.

As stated in [6], $p(\theta)$ can be written as a mixture of *N* von Mises distributions, where each of them characterizes one sub-cluster of scatterers.[2]

$$p(\theta) = \sum_{n=1}^{N} p_n \frac{\exp[\kappa_n \cos(\theta - \phi_n)]}{2\pi I_0(\kappa_n)}, \qquad \theta \in (-\pi, \pi], \tag{2}$$

where $I_0(z)$ is the zero-th order modified Bessel function of the first kind, ϕ_n is the mean angle of the *n*th sub-

[2] Each tap/path corresponds to a cluster, and each cluster may contain several sub-clusters.

cluster, κ_n controls the angle spread of the *n*th sub-cluster, and p_n represents the contribution of the *n*th sub-cluster, such that $\sum_{n=1}^{N} p_n = 1, 0 < p_n < 1$. If $\kappa_n = 0, \forall n,$ the above distribution reduces to

$$p(\theta) = 1/(2\pi), \theta \in (-\pi, \pi], \tag{3}$$

which is the Clarke's 2-D isotropic scattering model. It is easy to show that, if both antenna gain, $G(\theta)$, and angular distribution have a mixture of von Mises in (2), the normalized PAS, $p(\theta)$, will still have a mixture of von Mises. This observation makes it possible for the flexible Doppler model.

We consider the basic case where $N = 1$. If the normalized antenna pattern has the von Mises with ϕ_{ant} and κ_{ant}, and the angular distribution has the von Mises with ϕ_{env} and κ_{env}, the normalized PAS will have the von Mises with $\phi = \arctan(\kappa_{\text{env}} \sin\phi_{\text{env}} + \kappa_{\text{ant}} \sin\phi_{\text{ant}}, \kappa_{\text{env}} \cos\phi_{\text{env}} + \kappa_{\text{ant}} \cos\phi_{\text{ant}})$, where $\phi = \arctan(y, x)$ is the four quadrant arctangent,[3] and $\kappa = \sqrt{\kappa_{\text{env}}^2 + \kappa_{\text{ant}}^2 + 2\kappa_{\text{env}}\kappa_{\text{ant}} \cos(\phi_{\text{env}} - \phi_{\text{ant}})}$.

For example, the antenna pattern in Fig. 2 can be well approximated by the von Mises with $\phi_{\text{ant}} = \pi / 4$ and $\kappa_{\text{ant}} = 3.91625$ if the antenna boresight has $\pi / 4$ offset to the LOS direction. For the physical scattering environment, we consider the angular PDF in Fig. 6(a) of [12], which can be well approximated by a mixture of two von Mises with $\phi_{\text{env}} = [0, 0]$, $\kappa_{\text{env}} = [5,\ 1.1]$ and $p_{\text{env}} = [0.45,\ 0.55]$. Finally, the normalized PAS has a mixture of von Mises with $\phi = [0.3424, 0.6212]$, $\kappa = [8.2480,\ 4.7581]$ and $p = [0.4945,\ 0.5055]$. In addition, to see the effect of the approximation errors, we also approximate the angular PDF by one von Mises with $\phi_{\text{env}} = 0$, $\kappa_{\text{env}} = 2.3$. Fig. 3 shows the results, where "Ant. Pat. (exact)" denotes the actual antenna pattern, "Ant. Pat. (mixture, …)" is the von Mises approximation, "Scat. Env. (exact)" denotes the actual angular distribution, "Scat. Env. (mixture, …)" is the von Mises approximation, and "PAS (mixture, …)" is the combined effect of approximated antenna pattern and angular distribution. All the curves are normalized.

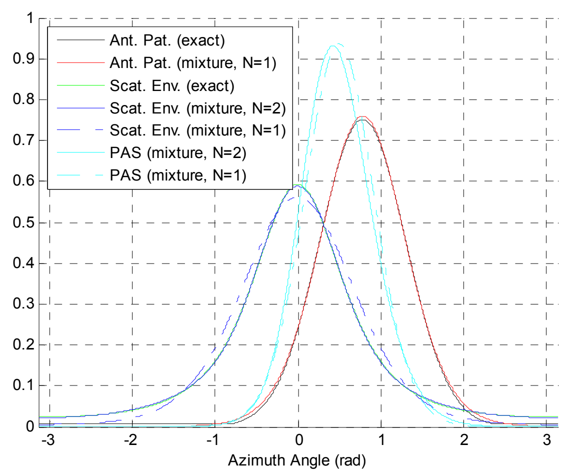


Fig. 3: A PAS example with directional antenna pattern and non-isotropic scattering environment.

[3] In Matlab, it can be calculated by $\text{atan2}(y, x)$.

3. Channel Temporal Autocorrelation and its Spectrum

With the PAS model in (2), the normalized autocorrelation and the spectrum of the channel, $g(t)$, are respectively given by [6]

$$
\begin{aligned}
r_g(\tau) &= \mathbb{E}\left[g(t)g^*(t-\tau)\right] = \mathbb{E}_\Theta\left[\exp(j2\pi f_m\tau\cos\Theta)\right] \\
&= \sum_{n=1}^{N} p_n \frac{I_0\left(\sqrt{\kappa_n^2 - 4\pi^2 f_m^2\tau^2 + j4\pi\kappa_n f_m\tau\cos\phi_n}\right)}{I_0(\kappa_n)},
\end{aligned} \tag{4}
$$

And

$$
S_g(f) = \mathfrak{F}\left[r_g(\tau)\right] = \sum_{n=1}^{N} p_n \frac{\exp\left(\kappa_n f\cos\phi_n / f_m\right)\cosh\left(\kappa_n\sqrt{1-\left(f/f_m\right)^2}\sin\phi_n\right)}{\pi\sqrt{f_m^2 - f^2}\, I_0(\kappa_n)}, \qquad |f| \le f_m, \tag{5}
$$

where $\mathfrak{F}[\cdot]$ denotes the Fourier transform, $\cosh(x) = \left(e^x + e^{-x}\right)/2$ is the hyperbolic cosine function. In addition, $f_m = v/\lambda = vf_c/c$ is the maximum Doppler frequency shift in Hertz, v is the moving speed of the mobile station, λ is the wavelength, f_c is the carrier frequency, and c is the speed of light in a vacuum. If $\kappa_n = 0, \forall n,$ i.e., the 2-D isotropic scattering, (4) and (5) reduce to the classical Jakes' correlation and Doppler models, given by

$$
r_g(\tau) = J_0\left(2\pi f_m\tau\right), \tag{6}
$$

and

$$
S_g(f) = \frac{1}{\pi\sqrt{f_m^2 - f^2}}, \qquad |f| \le f_m, \tag{7}
$$

We call Eq. (5) the <u>*von Mises' Doppler spectrum*</u>, and the model governed by (4) and (5) the <u>*von Mises' model*</u>.

If the bandwidth is large, each cluster only has one sub-cluster. Therefore, $N = 1$ is enough to characterize the PAS. This reduces, respectively, (2), (4) and (5) to

$$
p(\theta) = \frac{\exp[\kappa\cos(\theta - \phi)]}{2\pi I_0(\kappa)}, \qquad \theta \in (-\pi, \pi], \tag{8}
$$

$$
r_g(\tau) = \frac{I_0\left(\sqrt{\kappa^2 - 4\pi^2 f_m^2\tau^2 + j4\pi\kappa f_m\tau\cos\phi}\right)}{I_0(\kappa)}, \tag{9}
$$

and

$$
S_g(f) = \frac{\exp\left(\kappa f\cos\phi / f_m\right)\cosh\left(\kappa\sqrt{1-\left(f/f_m\right)^2}\sin\phi\right)}{\pi\sqrt{f_m^2 - f^2}\, I_0(\kappa)}, \qquad |f| \le f_m. \tag{10}
$$

Figs. 4 and 5 compare the Jakes' model and one real-world scenario in terms of temporal correlation and Doppler spectrum, respectively. From Figs. 4 and 5, we can conclude that the Jakes' model is far away from the real-world, and may not describe the non-uniform PAS environments. However, the proposed Doppler model can describe most practical PASs, including the uniform one (corresponding to the Jakes' model). In addition, according to Figs. 4 and 5, the difference between two approximations in both correlation and spectrum is marginal, although Fig. 3 shows obvious gaps, i.e., both correlation and spectrum are immune to small approximation errors. This further demonstrates that $N = 1$ is good enough to characterize the PAS in practice.

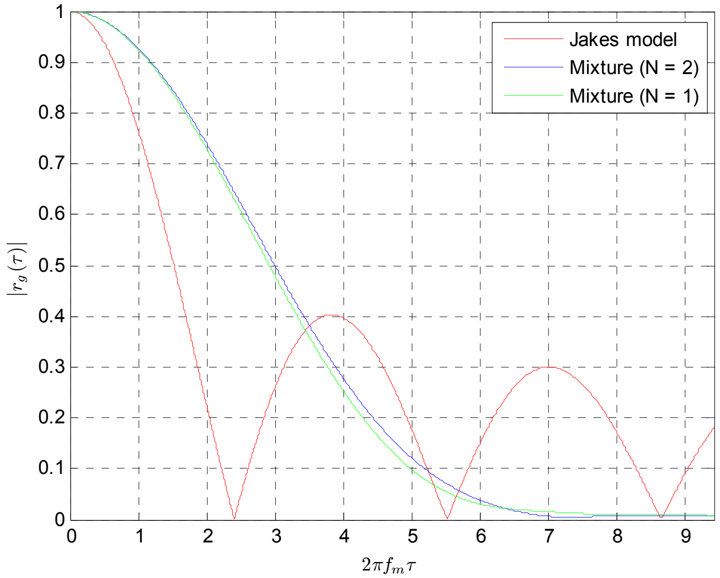


Fig. 4: Temporal correlation of the example in Fig. 3.

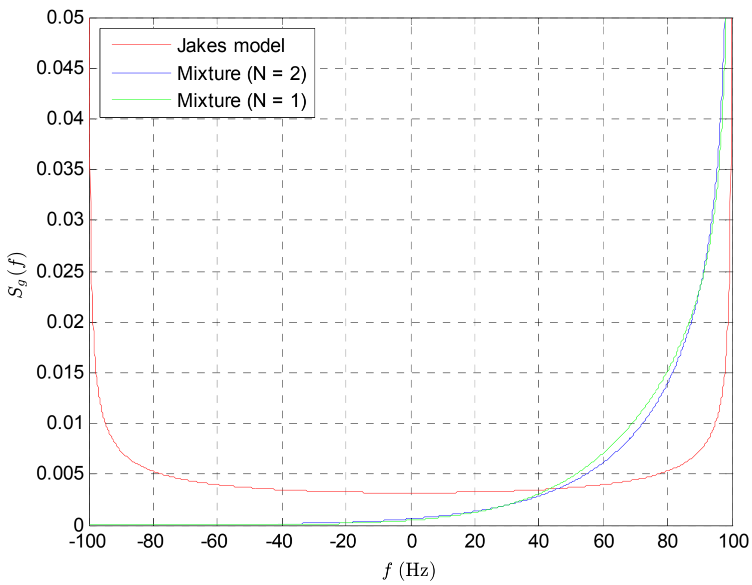


Fig. 5: Doppler spectrum of the example in Fig. 3.

With the von Mises distribution, the spatial correlations in [1] can be easily evaluated in the closed form without the numerical difficulties described in [1]. For example, the spatial correlation between the *p*th and *q*th antennas at the BS is given by

$$r_{n,\mathrm{BS}}(p,q)=\int_{-\pi}^{\pi}p(\theta)\exp\left[j\frac{2\pi d_{\mathrm{BS}}}{\lambda}(p-q)\sin(\mathrm{AoD}_n+\theta)\right]d\theta=\frac{I_0\left(\sqrt{\kappa_n^2-d_{pq}^2+j2\kappa_n d_{pq}\sin\mathrm{AoD}_n}\right)}{I_0(\kappa_n)}, \quad (11)$$

where $d_{pq}=2\pi d_{\mathrm{BS}}(p-q)/\lambda$ and $\kappa_n\approx \mathrm{AS}_{\mathrm{BS,path}}^{-2}$ for small angle spreads[4] [5]. Note that both AoD_n and $\mathrm{AS}_{\mathrm{BS,path}}$ are in radian. Eq. (11) is also valid for the spatial correlation at the MS by replacing corresponding parameters. It is clear to see that it will be much easier to generate the spatial correlation in the real-time simulation using the closed-form expression (11) instead of the numerical integration.

4. Modification in Existing Faders

It is straightforward to update some existing Rayleigh fading generators with the von Mises' model, i.e., replacing the Jakes' model with the von Mises' model. Specifically,

- If the classic correlation, $J_0(\cdot)$ in (6), is used to generate the Rayleigh fading channel, we replace it with the new correlation function shown in (4).
- If the classic spectrum in (7) is used, we replace it with the new spectrum shown in (5).
- If the sum-of-sinusoid (SoS) method is used, we replace the uniform distribution in (3) with the von Mises distribution in (2). The generation of von Mises random variables is discussed in [7] and [10].

As stated in Section 3, $N=1$ is enough to characterize the PAS in most practical cases. Therefore, (8)-(10) can be used instead of (2), (4) and (5).

Note that some Rayleigh faders are designed for the Jakes' model only, we may not apply the above methods to them directly without major changes, e.g., the simulation method proposed in [13].

5. Conclusions

In this contribution, we proposed a flexible Doppler behavior model. It can remedy the potential problems in the current draft. In addition, it includes the classical Jakes' model as a special case, and gives the *closed-form* expressions for both the autocorrelation and spectrum of the channel, which is highly desired in the real-time simulation. In addition, it only has *very minor* updates in some existing Rayleigh fading generators. Therefore, *we propose that the von Mises' model be used to characterize the Doppler behavior for the evaluation methodology document, and von Mises distribution be used to model the AoA and AoD instead of the Laplace for the evaluation methodology document*.

6. References

[1] R. Srinivasan, J. Zhuang, L. Jalloul, R. Novak, and J. Park, "Draft IEEE 802.16m Evaluation Methodology Document," IEEE C802.16m-07/080r2, Jun. 2007.

[2] G. L. Stüber, *Principles of Mobile Communication*. Boston, MA: Kluwer, 1996.

[3] M. Pätzold, U. Killat, Y. Li, and F. Laue, "Modeling, analysis, and simulation of non frequency selective mobile radio channels with asymmetrical Doppler power spectral density shapes," *IEEE Trans. Vehic. Technol.*, vol. 46, pp. 494-507, 1997.

[4] W. C. Y. Lee, "Finding the approximate angular probability density function of wave arrival by using a directional antenna," *IEEE Trans. Antennas Propagat.*, vol. 21, pp. 328-334, 1973.

[4] The exact value can be calculated according to $\kappa=\sqrt{\kappa_{\mathrm{env}}^2+\kappa_{\mathrm{ant}}^2+2\kappa_{\mathrm{env}}\kappa_{\mathrm{ant}}\cos(\phi_{\mathrm{env}}-\phi_{\mathrm{ant}})}$, as shown in Section 2.

[5] A. Abdi, 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 Trans. Vehic. Technol*., vol. 51, pp. 425-434, 2002.

[6] S. Wang, and A. Abdi, "On the Second-Order Statistics of the Instantaneous Mutual Information of Time-Varying Fading Channels," in *Proc. IEEE Int. Workshop on Signal Processing Advances in Wireless Commun.*, New York City, NY, 2005, pp. 405-409.

[7] K. V. Mardia, *Statistics of Directional Data*. London: Academic, 1972.

[8] W. C. Jakes, Ed., *Microwave Mobile Communications*. New York: Wiley-IEEE, 1994.

[9] K. I. Pedersen, P. E. Mogensen, and B. H. Fleury, "Power azimuth spectrum in outdoor environments," *Electron. Lett.*, vol. 33, No. 18, pp. 1583-1584, Aug. 1997.

[10] D. Best and N. Fisher, "Efficient simulation of the von Mises distribution," *Appl. Statist.*, vol. 28, no. 2, pp. 152–157, 1979.

[11] P. Kyösti, T. Jämsä, J. Meinilä, and A. Byman, "MIMO channel model approach and parameters for 802.16m," IEEE C802.16m-07/104, May 2007.

[12] R. B. Ertel, and J. H. Reed, "Angle and time of arrival statistics for circular and elliptical scattering models," *IEEE JSAC,* vol. 17, pp. 1829-1840, 1999.

[13] Y. Li, and X. Huang, "The Simulation of Independent Rayleigh Faders," *IEEE Trans. Commun.,* vol. 50, pp. 1503-1514, 2002.

7. Proposed Changes

I. Page 32, line 38, insert a footnote after "…power angular profile."

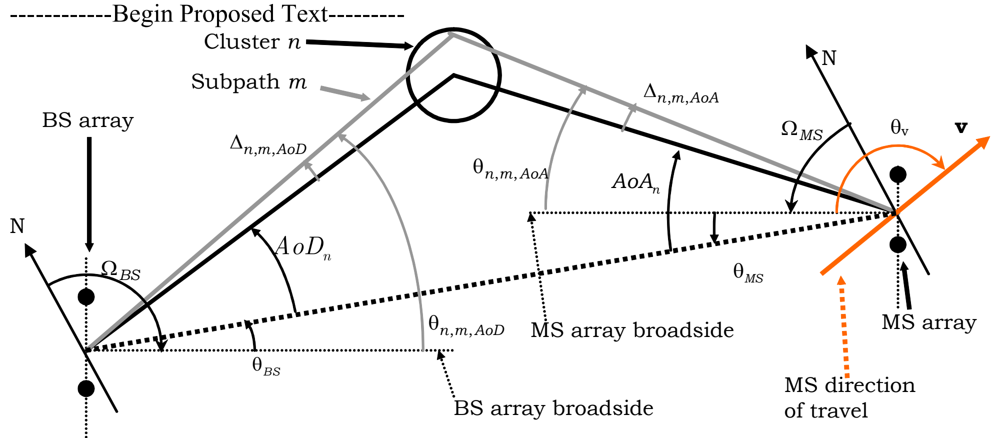
------------Begin Proposed Text---------

In this document, the power angular profile denotes the power azimuth spectrum (PAS), which is the combined effect of both the antenna pattern (the effect of the antenna radiation pattern) and the angular distribution (the effect of the physical radio propagation scattering environment in the tap/path level).

------------End Proposed Text-----------

II. Page 47, line 1, replace Figure 6 with the following one.

------------Begin Proposed Text---------



------------End Proposed Text-----------

III. From page 47, line 21 to page 48, line 8, make the following changes.

------------Begin Proposed Text---------

Once the per-tap AS, mean AoA, and mean AoD are defined, the theoretical spatial correlation at both BS and MS can be derived, assuming the von Mises PAS, which is given by [67][68]

$$p(\theta) = \frac{\exp[\kappa\cos(\theta-\phi)]}{2\pi I_0(\kappa)}, \qquad \theta \in (-\pi, \pi]$$

where $I_0(z)$ is the zero-th order modified Bessel function of the first kind, ϕ is the mean angle of the tap, κ controls the angle spread of the tap.

In particular, the antenna spatial correlations between the p-th and q-th antennas at the BS and MS, respectively, are

$$r_{n,\mathrm{BS}}(p,q) = \frac{I_0\left(\sqrt{\kappa_{n,\mathrm{BS}}^2 - d_{pq,\mathrm{BS}}^2 + j2\kappa_{n,\mathrm{BS}} d_{pq,\mathrm{BS}} \sin\varphi_n}\right)}{I_0(\kappa_{n,\mathrm{BS}})}$$

$$r_{n,\mathrm{MS}}(p,q) = \frac{I_0\left(\sqrt{\kappa_{n,\mathrm{MS}}^2 - d_{pq,\mathrm{MS}}^2 + j2\kappa_{n,\mathrm{MS}} d_{pq,\mathrm{MS}} \sin(\mathrm{AoA}_n + \theta_{\mathrm{MS}})}\right)}{I_0(\kappa_{n,\mathrm{MS}})}$$

where d_{BS} (d_{MS}) is the antenna spacing at BS (MS) and λ is the wavelength, $d_{pq,\mathrm{BS}} = 2\pi d_{\mathrm{BS}}(p-q)/\lambda$, $d_{pq,\mathrm{MS}} = 2\pi d_{\mathrm{MS}}(p-q)/\lambda$, $\kappa_{n,\mathrm{MS}} = \sigma_{n,\mathrm{MS}}^{-2}$ for small angle spreads [67], $\kappa_{n,\mathrm{BS}} = \sqrt{\sigma_{n,\mathrm{BS}}^{-4} + \kappa_{\mathrm{ant,BS}}^2 + 2\sigma_{n,\mathrm{BS}}^{-2}\kappa_{\mathrm{ant,BS}}\cos(\mathrm{AoD}_n + \theta_{\mathrm{BS}})}$, and $\varphi_n = \arctan\left(\sigma_{n,\mathrm{BS}}^{-2}\sin(\mathrm{AoD}_n + \theta_{\mathrm{BS}}), \sigma_{n,\mathrm{BS}}^{-2}\cos(\mathrm{AoD}_n + \theta_{\mathrm{BS}}) + \kappa_{\mathrm{ant,BS}}\right)$. AoD_n, AoA_n, $\sigma_{n,\mathrm{BS}}$ and $\sigma_{n,\mathrm{MS}}$ are given in Tables 8-15 for different scenarios, and $\kappa_{\mathrm{ant,BS}} = 3.916$ for the antenna pattern shown in Figure 2.

[Note that, if the mean AoDs (AoAs), tabulated in Tables 8-15, are defined with respect to the broadside of the BS (MS) array, the spatial correlations will keep fixed for any drop. It is not desired for the system-level simulation. The same situation will happen to the ray-based method. Therefore, the mean AoD and AoA should be defined with respect to the LOS direction, as shown in the previous page. This will ensure that different drops may have different spatial correlations, desired in system-level simulations for geometrical averaging.]

------------End Proposed Text-----------

IV. From page 47, line 21 to page 48, line 8, make the following changes.

------------Begin Proposed Text---------

Step 6: *Determine the Doppler spectrum of each tap, based on a random traveling direction, the array broadside direction defined in step 4, a von Mises angular distribution with the RMS angular spread AS defined in the CDL models.*

The temporal autocorrelation and Doppler spectrum at tap-n for the case of von Mises PAS are respectively given by [67][68]:

$$r_n(\tau) = \frac{I_0\left(\sqrt{\kappa_{n,\mathrm{MS}}^2 - 4\pi^2 f_m^2 \tau^2 + j4\pi\kappa_{n,\mathrm{MS}} f_m \tau \cos\phi_n}\right)}{I_0(\kappa_{n,\mathrm{MS}})}$$

Deleted: AOA

Deleted: AOD

Deleted: Laplacian power angular distribution

Deleted: $r_{n,BS}(p,q) = \int_{-\infty}^{\infty} p(\alpha)\exp$ … $r_{n,MS}(p,q) = \int_{-\infty}^{\infty} p(\beta)\exp$ …

Deleted: .

Deleted: α is the angular offset around the mean AOD at BS, and β is the angular offset around the mean AOA at MS. The pdf of angular offsets is

$$p(\alpha) = \frac{1}{\sqrt{2}AS_{BS,Path}}\exp\{- \ldots$$

$$p(\beta) = \frac{1}{\sqrt{2}AS_{MS,Path}}\exp\{- \ldots$$

The above integration can be computed with two approaches (other alternatives may also exist). See Appendix-1 for details. In summary, the first approach is to approximate the Laplacian PDF with 20 rays, after which the integration is reduced to a summation. The second approach is to compute the integration using a numerical method. Either using 20-ray approximation or numerical integration, it is possible to quantize the AOA or AOD and then pre-compute the spatial correlation for each quantized AOA and AOD values. Using pre-stored correlation matrices may reduce the simulation run-time.

Deleted: *Laplacian power angular profile*

Deleted: From the Doppler spectrum defined for any arbitrary Doppler spectrum in [21], t

Deleted: Laplacian power angular profile

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and

$$S_n(f) = \frac{\exp\left(\kappa_{n,\mathrm{MS}} f \cos\phi / f_m\right) \cosh\left(\kappa_{n,\mathrm{MS}} \sqrt{1-\left(f/f_m\right)^2} \sin\phi_n\right)}{\pi\sqrt{f_m^2 - f^2}\, I_0(\kappa_{n,\mathrm{MS}})}, \qquad |f| \le f_m.$$

where $f_m = v/\lambda$ is the maximum Doppler frequency, ϕ_n is the angle between the traveling direction and the mean AoA for tap-n.

[Note that the above autocorrelation and spectrum include the Jakes' model as a special case by setting $\kappa_{n,\mathrm{MS}}$ to be zero. This feature will make it convenient to simulate both Jakes' and non-Jakes' Doppler spectrums in a uniform frame.]

Deleted: $S_n(f) \propto \begin{cases} \frac{1}{\sqrt{f_{\max}^2 - f}} \\ 0, \end{cases}$

where ϑ_n is the angle between the traveling direction and the mean AOA for tap-n.

<Editor's notes: Nortel expressed the simulation convenience of using Jakes spectrum as an option. So the text in [.] reflects that option> [Generating the time-varying fading process from a Doppler spectrum based on the traveling direction and mean AoA can be computationally expensive. The impact on the overall system level performance with this more accurate method may be small. Therefore, the Jakes spectrum should be used as a tradeoff between simulation complexity and model accuracy. This will facilitate easy generation of such a time-varying process (e.g. offline generation)]

------------End Proposed Text-----------

V. Pages 114 and 115, delete Appendix A.

VI. Add two more references.

------------Begin Proposed Text---------

[67] A. Abdi, 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 Trans. Vehic. Technol.*, vol. 51, pp. 425-434, 2002.

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