Time and Angle of Arrival Statistics of Mobile-to-Mobile Communication Channel Employing Circular Scattering Model

Babu Sena Paul, Abul Hasan, Himanshu Madheshiya and Ratnajit Bhattacharjee

Department of Electronics and Communication Engineering, Indian Institute of Technology Guwahati, Assam, India

ABSTRACT

Mobile-to-mobile communication becomes necessary in many emerging wireless communication systems. Characteristics of mobile-to-mobile communication channel have been studied through a geometrical single bounce scattering model and analytical expressions for angle of arrival and time of arrival probability density functions have been derived for such models. Analytical expressions have been verified through computer simulations. This paper aims to provide a better understanding of mobile-to-mobile channel behavior in terms of the parameters studied.

Keywords:
Angle of arrival, Time of arrival, Channel model, Geometry based single bounce modeling, Mobile-to-mobile communication.

1. INTRODUCTION

Studies on mobile-to-mobile (M2M) communication and relay based communication have been attracting significant attention of the research community [1-5] with the advent and popularity of wireless adhoc networks, advanced cellular networks and wireless sensor networks. In an M2M channel both the transmitter and receiver are surrounded by local scatterers. Making it channel different from a conventional macro cellular channel. In a scattering environment the angle of arrival (AOA) and time of arrival (TOA) probability density functions (PDF) depend on the location as well as distribution of scatterers. Beam steering and interference mitigation, in a wireless environment using antenna arrays, require prior knowledge of the AOA of signals. Information on the TOA statistics helps determine data rates and symbol periods so as to avoid ISI. As in the case of the macro cellular scenario [6,7], it is necessary to develop appropriate models representing M2M channels and study the distribution of TOA and AOA pertaining to such models.

A widely used geometrical model for macro cellular scenario consists of a uniformly distributed circular scattering region around the mobile station [8,9]. This modeling technique has been extended for the M2M case by considering uniformly distributed circular scattering region around both transmitter and receiver. Further, only single scattered waves have been considered significant. The analytical expressions for AOA and TOA PDFs for the single bounce geometrical model for M2M communication have been derived and verified through simulation studies.

The paper is organized as follows: Section 2 elaborates on the model under consideration. Analytical expressions for time and angle of arrival have been derived in section 3 and section 4 respectively. Finally, conclusions are drawn in section 5.

2. MODEL DESCRIPTION

The M2M channel model under consideration may be considered a geometry-based single bounce model as shown in Figure 1. M_1 and M_2 denote the transmitting and receiving mobile communicating devices respectively, separated by a distance D. The model can take into account mobile devices with one or more antennas. In this model, scatterers are assumed to be distributed in two circular regions around M_1 and M_2. In general, the distribution of scatterers may be arbitrary, and it will affect the AOA and TOA PDFs evaluated using the model. The analysis presented here has been carried out assuming uniform distribution of scatterers. R_1 and R_2 respectively denote the radii of the scattering regions around M_1 and M_2. N_1 and N_2 represent the number

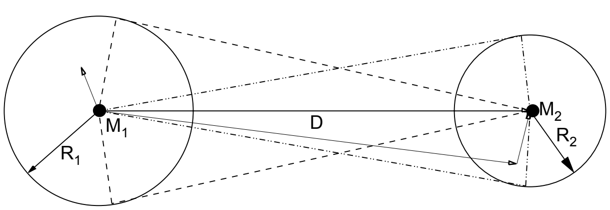

Figure 1: Uniformly distributed circular scattering regions surrounding mobile nodes modeling mobile-to-mobile propagation environment.

of scatterers at the transmitting and receiving ends. It is assumed that a ray emanating from the transmitter reaches the receiver only after being scattered by a single scatterer either at the transmitter/receiver-end. It is also assumed that all scattered rays that reach the receiver have the same power. The rays reaching the receiver after multiple scattering are assumed to have very little power compared to the rays reaching the receiver after single scattering. Hence, multiple scattering has not been taken into account. The separation between the transmitter and the receiver is assumed to be large in comparison with the radii of the scattering regions. This assumption permits the application of geometrical optics and the waves can be represented as rays.

3. DERIVATION OF TIME OF ARRIVAL PROBABILITY DENSITY FUNCTION

In this section we derive the expression for TOA PDF for the geometrical model described in section 2. For the model under consideration, the transmitted signal, after being scattered by the scatterers, reaches the receiver as multipath components with different time delays depending on path lengths. The difference in time delays of different multipath components introduces delay spread in the channel which in turn may introduce inter symbol interference (ISI) depending on the data rate of the system. The maximum data rate that can be supported by a channel without introducing ISI and requirement for equalization is determined by the time dispersive nature of the channel [10]. TOA profile also helps determine navigational services like position of a device. Moreover, there is a strong relation between signal bandwidth and delay spread (which are inversely related) making characterization of TOA statistics essential.

In deriving TOA PDF expression analytically for the model described in section 2, joint TOA/AOA PDF can be derived from which marginal TOA PDF can be found. In [11] it was observed that this approach becomes intractable even for uniformly distributed scatterers. An alternative approach for obtaining analytical expression for the TOA PDF for macro cellular scenario through computation of cumulative distribution function (CDF) of TOA using a geometrical basis was presented by the authors of [11]. In deriving TOA PDF for M2M channel model, the same methodology has been adopted.

To obtain the TOA CDF for a M2M communication channel represented through geometrical model containing finite number of scatterers, the first step is to determine the scatterers responsible for contribution towards a certain TOA, say τ. If the scatterers are assumed to reside on an ellipse having M_1 and M_2 at its foci, the rays from M_1 to M_2 (or from M_2 to M_1) involving such scatterers will have equal path delays. An ellipse corresponding to a given path delay τ, intersecting with the circular scattering regions is shown in Figure 2. The scatterers within the ellipse cause delay less than τ. The scatterers present in the shaded regions shown in Figure 2 contribute towards determining the CDF, $F_\tau(\tau)$. Hence the CDF for the TOA for any particular τ, may be written as,

$$F_\tau(\tau) = P_r\{t_{TOA} \le \tau\} = \lim_{N\to\infty} \frac{n(\tau)}{N} \quad (1)$$

Where, $F_\tau(\tau)$ is the CDF of the TOA. P_r represents the probability.

$n(\tau)$ gives the total number of scatterers present inside the ellipse having constant delay τ and hence contributing towards the CDF. N gives the total number of scatterers present in the system.

If $n_1(\tau)$ and $n_2(\tau)$ represent the total number of scatterers around M_1 and M_2 respectively and contributing to the CDF and N_1 and N_2 are the total number of scatterers around M_1 and M_2 respectively, then equation 1 can be written as,

$$F_\tau(\tau) = \lim_{N_1,N_2\to\infty} \frac{n_1(\tau)+n_2(\tau)}{N_1+N_2} \quad (2)$$

The TOA PDF is obtained from the TOA CDF, $F_\tau(\tau)$, on differentiating it with respect to time delay τ. Hence the TOA PDF, $f_\tau(\tau)$, can be written as, 1 d

$$f_\tau(\tau) = \lim_{N_1,N_2\to\infty} \frac{1}{N_1+N_2}\frac{d}{d\tau}(n_1(\tau)+n_2(\tau)) \quad (3)$$

Let, ρ_1 and ρ_2 be the scatterer densities around M and M respectively, and assuming uniform distribution of the scatterers, the number of scatterers $n_1(\tau)$, $n_2(\tau)$, N_1 and N_2 can be written as follows,

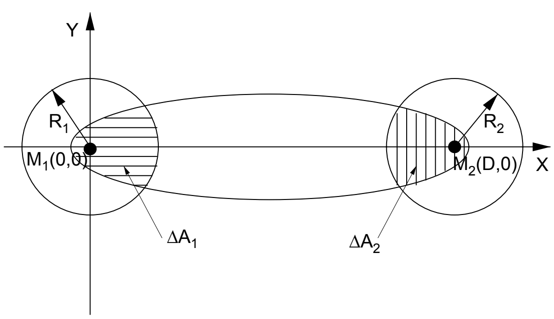

Figure 2: Shaded regions of scatterers for evaluating time of arrival cumulative distribution function.

$$n_1(\tau) = \rho_1 \Delta A_1(\tau) \tag{4}$$

$$n_2(\tau) = \rho_2 \Delta A_2(\tau) \tag{5}$$

$$N_1 = \rho_1 \pi R_1^2 \tag{6}$$

$$N_2 = \rho_2 \pi R_2^2 \tag{7}$$

The areas ΔA_1 and ΔA_2 are as shown in Figure 2.

Combining equation 3 to 7, the PDF of the TOA may be written as,

$$f_\tau(\tau) = \frac{\rho_1}{\rho_1 \pi R_1^2 + \rho_2 \pi R_2^2} \frac{d\Delta A_1(\tau)}{d\tau} + \frac{\rho_2}{\rho_1 \pi R_1^2 + \rho_2 \pi R_2^2} \frac{d\Delta A_2(\tau)}{d\tau} \tag{8}$$

Equation 8 can be written as,

$$f_\tau(\tau) = \frac{\rho_1}{\rho_1 \pi R_1^2 + \rho_2 \pi R_2^2} \cdot \pi R_1^2 \left(\frac{1}{\pi R_1^2} \cdot \frac{d\Delta A_1(\tau)}{d\tau} \right) + \frac{\rho_2}{\rho_1 \pi R_1^2 + \rho_2 \pi R_2^2} \cdot \pi R_2^2 \left(\frac{1}{\pi R_2^2} \cdot \frac{d\Delta A_2(\tau)}{d\tau} \right) \tag{9}$$

With reference to Figures 3 and 4, it may be observed that the terms inside the parentheses of equation 9 represent the TOA PDF for a macro cellular scenario. The term inside the first parenthesis of equation 9 gives the TOA PDF for a macro cellular scenario depicted in Figure 4, whereas the term within the second parenthesis gives the TOA PDF for the scenario shown in Figure 3. Thus it may be observed that the TOA PDF for a M2M channel can be written in terms of the TOA PDF of two macrocellular channels combined with suitable weighting factors. For the sake of brevity and better readability, the terms within the parenthesis of equation 9 are denoted as,

$$f_{1\tau}(\tau) = \left(\frac{1}{\pi R_1^2} \cdot \frac{d\Delta A_1(\tau)}{d\tau} \right) \tag{10}$$

$$f_{2\tau}(\tau) = \left(\frac{1}{\pi R_2^2} \cdot \frac{d\Delta A_2(\tau)}{d\tau} \right) \tag{11}$$

Hence equation 9 can be written as,

$$f_\tau(\tau) = \frac{\rho_1 R_1^2}{\rho_1 R_1^2 + \rho_2 R_2^2} \cdot f_{1r}(\tau) + \frac{\rho_2 R_2^2}{\rho_1 R_1^2 + \rho_2 R_2^2} \cdot f_{2\tau}(\tau) \tag{12}$$

or else,

$$f_\tau(\tau) = \frac{\rho_1 R_1^2 / \rho_2 R_2^2}{1 + \rho_1 R_1^2 / \rho_2 R_2^2} \cdot f_{1\tau}(\tau) + \frac{1}{1 + \rho_1 R_1^2 / \rho_2 R_2^2} \cdot f_{2\tau}(\tau) \tag{13}$$

$$f_\tau(\tau) = \frac{\rho}{1+\rho} \cdot f_{1\tau}(\tau) + \frac{1}{1+\rho} \cdot f_{2\tau}(\tau) \tag{14}$$

$$\rho = \frac{\rho_1 R_1^2}{\rho_2 R_2^2} \tag{15}$$

Where, ρ gives the relative scatterer density at M_1 with reference to scatterer density at M_2. $f_{i\tau}$ (τ), for i = 1 and 2 respectively represent the TOA PDF's for a macro-cellular communication system, where the scatterers are present only around the mobile station (M_2 for Figure 3 and M_1 for Figure 4), whereas the base station (M_1 for Figure 3 and M_2 for Figure 4) is devoid of scatterers.

Expressions for TOA PDF for a circular scattering model with uniform distribution of scatterers representing macro cellular environment can be found in [11] which has been reproduced in equation 16 for the sake of continuity,

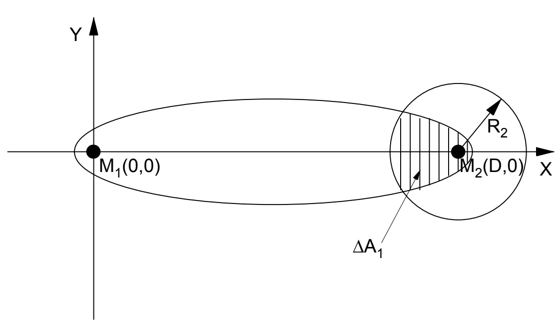

Figure 3: Area contributing to time of arrival probability density functions, with M_1 as transmitter and M_2 as receiver.

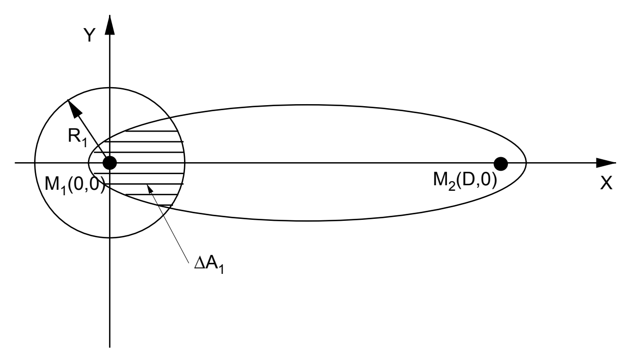

Figure 4: Area contributing to time of arrival probability density functions, with M_2 as transmitter and M_1 as receiver.

$$f_\tau(\tau) = \frac{1}{\pi R^2}\frac{d\Delta A(\tau)}{d\tau}$$
$$= \frac{c}{\pi R^2} \times$$
$$\left[\frac{\pi\tau^2c^2k_2 - \tau ck_2^2 + \pi k_2k_1^2 + \tau ck_1^2 - 2Rk_1^2}{4k_1k_2}\right.$$
$$+\frac{\tau^2c^2k_0k_4 + \tau ck_0k_1^2}{2k_4^2 + 2k_0^2k_1^2} + \frac{\tau^2c^2 + k_1^2}{2k_1}$$
$$\cdot\arctan\left(\frac{k_0k_1}{k_4}\right) - \frac{R - \tau c}{(4R^2D^2 - k_3^2)^{1/2}}$$
$$\left.\cdot\left(2R^2 + \frac{\tau ck_1^2k_4(1 + k_0^2)}{(2k_4^2 + 2k_0^2k_1^2)^{1/2}}\right)\right] \tag{16}$$

Where,

$$k_0 = \tan\left(\frac{1}{2}\arccos\left(\frac{-\tau^2c^2 + D^2 + 2R\tau c}{2RD}\right)\right)$$
$$k_1 = \sqrt{\tau^2c^2 - D^2}$$
$$k_2 = \sqrt{D^2 - 4R^2 - \tau^2c^2 + 4R\tau c}$$

$k_3 = -\tau^2c^2 + D^2 + 2R\tau c$

$k_4 = D - \tau c$

c = *velocity of light*

R = *radius of the circle containing scatterers around the mobile station*

D = *distance between the base station and the mobile station*.

Equation 16 is valid only for $(D/c) < \tau \leq (D + 2R/c)$. When = (D/c), the values of k_0, k_1, and k_4 becomes equal to zero and a few of the terms result in an indeterminate 0 condition. Although it may be possible to apply L' Hospital's rule and find the limit as → (D/c), the value of has been restricted to be strictly greater than D/c to avoid any singularity.

We verified the above formulation of the TOA PDF for a M2M channel, depicted by two disc of scatterers around the transmitting and the receiving mobile stations through computer simulations. Uniform distribution of scatterer positions were obtained by generating ordered pairs of random variables giving the angular position and the radial distance from the mobile stations. The angular positions were chosen to be uniformly distributed in [0,2π]. The radial distances were obtained from the product of the square root of uniformly distributed numbers between 0 and 1, multiplied with the radius of the scattering circles (R_1 for scatterers around mobile station M_1 and R_2 for scatterers around mobile station M_2). The simulations were run for 10 iterations each having different number of scatterers distributed uniformly with all the other model parameters remaining the same. The distribution of scatterers remains same but actual scatterer position changes in different runs.

The final results were obtained by averaging the results of different iterations. Some representative results for different model parameters, as given in the legends of the respective figures, have been shown in Figures 5 and 6. For the results shown in these figures, D, the separation between the two mobile stations M_1 and M_2 has been taken as 1000 m. For $R_1/R_2 = 1$, the radii R_1 and R_2 have been taken as 100 m each. For different simulation trials, changes have been made in the value of either R_2 or N_2. Theoretical and simulated results for various values of ρ and R_1/R_2 have been plotted. These plots verify the validity of equation 14.

4. DERIVATION OF AOA PROBABILITY DENSITY FUNCTION FOR M2M CHANNEL

Multiple antenna elements are often used either at the transmitter and/or at the receiving end of a

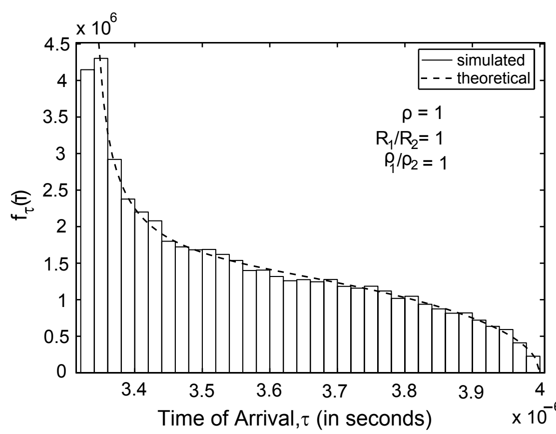

Figure 5: Theoretical and simulated density function of time of arrival for ρ = 1 and R_1/R_2 = 1.

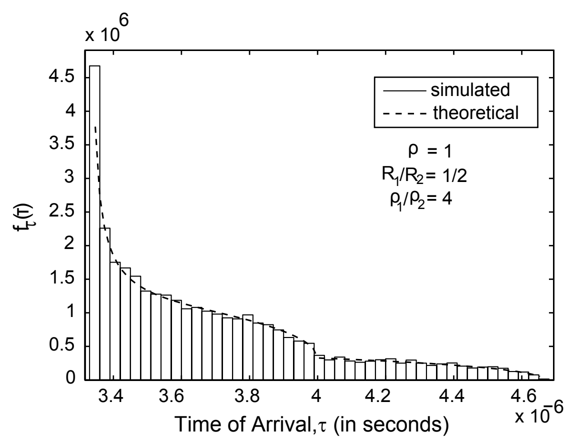

Figure 6: Theoretical and simulated density function of time of arrival for ρ = 1 and R_1/R_2 = 1/2.

communication system. Multiple antennas may be used for spatial multiplexing or beam forming purposes. In beam forming applications the knowledge of the angle of arrival (AOA) helps in steering the main lobe to the desired direction. Beam steering reduces the effect of interference and maximizes the desired signal by forming beam nulls at the direction of the interfering signals and directing the main lobe to the direction of the desired signal.

The AOA statistics for M2M channel differs from those for macrocellular scenario as the scatterers are present both at transmitter and receiver ends. The AOA statistics for macro cellular scenario represented by circular scattering model have been dealt with and reported in detail in literature [7,11]. In an M2M channel, the scatterers around both the mobile units M_1 and M_2 and their distributions along with the model parameters viz. the distance between the mobile terminals, radii of the circular scattering region, relative scatterer density, determines the AOA statistics at the receiving mobile station. As in the previous section, the PDF of the AOA at the mobile station is obtained by differentiating the CDF of the AOA at the receiving mobile station with respect to the angle of arrival θ.

The PDF of the AOA, $f_\theta(\theta)$, at the mobile station, M_1, spans the range $[-\pi, \pi]$. The probability of a scatterer being placed inside the shaded regions corresponding to an angle of arrival less than or equal to θ, as shown in Figure 7, gives the AOA CDF for that particular angle θ. As symmetry exists in the system model around the x-axis, the AOA PDF is symmetrical about $\theta = 0$.

Scatterers are assumed to be uniformly distributed around M_1 and M_2. The AOA CDF is given by the ratio of the number of scatterers lying inside the shaded regions to the total number of scatterers in the system, in the limiting sense. The AOA CDF can be written as,

$$\begin{aligned} F_\theta(\theta) &= \mathrm{P_r}\{\phi_{AOA} \le \theta\} \\ &= \lim_{N\to\infty} \frac{n_\theta(\theta)}{N} \\ &= \lim_{N_1, N_2\to\infty} \frac{n_1(\theta)+n_2(\theta)}{N_1+N_2} \end{aligned} \tag{17}$$

Where, $n_\theta(\theta)$ gives the number of scatterers contributing towards the CDF for an AOA, θ.

Similarly, $n_1(\theta)$ and $n_2(\theta)$ corresponds to the number of scatterers around M_1 and M_2 which contributes towards the CDF for an AOA, θ. N gives the total number of scatterers in the system, while N_1 and N_2 gives the total number of scatterers around M_1 and M_2 respectively and $= N_1 + N_2$.

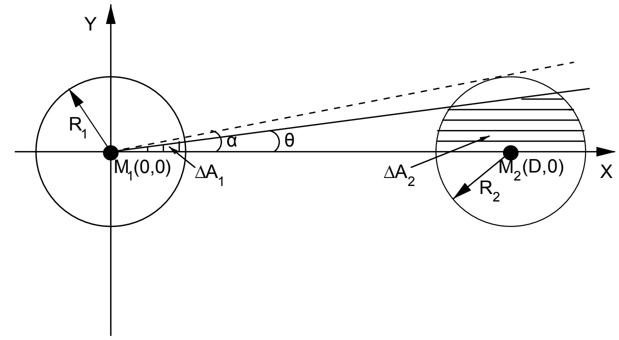

Figure 7: Shaded regions for evaluating angle of arrival cumulative distribution function.

The AOA PDF is obtained upon differentiating equation 17 with respect to θ. Hence,

$$f_\theta(\theta) = \lim_{N_1, N_2\to\infty} \frac{1}{N_1+N_2}\frac{d}{d\theta}(n_1(\theta)+n_2(\theta)) \tag{18}$$

$$n_1(\theta) = \rho_1 \, \Delta A_1(\theta) \tag{19}$$

$$n_2(\theta) = \rho_2 \, \Delta A_2(\theta) \tag{20}$$

$$N_1 = \rho_1 \pi R_1^2 \tag{21}$$

$$N_2 = \rho_2 \pi R_2^2 \tag{22}$$

Where, ρ_1 and ρ_2 are scatterer densities around the mobile stations M_1 and M_2 respectively.

The areas ΔA_1 (θ) and ΔA_2 (θ) are as shown in Figure 7.

The sectorial area ΔA_1 (θ) is given by,

$$\Delta A_1(\theta) = \frac{\theta R_1^2}{2} \tag{23}$$

Combining equation 18 to equation 23 gives,

$$\begin{aligned} f_\theta(\theta) &= \frac{1}{\rho_1\pi R_1^2 + \rho_2 \pi R_2^2}\frac{d}{d\theta}(\rho_1\Delta A_1(\theta)+\rho_2\Delta A_2(\theta)) \\ &= \frac{\rho}{1+\rho}\frac{1}{2\pi} + \frac{1}{1+\rho}\frac{1}{\pi R_2^2}\frac{d\Delta A_2(\theta)}{d\theta} \end{aligned} \tag{24}$$

ρ is as defined in equation 15,

$$\rho = \frac{\rho_1 R_1^2}{\rho_2 R_2^2} \tag{25}$$

The term $\frac{1}{\pi R_2^2}\frac{d}{d\theta}$ (ΔA_2 (θ)) denoted as $f_{2\theta}$ (θ) gives the PDF of the AOA for a macro cellular scenario, as derived in [11]. The PDF of the AOA for a macro cellular scenario, with D as separation between the transmitter and receiver and R_2 as radius of scattering circle, is given as,

$$f_{2\theta}(\theta) = \begin{cases} \dfrac{2D\cos(\theta)\sqrt{D^2\cos^2(\theta) - D^2 + R_2^2}}{\pi R_2^2} & for, -\sin^{-1}\left(\dfrac{R_2}{D}\right) \le \theta \le \sin^{-1}\left(\dfrac{R_2}{D}\right) \\ 0 & elsewhere \end{cases} \quad (26)$$

Combining equation 24 and equation 26, the PDF of AOA for a M2M channel may be written as,

$$f_{\theta}(\theta) = \begin{cases} \dfrac{\rho}{1+\rho}\cdot\dfrac{1}{2\pi} + \dfrac{1}{1+\rho}\cdot\dfrac{2D\cos(\theta)\sqrt{D^2\cos^2(\theta) - D^2 + R_2^2}}{\pi R_2^2} & for, -\sin^{-1}\left(\dfrac{R_2}{D}\right) \le \theta \le \sin^{-1}\left(\dfrac{R_2}{D}\right) \\ 0 & elsewhere \end{cases} \quad (27)$$

where, ρ is defined in equation 25 and $\theta \in [-\pi, \pi]$.

The above formulation for the PDF of AOA was verified through computer simulation.

Uniformly distributed scatterers were generated by the method described in section 3. Some of the representative results have been plotted in Figures 8 and 9. The model parameters for the simulation were same as that for the TOA PDF simulations. Theoretical and simulated results for various values of and R_1/R_2 have been plotted. The agreement of the theoretical and the simulation results verify the validity of equation 27.

5. CONCLUSION

The paper investigates a geometrically based single bounce channel model for a M2M channel. The scatterers are assumed to be uniformly distributed in circular discs with the transmitter and receiver located at the center. The PDFs for the time and angle of arrival for such M2M channels have been derived. The derived density functions were verified through computer simulations. The modeling and analysis presented in this paper would contribute towards better understanding of M2M communication and design of such systems.

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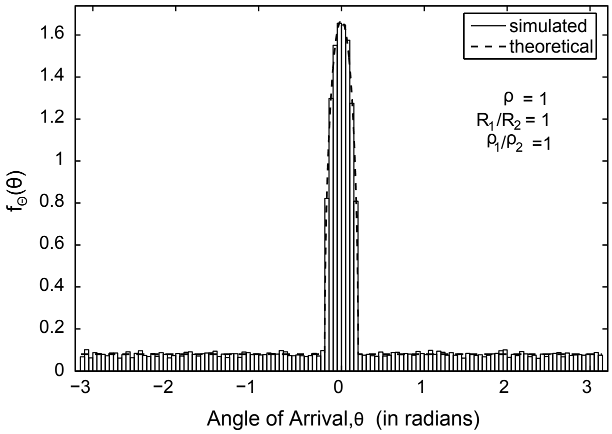

Figure 8: Theoretical and simulated density function of angle of arrival for ρ = 1 and R_1/R_2 = 1.

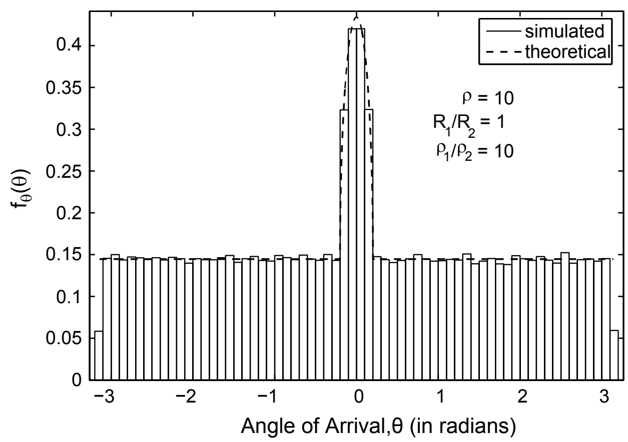

Figure 9: Theoretical and simulated density function of angle of arrival for ρ = 10 and R_1/R_2 = 1.

REFERENCES

1. A S Akki, Statistical properties of mobile-to-mobile land communication channels, *IEEE Transactions on Vehicular Technology*, Vol. 43(4), pp. 826-31, 1994.
2. C S Patel, G L Stuber, and T G Pratt, Simulation of Rayleigh-faded mobile-to-mobile communication channels, *IEEE Transactions on Communications*, Vol. 53(11), pp. 1876-84, 2005.
3. M Patzold, B O Hogstad, N Youssef, and D Kim, A MIMO mobile-to-mobile channel model: Part I the referencemodel, *In Proceedings of IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, Vol. 1, pp. 573-8, Sep. 2005.
4. M Patzold, B O Hogstad, N Youssef, and D Kim, A MIMO mobile-to-mobile channel model: Part II the simulationmodel, *In Proceedings of IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, Vol. 1, pp. 562-7, Sep. 2005.
5. F Vatalaro, and A Forcella, Doppler spectrum in mobile-to-mobile communications in the presence of threedimensional multipath scattering, *IEEE Transactions on Vehicular Technology*, Vol. 46(1), pp. 213-9, 1997.
6. P Petrus, J H Reed, and T S Rappaport, Geometrically based statistical channel model for macrocellular mobile environments, *In Proceedings of IEEE Globecom*, pp. 1197-201, 1996.
7. P Petrus, J H Reed, and T S Rappaport, Geometrical-based statistical macrocell channel model for mobileenvironments, *IEEE Transactions*

on Communications, Vol. 50(3), pp. 495-502, Mar. 2002.

8. B O Hogstad, and M Patzold, Capacity studies of MIMO channel models based on the geometrical one-ring scatteringmodel, *In Proceedings of the 15th IEEE International Symposium Personal, Indoor and Mobile Radio Communications (PIMRC 2004)*, Vol. 3, pages 1613-1617, Sep. 2004.
9. M Patzold, and B O Hogstad, A space-time channel simulator for MIMO channels based on the geometrical one-ringscattering model, *In Proceedings of the Vehicular Technology Conference (VTC 2004)*, Vol. 1, pages 144-9, Sep. 2004.
10. J B Anderson, T S Rappaport, and S Yoshida, Propagation measurements and models for wireless communicationchannels, *IEEE Communication Magazine*, Vol. 33(1), pp. 42-49, Jan. 1995.
11. R B Ertel, and J H Reed, Angle and time of arrival statistics for circular and elliptical scattering models, *IEEE Journal on Selected Areas in Commnunication*, 17(11):1829-1840, Nov. 1999.

AUTHORS

Babu Sena Paul received his B.Tech and M.Tech degree in Radio physics and Electronics from the University of Calcutta, West Bengal, India, in 1999 and 2003 respectively. He was with Philips India Ltd from 1999-2000. From 2000-2002 he was lecturer of Electronics and Communication Engineering Dept. at SMIT, Sikkim, India. He is currently pursuing his Ph.D. in the area of wireless communication at IIT Guwahati, Assam, India. He has attended and published several papers in international and national conferences and symposiums. He was awarded the IETE Research Fellowship. He is a life member of IETE.

E-mail: babusena_paul@yahoo.com

Abul Hasan is an Electronics Engineering graduate who completed his B.Tech (Electronics and Communication Engineering) from Indian Institute of Technology Guwahati in 2008. Currently he is working with PicoPeta Simputers Pvt Ltd (now a subsidiary of Geodesic Ltd) as a Hardware Design Engineer. He is engaged in design and development of Simputers and Electronic Systems Hardware.

E-mail: abul.hasan@geodesic.com

Himanshu Madheshiya received his B.Tech (Electronics and Communication Engineering) from Indian Institute of Technology Guwahati in 2008. Currently he is working as Operations and maintenance engineer at NTPC (India's largest thermal power generating company).

E-mail: him13may@gmail.com

Ratnajit Bhattacharjee received his B. E. in Electronics and Telecommunication Engineering (First Class Honors) from Gauhati University (REC (at present NIT) Silchar), M. Tech. (E and ECE Department, Microwave Engineering specialization) from IIT Kharagpur and Ph. D. (Engineering) from Jadavpur University Kolkata. Presently he is an Associate Professor in the Department of Electronics and Communication Engineering, IIT Guwahati. Prior to joining IIT Guwahati, he was a faculty member in REC (NIT) Silchar. His research interest includes Wireless communication, Wireless networks, Microstrip antennas, Microwave Engineering and Electromagnetics. He has published over sixty research papers in journals, international and national conferences. He has developed the web course on Electromagnetic Theory under the NPTEL project of MHRD. He has also been involved in several research projects. He has been a Co-investigator for the contracted research from NICT Japan in the area of Next Generation Wireless Networks and currently a member of the research team of the Tiny6 STIC project (funded by French ministry of Foreign Affairs), which deals with IPv6 and Sensor Networks. In NIT Silchar, he was a coordinator for the setting up of Campus Wide Optical Fiber based network under the Centre for Excellence scheme. He was also associated in a number of projects from DRDO India, in the field of development of antenna system. He has done consultancy project works for the industry as well. He is a member of IEEE and life member of Indian Society of Technical Education.

E-mail: ratnajit@iitg.ernet.in

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