International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 7 (July, 2024), PP. 81-89

Space-Time Correlated Model for Mobile-to-Mobile Rayleigh Fading Channel: Simulator Performance

Sylvester Akiishi[1]
[1]*Department of Electrical and Electronic Engineering, University of Johannesburg, Johannesburg, South Africa*

Ahmed Ali[2]
[2]*Department of Electrical and Electronic Engineering, University of Johannesburg, Johannesburg, South Africa*
Ebenezer Esenogho[3]
[3]*Department of Electrical Engineering, University of Botswana, Gabrone, Botswana*

ABSTRACT: *For a good design framework and performance evaluation of MIMO wireless channel models, it is imperative to have accurate and realistic channel models. Furthermore, this arduous task is achieved using MIMO channel simulators. Thus, the MIMO simulator reproduces the statistical properties of the non-realizable reference model with sufficient accuracy while keeping complexity very low. However, designing accurate and efficient deterministic MIMO channel simulators is often challenging. In this paper, the theoretical performance of the MIMO channel simulator is studied under an isotropic environment with existing and newly modified parameterisation methods. The existing methods are the Extended Method of Exact Doppler Spread (EMEDS) and the Modified Method of Equal Area (MMEA). The Modified Extended Method of Exact Doppler Spread (MEMEDS) and New Modified Method of Equal Area (NMMEA) are the new improved parameterization methods. Theoretical performance evaluation of the existing conventional parameterisation methods with the newly enhanced methods is investigated.*
Keywords: *Modified Extended Method of Exact Doppler Spread, New Modified Method of Equal Area.*

Date of Submission: 01-07-2024 Date of Acceptance: 11-07-2024

I. INTRODUCTION

The wireless communication system can be divided into three basic segments: transmitter (Tx), receiver (Rx), and the wireless channel, which stands between the Tx and the Rx antennas facilitate the propagation of wireless signals. In contrast to the Tx and Rx, which can be designed to provide the wireless communication system with a better tradeoff between reliability and efficiency, the wireless channel cannot be remodeled or changed. While all channel models are wrong, some are useful. Hence, a good understanding of the wireless channel model is the basis for a reliable multiple input multiple output (MIMO) communication system design and analysis [1]. Therefore, MIMO channel simulators play an essential role in channel modeling; they replicate the statistical characteristics of the channel, considering the temporal, spatial, frequency correlation power spectral density (PSD), level crossing rate (LCR) etc. However, to fully exploit the advantages inherent in deterministic MIMO channel simulators, one must carefully decide, define, and classify the parameters necessary for model specification.

The literature on channel modeling in MIMO systems has shown a variety of modeling approaches: Geometric-based stochastic model (GBSM), Non-Geometric stochastic model (NGSM), Correlation-based model (CBM), Propagation motivated model and Ray-tracing. However, of recent, many studies have explored using regular-shaped geometry-based stochastic modeling (RS-GBSMs) techniques in MIMO communication networks [2], [3], [4]. These studies collectively highlight the importance, versatility and potential of RS-GBSM in diverse MIMO communication environments: fixed-to-mobile (F2M), vehicle-to-vehicle (V2V) and machine-to-machine (M2M). The RS-GBSM techniques used are the one-ring, two-ring and ellipse models presented in two-dimensional (2D) and three-dimensional (3D) domains, and they have been an effective and suitable method. The channel simulator's performance for these techniques mainly depends on the parameterization method adopted. It thus extensively affects the accuracy and efficiency of the channel simulators to perfectly mimic the MIMO channel model.

One-ring and two-ring models have gained popularity in the past and are primarily known for modeling narrowband channels in MIMO limiting its applications. Of recent, the ellipse model has become popular and has shown promising outcomes for a realistic and effective method of modeling both narrowband and wideband channel models symmetric (isotropic) and asymmetric (non-isotropic) scenarios. The elliptical models have attractive features for investigating the performance of MIMO wireless systems for high data rates with its frequency selectivity feature, which has been an interest of most researchers. It also leverages on its elliptical geometry to model scattering environments extending to adjustable dimensions to capture the streets and highways with their length and width accordingly. A 2D ellipse RS-GBSM was first proposed in [5] to model a line of sight (LOS) multipath radio channel with adaptive low antenna heights, and the model was further improved in [6] for a single input multiple output (SIMO) network. The elliptical model was fully explored in [7] to model a wideband MIMO channel, considering the azimuth angle of departure (AoD) and azimuth angle of arrival (AoA). The model's performance was limited to the existing parameterization methods, which are less optimal for determining channel’s statistical properties.

In this paper, we study the existing performance-limited parameterization computation methods, i.e. EMEDS and MMEA, as well as the new class of recently proposed methods, NEMEDS and NMMEA. The performance of the MIMO simulator with respect to the existing parameterization method is compared with that of the newly modified methods. The channel simulator investigates the following statistical properties: AoD, AoA, the temporal autocorrelation function (ACF) and the 2D cross-correlation function (CCF). The remainder of the paper is outlined as follows: Section II describes the theoretical reference and simulation models, with the closed-form solutions outlined. A focus on the parameter computation methods is discussed in III. The MIMO simulator's performance analysis under different computation methods is investigated in IV, followed by section V, which summarises and draws conclusions.

II. ELLIPTICAL MODEL FOR MIMO CHANNELS

Based on the approach and concept presented in [7], the geometric-elliptical shape, as depicted in Fig. 1, is used to model the MIMO channel in a macrocell scenario. The elliptic model has leverage, for it can model both the narrowband and the wide-band models under symmetric and asymmetric conditions. It acknowledges the relationship and dependency between the AoD and AoA, simplifying general analytical solutions and reducing computational complexity. The diagram illustrates the position of the transceivers at the ellipse focal points and all the direction of scatterers associated with the path lengths impinging on the antennas of the transceiver. Without loss of generality, we constrained our investigation accordingly: only scatterers within the ellipse are considered; the LOS component is neglected; infinite number of scatterers when deriving a theoretical reference model. The other parameters shown in Fig. 1 are defined in Table 1.

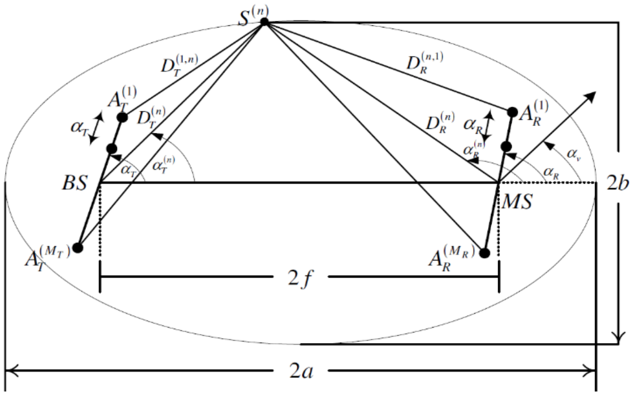

Fig. 1: Elliptical Geometric model [7]

Table 1. Definition of parameters of the elliptical channel model in Fig.1

a, b	Semi-major axis and semi-minor axis of the ellipse
$2f$	Distance between the centres of the Tx and Rx spheres
δ_T, δ_R	Antenna element spacing of the Tx and Rx, respectively
β_T, β_R	Tx and Rx antenna element tilt angles
α_v	The angle of motion of Rx
v	Velocity of the mobile Rx

α_n^T $(n = 1,2,\dots,N)$	AoD from Tx impinging on theeffective scatterer (S_n)
α_n^R $(n = 1,2,\dots,N)$	AoA from the effective scatterer (S_n) reaching the Rx
D_{ln}^T,D_{nl}^R	Path length: $A_T^l - S_n$ and $S_n - A_R^k$
D_T^n,D_R^n	Path length:$BS - S_n$ and $S_n - MS$
M_T, M_R	Number of antenna elements at BS and MS

A. THE THEORETICAL REFERENCE MODEL FOR THE ELLIPTICAL MIMO CHANNEL SIMULATOR

The realization of the reference model is based on the relationship between the Tx at the base station (BS), the Rx at the mobile station (MS) and the pathways travelled by certain scatterers between them, as shown in Fig. 1. For simplicity, the MIMO channel can be expressed by the matrix $H(t) = [h_{kl}(t)]_{M_R \times M_T}$ for the link $D_{1n}^T - S^n - D_{n1}^R$, and $M_R = M_T = 2$. As shown in [7], [8], the MIMO channel gains ($[h_{kl}(t)]_{M_R \times M_T}$) of the elliptical model is expressed by the following:

$$h_{kl}(t) = \lim_{N\to\infty} \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_{ln} b_{nk} e^{j(2\pi f_n t + \theta_n + \theta_0)}, \quad (1)$$

where

$$a_{ln} = e^{\pi(M_T - 2l + 1)(\delta_T/\lambda_0)\cos(\alpha_n^T - \beta_T)}, (1)$$

$$b_{nk} = e^{j\pi(M_R - 2k + 1)(\delta_T/\lambda_0)\cos(\alpha_n^R - \beta_R)}, \quad (3)$$

$$f_n = f_{max}\cos(\alpha_n^R - \alpha_v), \quad (2)$$

$$\theta_0 = -\frac{4\pi a}{\lambda_0}. \quad (3)$$

Where the symbols λ_0 and f_{max} denote the wavelength and the maximum Doppler frequency at Rx. The phase shift θ_0 is i.i.d random variable with a uniform distribution ranging from $[0, 2\pi)$.

Since the AoD is dependent on the AoA in the elliptical geometric model within the range of $[0, 2\pi)$, the following equations exist for AoD α_n^T:

$$\alpha_n^T = \begin{cases} f(\alpha_n^R), \ if \ \ 0 < \alpha_n^R \le \alpha_0 \\ f(\alpha_n^R) + \pi, \ if \ \alpha_0 < \alpha_n^R \le 2\pi - \alpha_0 \quad (4) \\ f(\alpha_n^R) + 2\pi \quad if \ 2\pi - \alpha_0 < \alpha_n^R \le 2\pi, \end{cases}$$

where

$$f(\alpha_n^R) = arctan\left[\frac{(K_0^2 - 1)\sin(\alpha_n^R)}{2K_0 + (K_0^2 + 1)\cos(\alpha_n^R)}\right], (5)$$

and

$$\alpha_0 = \pi - arctan\left(\frac{K_0^2 - 1}{2K_0}\right), (6)$$

Also, the parameter K_0 represents the reciprocal of the ellipse eccentricity e value and is denoted by $K_0 = 1/e = a/f$.

We also consider the PDF distribution of AoA and AoD of the scattering linked to the correlation functions (CFs) according to Von Mises distribution[9] .

$$f(\alpha_n^R) = \frac{exp[K_0 cos(\alpha^R - m_R)]}{2\pi I_0(K)}, \quad (7)$$

and

$$f(\alpha_n^T) = \frac{exp[K_0 cos(\alpha^T - m_T)]}{2\pi I_0(K)}, \quad (8)$$

The parameters are defined accordingly as: $I_0(.)$ known as zeroth-order modified Bessel function of the first kind. m_R and m_T are the mean angle at the AoA and AoD respectively.K is designated as kappa and it defines the uniform scattering type; for when $K > 0$ it is referred to as non-isotropic scattering and when $K = 0$ it is known as isotropic scattering approximating the Von Mises PDF to $\frac{1}{2\pi I_0(K)}$.

Then, the various CFs of the reference model at Tx and Rx are obtained according to [7] For instance, the 3D space-time CCF is written as

$$\rho_{kl,k'l'}(\delta_T,\delta_R,\tau) = \int_{-\pi}^{\pi} a_{ll'}^2(\delta_T,\alpha^T) b_{kk'}^2(\delta_R,\alpha^R) e^{-2\pi f(\alpha^R)\tau} \rho_{\alpha^R}(\alpha^R) d\alpha^R, \quad (11)$$

where

$$a_{ll'}(\delta_T,\alpha^T) = e^{j\pi(l-l')(\delta_T/\lambda_0)\cos(\alpha^T-\beta_T)}, \quad (9)$$

$$b_{kk'}(\delta_R,\alpha^R) = e^{j\pi(k-k')(\delta_R/\lambda_0)\cos(\alpha^R-\beta_R)}, \quad (10)$$

$$f(\alpha^R) = f_{max}\cos(\alpha^R-\alpha_v). \quad (11)$$

This result clearly buttresses the fact that 3-D space-time CCF is not dependent on the major component a, b and c that describes the ellipse.

The 2D-CCF is defined from the 3D space-time CCF by making $\tau = 0$, i.e $\rho_{kl,k'l'}(\delta_T,\delta_R,\tau) = \rho_{kl,k'l'}(\delta_T,\delta_R,0)$. Hence,

$$\rho_{kl,k'l'}(\delta_T,\delta_R) = \int_{-\pi}^{\pi} a_{ll'}^2(\delta_T,\alpha^T) b_{kk'}^2(\delta_R,\alpha^R) \rho_{\alpha^R}(\alpha^R) d\alpha^R. \quad (15)$$

It can also be obtained from the 2D space-time CCF by either substituting $\delta_T = 0$ or $\delta_R = 0$ and it is given as:

$$\rho_{kl,k'l'}(\delta_T,\tau) = \int_{-\pi}^{\pi} a_{ll'}^2(\delta_T,\alpha^T) e^{-2\pi f(\alpha^R)\tau} \rho_{\alpha^R}(\alpha^R) d\alpha^R \quad (16)$$

$$\rho_{kl,k'l'}(\delta_R,\tau) = \int_{-\pi}^{\pi} b_{kk'}^2(\delta_R,\alpha^R) e^{-2\pi f(\alpha^R)\tau} \rho_{\alpha^R}(\alpha^R) d\alpha^R, \quad (17)$$

The time autocorrelation (ACF) function can also be obtained from the 3D space-time CCF in (11) by substituting $\delta_T = \delta_R = 0$. And ACF can be obtained as:

$$r_{kl}(\tau) = \int_{-\pi}^{\pi} e^{-2\pi f_{max}\cos(\alpha^R-\alpha_v)\tau} \rho_{\alpha^R}(\alpha^R) d\alpha^R. \quad (18)$$

The ACF integral can be solved analytically especially for the case of isotropic scattering $(K = 0)$, where $\rho_{\alpha^R}(\alpha^R) = \frac{1}{2\pi}$. An analytical solution of $r_{kl}(\tau) = J_0(2\pi f_{max}\tau)$ is obtained.

B. THE DETERMINISTIC SIMULATION MODEL FOR THE ELLIPTICAL MIMO CHANNEL SIMULATOR

The deterministic simulation model is derived from the reference model by making fundamental assumptions: fixing all model parameters, including phases, and ensuring that the scatterers number around the Tx and Rx is finite. Thus, the MIMO channel matrix is expressed as $\tilde{H}(t) = [\tilde{h}_{kl}(t)]$ making it relatively deterministic dependent. The expression for the elliptical MIMO channel gain $\tilde{h}_{kl}(t)$ with propagation from the Tx antenna element $(A_T^l - S_n)$ to the Rx antenna element $(S_n - A_R^k)$ is expressed according to [8].

$$\tilde{h}_{pq}(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_{ln} b_{nk} e^{j(2\pi f_n t + \theta_n)} \quad (19)$$

The parametersa_{ln}, b_{nk}, and f_n defined in (2)-(4) accordingly. From the knowledge of (1), the 3D CCF can be computed as follows:

$$\tilde{\rho}_{kl}(\delta_T,\delta_R,\tau) = \tilde{h}_{11}(t) * \tilde{h}_{22}(t+\tau), \quad (12)$$

$$\tilde{\rho}_{kl,k'l'}(\delta_T,\delta_R,\tau) = \frac{1}{N}\sum_{n=1}^{N} a_{ll'}^2(\delta_T) b_{kk'}^2(\delta_R) e^{-j2\pi f_n t}. \quad (13)$$

The 2-D CF for the Tx and Rx is given as

$$\tilde{\rho}_T(\delta_T,\tau) = \frac{1}{N}\sum_{n=1}^{N} a_{ll'}^2(\delta_T) e^{-j2\pi f_n t}, \quad (14)$$

$$\tilde{\rho}_R(\delta_R,\tau) = \frac{1}{N}\sum_{n=1}^{N} b_{ll'}^2(\delta_R) e^{-j2\pi f_n t}. \quad (15)$$

The temporal ACF of the simulation model is obtained as

$$\tilde{\rho}_{h_{pq}}(\tau) = \frac{1}{N}\sum_{n=1}^{N} e^{-j2\pi f_{max}\cos(\alpha_n^R-\alpha_v)\tau}. \quad (16)$$

III. PARAMETERIZATION METHODS FOR MODEL IMPLEMENTATION

In the literature, several efficient techniques for parameter computation have been identified. However, to fully exploit the advantages associated with each technique, it must be able to replicate the reference model accordingly. Again, a parameterization method is assumed effective if its computation complexity is minimal and has sufficient accuracy.

In order to design and implement the elliptical model simulator on the MIMO channel model, we assume all other model parameters are identical for both the simulation and the corresponding reference models and our emphasis is on AoA $\{\alpha_n^R\}_{n=1}^N$ parameter. Four computation methods were studied in total, comprising of two already existing techniques (EMEDS, MMEA) and two improved modified methods (MEMEDS, NMMEA) from the existing methods [10] to simulate the elliptical model on MIMO channel.

A. EXTENDED METHOD OF EXACT DOPPLER SPREAD

The extended method of doppler spread (EMEDS) was first introduced in [11] as an extension of the method of doppler spread (MED) studied in [8]. This techniqueis often referred as a high-performance computation method suitable for determining statistics of a MIMO channel simulation in an isotropic scattering environment. This computation technique can be conveniently applied to an elliptical model for MIMO channel and the closed form solutions of AoDα_n^T and AoA α_n^R are given as:

$$\alpha_m^T = \frac{2\pi}{M}\left(m - \frac{1}{2}\right) + \alpha_v^T, \; m = 1,2,\ldots,M, \qquad (17)$$

$$\alpha_n^R = \frac{2\pi}{N}\left(n - \frac{1}{2}\right) + \alpha_v^R, \; n = 1,2,\ldots,N, \qquad (18)$$

The parameters $\alpha_\upsilon^T$and α_υ^R are referred to as the angle of rotation at Tx and Rx given by:

$$\alpha_v^T = \frac{\alpha_n^T - \alpha_{n-1}^T}{4} = \frac{\pi}{2N}, \qquad (19)$$

$$\alpha_v^R = \frac{\alpha_n^R - \alpha_{n-1}^R}{4} = \frac{\pi}{2N}. \qquad (20)$$

B. MODIFIED METHOD OF EQUAL AREA

The modified method of equal area (MMEA) is quite useful for modeling MIMO channel parameters and is not restricted to isotropic scattering models. It has shown promising results in modelling unsymmetrical-scattering scenarious and thus greatly implemented in the lab analysis of mobile wireless systems under non istropic scattering conditions. Studies in [12] shows that MMEA originated from the method of equal area (MEA) and can be applied to any given distribution. The parameters of interest AoD α_n^T and AoA α_n^R can be obtained via numerical root finding techniques on the equations given below:

$$\frac{m - 1/4}{M} - \int_{m_\alpha^T - \pi}^{\alpha_m^T} \rho_{\alpha^T}(\alpha^T) d\alpha^T = 0, \; m = 1,2,\ldots,M, \qquad (29)$$

$$\frac{n - 1/4}{N} - \int_{m_\alpha^R - \pi}^{\alpha_m^R} \rho_{\alpha^R}(\alpha^R) d\alpha^R = 0, \; n = 1,2,\ldots,N \qquad (30)$$

C. MODIFIED EXTENDED METHOD OF EXACT DOPPLER SPREAD

The modified extended method of exact doppler spread (MEMEDS) is among the recent parameter computation solutions proposed in [10]. It has the advantage of generating a multiple numbers of wave form signal while maintaining low complexity. The equations of interest of parameters for simulation AoD α_n^T and AoA $\alpha_n^R$are given below:

$$\alpha_m^T = \frac{2\pi}{M} m + \alpha_v^T, \; m = 1,2,\ldots,M, \qquad (211)$$

$$\alpha_n^R = \frac{2\pi}{N} n + \alpha_v^R, \; n = 1,2,\ldots,N. \qquad (32)$$

Where α_v^T and α_v^R are known as the angle of rotation at the Tx and Rx respectively and are defined accordingly as:

$$\alpha_v^T = \frac{\alpha_m^T - \alpha_{m-1}^T}{2} = \frac{\pi}{M} \qquad (33)$$

$$\alpha_v^R = \frac{\alpha_n^R - \alpha_{n-1}^R}{2} = \frac{\pi}{N} \qquad (34)$$

D. NEW MODIFIED METHOD OF EQUAL AREAS

The MMEA computation technique has a major limitation of increasing absolute error of the simulation model in non-isotropic scattering scenarios. The new modified method of equal areas (NMMEA) also demonstrated in [10] shows promising results of keeping the absolute error functions marginal. According to the NMMEA, the AoD α_n^T and AoA α_n^R can be obtained as follow:

$$\frac{m - 0.55}{M} - \int_{m_\alpha^T - \pi}^{\alpha_m^T} \rho_{\alpha^T}(\alpha^T) d\alpha^T = 0, \; m = 1,2,\ldots,M. \qquad (35)$$

$$\frac{m-0.55}{N} - \int_{m_\alpha^R-\pi}^{\alpha_m^R} \rho_{\alpha^R}(\alpha^R) d\alpha^R = 0, \quad n = 1,2,\ldots,N. \qquad (36)$$

IV. PERFORMANCE ANALYSIS BASED ON COMPUTATION METHODS

Several statistical properties exist as metrics to measure the performance of MIMO channel simulator models.In this subsection we will investigate the AoA, AoD, correlation properties (temporal ACF and 2D-space CCF) and evaluate the performance based on the parameter computation method used. The EMEDS and MEMEDS computation methods are applied on the elliptical model and its performance superiority compared. Again, the MMEA is matched with NMMEA for performance evaluation. Numerical results validating the utility of results from the comparison presented.

1) EMED Vs MEMEDS: All results presented in this section are obtained using $\mathbf{f_{max} = 91, N = 25, \beta_T = \beta_R = 90, k = 0}$. Fig. 2-4) compares the difference in the time ACF and the 2D-space CCF of the simulation model obtained using the EMEDS and MEMEDS parameter computation methods. Fig. 2 depicts time ACF using the EMEDS and the MEMEDS techniques to the reference model. It is clear that the MEMEDS consistently outclass the EMEDS for different isotropic scattering settings. It was also observed that there is a good agreement between the MEMEDS and the reference model and the equality of $\mathbf{r(\tau) = \tilde{r}(\tau)}$ strongly holds between $[\mathbf{0, N/4}]$. Figure 4.1 further shows that the EMEDS results in a relatively considerable difference with the reference model. A plot of 2D-space CCF, the absolute error against the transmit antenna separation and the receive antenna separation respectively for the reference and simulation model applying the EMEDS and MEMED is illustrated in Fig. 3 and Fig. 4. The performance of the reference and the simulation model using both methods are in good agreement with values hardly distinguishable. Nevertheless, EMEDS has more computation complexity.

2) MMEA vs NMMEA: All results presented in this section are obtained using $\mathbf{f_{max} = 91, N = 50, \beta_T = \beta_R = 90, k = 0}$. Fig. 5 depicts the corresponding time ACFs using EMEDS and MEMED. Inspite of thedifferent methods, it is clear that ACF from two computation methods are alike with of the reference model, particularly the result from the NMMEA provides a fairly better approximation of the reference model. For example, the approximation of $\mathbf{r(\tau) = \tilde{r}(\tau)}$ is exceptional between the range of $[\mathbf{N/10}, \mathbf{N/2}]$. The CCFs performance comparison of MMEA and NMMEA shows a good fit with the reference model. Nevertheless there is a more excellent agreement using NMMEA as illustrated with Fig. 6 and Fig. 7. Further evaluation of the absolute error for both methods as also plotted in Fig. 6 and Fig. 7, and are undoubtedly in agreement showing a ripple behaviour and a maximum error value max$\{\mathbf{e_T(\delta_T, \delta_R)}\}$=3.0. Again, it is evident that the error function decreases using the NMMEA.

V. CONCLUSION

These studies collectively demonstrate the potentials of elliptical channel models in capturing the complex characteristics of a MIMO wireless channel in an isotropic scatterring environment. In this context, two new modified methods MEMED and NMMEA were applied in the design of MIMO simulation model. A performance analysis of the new proposed method and its original method is implemented. Numerical results have shown that the proposed simulation model with MEMED and NMMEA outperforms, giving a fairly good approximation of the desired properties of ACF, CCFs and $\{e_T(\delta_T, \delta_R)$ to reference model.Summing up the results, it can be concludethat the performance of MIMO wireless channel simulators can be implemented with enhance parameter computerization methods. Thus, with this achievement, a more accurate and efficient MIMO simulator model can be obtained.

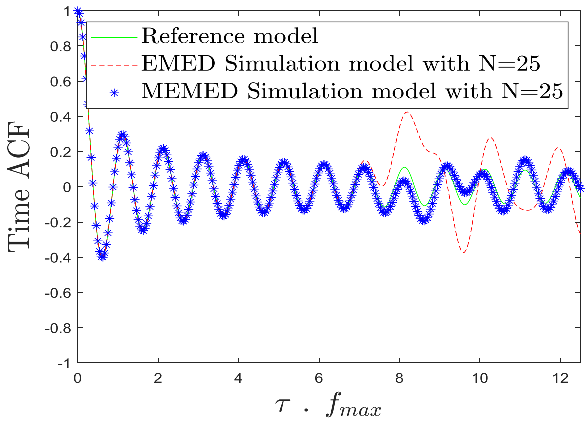

Fig. 2: ACF comparison of the reference and simulation model using EMED and MEMED ($f_{max} = 91, N = 25, \beta_T = \beta_R = 90, k = 0$)

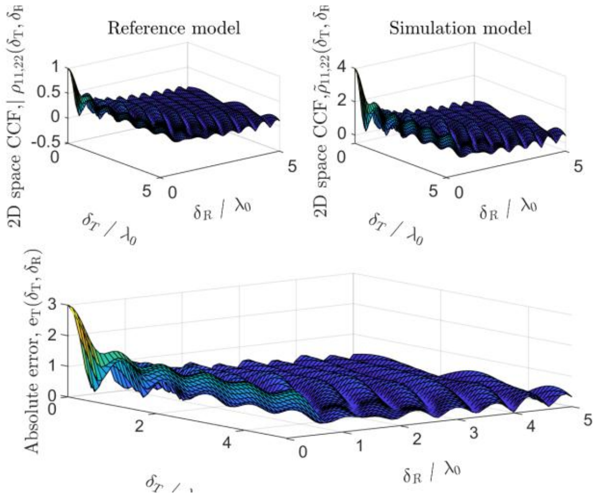

Fig. 3:2D-CCFs of reference, simulation models and Absolute error function using EMEDS ($f_{max} = 91, N = 25, \beta_T = \beta_R = 90, k = 0$)

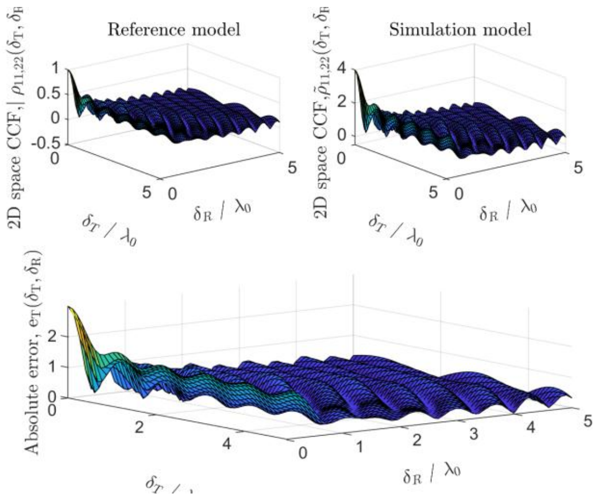

Fig. 4: 2D-CCFs of reference, simulation models and Absolute error function using MEMED ($f_{max} = 91, N = 25, \beta_T = \beta_R = 90, k = 0$)

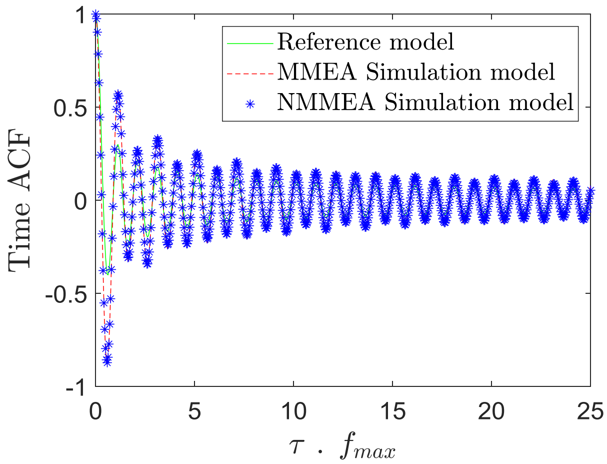

Fig. 5: ACF comparison of the reference and simulation model using MMEA and NMMEA($f_{max} = 91, N = 50, \beta_T = \beta_R = 90, k = 0$*)*

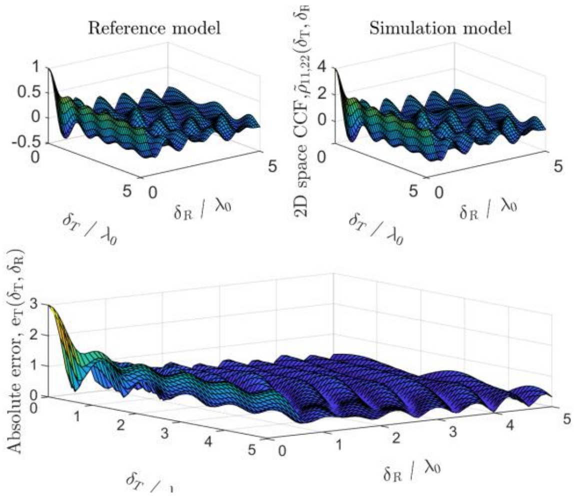

Fig. 6: 2D-CCFs of reference, simulation model and Absolute error function using MMEA ($f_{max} = 91, N = 50, \beta_T = \beta_R = 90, k = 0$*)*

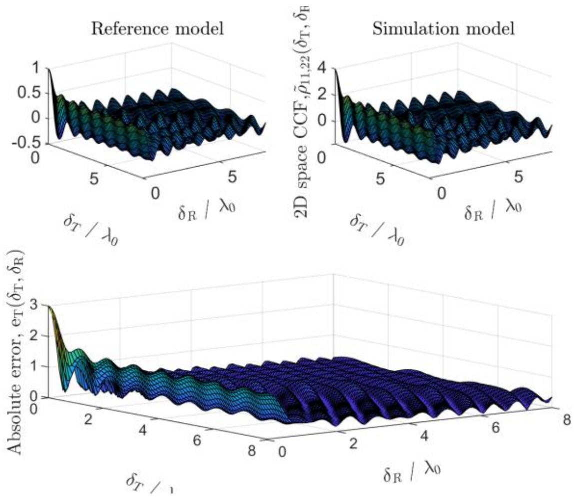

Fig. 7: 2D-CCFs of reference, simulation model and Absolute error function using NMMEA($f_{max} = 91, N = 50, \beta_T = \beta_R = 90, k = 0$*)*

REFERENCES

[1]. F. Pérez Fontán and P. Mariño Espiñeira, "Modelling the Wireless Propagation Channel: A Simulation Approach with MATLAB," Modelling the Wireless Propagation Channel: A Simulation Approach with MATLAB, pp. 1–252, Aug. 2008, doi: 10.1002/9780470751749.

[2]. X. Yin and X. Cheng, "Geometry- based Stochastic Channel Modeling," Propagation Channel Characterization, Parameter Estimation, and Modeling for Wireless Communications, pp. 77–105, Feb. 2018, doi: 10.1002/9781118188248.CH4.

[3]. S. Beygi, E. G. Strom, and U. Mitra, "Geometry-based stochastic modeling and estimation of vehicle to vehicle channels," ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings, pp. 4289–4293, 2014, doi: 10.1109/ICASSP.2014.6854411.

[4]. H. Hofstetter and G. Steinböck, "A geometry based stochastic channel model for MIMO systems," 2004 ITG Workshop on Smart Antennas - Proceedings, pp. 194–199, 2004, doi: 10.1109/WSA.2004.1407668.

[5]. J. C. Liberti and T. S. Rappaport, "Geometrically based model for line-of-sight multipath radio channels," IEEE Vehicular Technology Conference, vol. 2, pp. 844–848, 1996, doi: 10.1109/VETEC.1996.501430.

[6]. M. Pätzold and N. Youssef, "Modelling and simulation of direction-selective and frequency-selective mobile radio channels," AEU-Archiv fur Elektronik und Ubertragungstechnik, vol. 55, no. 6, pp. 433–442, 2001, doi: 10.1078/1434-8411-54100064.

[7]. M. Pätzold and B. O. Hogstad, "A wideband MIMO channel model derived from the geometric elliptical scattering model," WirelCommun Mob Comput, vol. 8, no. 5, pp. 597–605, Jun. 2008, doi: 10.1002/WCM.572.

[8]. M. Pätzold, "Mobile Radio Channels: Second Edition," Mobile Radio Channels: Second Edition, pp. 1–583, Jan. 2011, doi: 10.1002/9781119974116.

[9]. 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 Veh Technol, vol. 51, no. 3, pp. 425–434, May 2002, doi: 10.1109/TVT.2002.1002493.

[10]. O. Alzoubi, "Improving the Performance of MIMO Mobile-to-Mobile Fading Channel Simulators Using New Parameterization Methods," 3rd International Conference on Electrical, Communication and Computer Engineering, ICECCE 2021, Jun. 2021, doi: 10.1109/ICECCE52056.2021.9514185.

[11]. B. O. Hogstad', M. Patzold', N. Youssef2, and D. Kim3, "A MIMO MOBILE-TO-MOBILE CHANNEL MODEL: PART II-THE SIMULATION MODEL," 2005.

[12]. C. A. Gutierrez-Diaz-De-Leon and M. Pätzold, "Sum-of-sinusoids-based simulation of flat fading wireless propagation channels under non-isotropic scattering conditions," GLOBECOM - IEEE Global Telecommunications Conference, pp. 3842–3846, 2007, doi: 10.1109/GLOCOM.2007.730.