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Published in:
I E E E Antennas and Wireless Propagation Letters

DOI (link to publication from Publisher):
10.1109/LAWP.2014.2368172

Publication date:
2015

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):
Fan, W., Jämsä, T., Nielsen, J. Ø., & Pedersen, G. F. (2015). On Angular Sampling Methods for 3-D Spatial Channel Models. *I E E E Antennas and Wireless Propagation Letters*, *14*, 531 - 534.
https://doi.org/10.1109/LAWP.2014.2368172

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On Angular Sampling Methods for 3D Spatial Channel Models

Wei Fan, Tommi Jämsä, Jesper Ø. Nielsen, and Gert F. Pedersen

***Abstract*—This paper discusses generating three dimensional (3D) spatial channel models with emphasis on the angular sampling methods. Three angular sampling methods, i.e. modified uniform power sampling, modified uniform angular sampling, and random pairing methods are proposed and investigated in detail. The random pairing method, which uses only twenty sinusoids in the ray-based model for generating the channels, presents good results if the spatial channel cluster is with a small elevation angle spread. For spatial clusters with large elevation angle spreads, however, the random pairing method would fail and the other two methods should be considered.**

***Index Terms*—3D spatial channel modeling, ray-based model, angular sampling methods, spatial and temporal correlation**

I. Introduction

In the current releases of the 3GPP long-term evolution (LTE) and LTE-advanced, antenna configurations at the base station (BS) side were designed to support adaptive beam steering in azimuth dimension only. Recently, the use of active antenna systems (AAS) that have a two-dimensional (2D) array structure, is now gaining significant interest [1], since it allows adaptive beam steering both over the elevation and azimuth dimensions. The reason can be attributed to its potential for offering a variety of benefits, e.g. improved beamforming capability (both azimuth and elevation beamforming), improved system capacity, etc [2]. Since it is not supported by current LTE releases, the 3GPP is working on defining the required specifications, where one of the main objectives is to get accurate three dimensional (3D) channel models including the multipath fading characteristics in both elevation and azimuth domains [3].

The proposed 3D channel model in 3GPP is based on the same Geometry-based Stochastic Channel Model (GSCM) principles as the 3GPP Spatial channel model (SCM) [4], Extended SCM (SCME) [5], WINNER II [6], IMT-advanced [7] and WINNER+, and the latest channel model description is reported in the TR36.873 [8].

Ray-based models have been used to generate the above GSCMs, where the spatial-temporal characteristics of the channels are generated by a limited number of plane waves (i.e. sinusoids). The number of sinusoids is twenty in the SCM [4], and the same number has been considered as well for the 3D channel model [8]. In addition to the number of sinusoids, the other aspect to be considered is the angular location and amplitude of each sinusoid (i.e. the angular sampling for the spatial cluster).

The paper investigates the impact of different angular sampling methods on the accuracy of the 3D spatial-temporal channel models. The paper is organized as follows. We describe the temporal correlation and spatial correlation of the generated channel models and target channel models in Section II, respectively. In Section III, different angular sampling methods are discussed. Then, we present in Section IV the simulation results for different angular sampling methods for the two dimensional (2D) and 3D channel models.

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II. Channel Characteristics

A. Channel PAS

The power angular spectrum (PAS) shape of clusters has been widely studied in the literature for 2D channel models. Several PAS models, e.g. wrapped Gaussian, uniform, truncated Laplacian and Von Mises distributions have been proposed based on extensive measurements in various scenarios, see e.g. [9]. In this paper, the power azimuth spectrum is defined with an interval of $[\phi_0 - 180^o, \phi_0 + 180^o]$ of size 360^o and centered at azimuth angel of arrival (AoA) ϕ_0, while the power elevation spectrum is with an interval of $[\theta_0 - 90^o, \theta_0 + 90^o]$ of size 180^o and centered at elevation angle of arrival (EoA) θ_0.

The target spatial channel model may consist of several clusters, each with a specific continuous PAS shape. Since multi-cluster channels consist of independently generated single clusters, the discussion in this paper is limited to a single cluster channel model. However, it can be easily extended to the multi-cluster case.

B. Spatial correlation

The spatial correlation is a statistical measure of the similarity of the received signals. Note the discussion in the paper is limited to propagation channels, which only depend on the environment and exclude as such the effect of antennas. Spatial correlation can be used as a measure to show how the spatial characteristics of generated channel follow those of the target.

Assuming isotropic antenna patterns, the spatial correlation can be determined according to [10], for a single polarization:

$$\rho = \oint \exp(j\frac{2\pi}{\lambda}(\overline{r}_u - \overline{r}_v)\cdot\overline{\Omega})p(\Omega)d\Omega, \qquad (1)$$

where $\overline{r}_u$ and $\overline{r}_v$ are row vectors containing the position information of antenna sample u and v, respectively. $p(\Omega)$ denotes the incoming power angular spectrum of the channel.

$\overline{\Omega}$ is a unit column vector denoting space angle Ω. $(\cdot)$ is the vector product operator which will gives a scalar. λ is the wavelength. The spatial vectors $\overline{r}_u$ and $\overline{r}_v$ are selected from three orthogonal axes (e.g. $\bar{x}$, $\bar{y}$, and $\bar{z}$) in this paper.

The spatial correlation of the generated channel with a limited number of sinusoids, can be analytically expressed as:

$$\hat{\rho} = \sum_{m=1}^{M} p_m \exp(j\frac{2\pi}{\lambda}(\overline{r}_u - \overline{r}_v) \cdot \overline{\Phi}_m), \tag{2}$$

where p_m is the power value for the mth sinusoid. $\overline{\Phi}_m$ is a column position vector of the mth sinusoid. M is the total number of sinusoids. p_m and $\overline{\Phi}_m$, which basically describe the power and angular location of the mth sinusoid, are determined by the angular sampling method detailed in Section III. Note that spatial correlation can be calculated from the fading channel impulse responses (CIRs) received at the two spatial samples as well, according to the correlation definition.

C. Temporal correlation

The Doppler shift ω_m of the mth sinusoid, resulting from a DUT's motion with velocity vector $\bar{\vartheta}$ can be calculated as:

$$\omega_m = -\bar{\beta}_m \cdot \bar{\vartheta}, \tag{3}$$

where $\bar{\beta}_m$ is the wave vector of the mth sinusoid, which is determined by $\overline{\Phi}_m$. The fading CIRs can be represented as:

$$h(t) = \sum_{m=1}^{M} \sqrt{p_m} \exp(-jt\omega_m + \epsilon_m), \tag{4}$$

where ϵ_m is the initial phase for the mth sinusoid, which is a random variable that follows a uniform distribution over $[0, 2\pi)$. The temporal correlation can be easily calculated from the CIRs. Temporal correlation can be used as a measure to determine how well the temporal characteristics of the generated channels follow those of the target channel.

III. Angular Sampling Methods

As explained in Section II, both the spatial and temporal characteristics of the generated channel depend on the angular sampling of the cluster. In this section, the angular sampling methods for the 2D spatial cluster is first revisited. Then three angular sampling methods are proposed for the 3D case.

A. Angular sampling for 2D clusters

A target PAS can be sampled by a number of sinusoids, each with a AoA and amplitude. One option, named uniform power sampling, is to allocate the same power to each sinusoid while arranging the sinusoid angles in a non-uniform manner, as shown in Figure 1 (right). The SCM channel model adopted this method with $M = 20$. Another option, named uniform angular sampling, is that the angular range is sampled uniformly and power values can be obtained according to the target PAS, as shown in Figure 1 (left). The spatial correlation of the generated channels with the two different angular sampling methods is shown in Figure 2. A deviation up to 0.1 within an antenna separation of 1.5λ is observed.

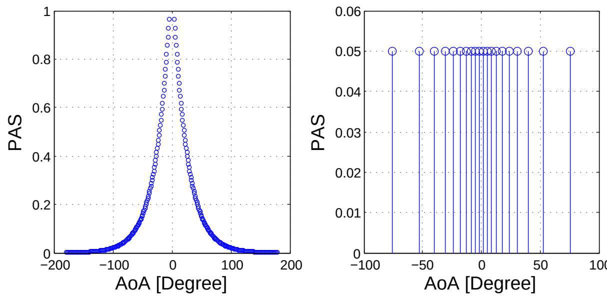

Figure 1. An illustration of different angular sampling for 2D cluster with AoA = 0^o and azimuth spread of arrival (ASA) = 35^o. Uniform angular sampling with $M = 360$ is used in the left figure and uniform power sampling with $M = 20$ is used in the right figure.

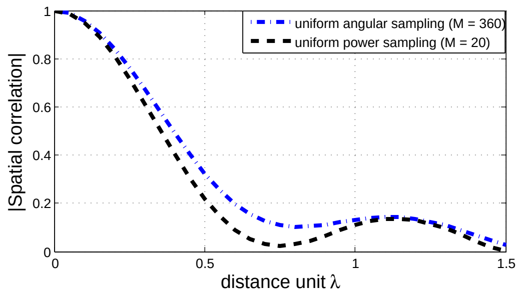

Figure 2. An illustration of different angular sampling methods for 2D Laplacian shaped cluster with AoA = 0^o and ASA = 35^o.

B. Angular sampling for 3D clusters

The cluster elevation spread of arrival (ESA) in the literature is rather small [6], [8], as the device is often far away from the BS. Cluster ESA of 3^o or 7^o are typically assumed. Intuitively, same number of sinusoids can be selected to sample the whole elevation domain as the azimuth domain (e.g. 20×20 sinusoids). However, with the uniform power method, the sinusoids would be strictly concentrated to a very small elevation range due to the small cluster ESA, and hence the number of sinusoids might be unnecessarily large with respect to the elevation domain. With the uniform angular method, the majority of the sinusoids might be with 0 amplitudes, as a result of the small ESA, and hence not utilized in generating the channels. Furthermore, it will be computationally complex due to the high number of sinusoids used. To tackle these issues, three angular sampling methods are proposed and investigated:

1) Modified uniform power method. To limit the total number of sinusoids while still approximate the target PAS, the number of sinusoids in elevation domain is selected to be a small value that fits the small ESA. The elevation and azimuth angles can be calculated the same way as the uniform power method in the 2D case. An illustration of the method is shown in Figure 3 (left).
2) Modified uniform angle sampling method. M sinusoids can be obtained by directly sampling the 3D spatial cluster with uniform angles over azimuth and elevation domain. To limit the total number of sinusoids, N

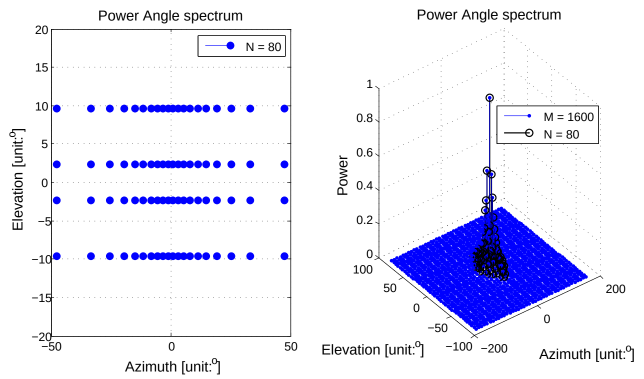

Figure 3. The discrete PAS with the modified uniform power (left) and uniform angular sampling method (right). The target spatial cluster is with AoA = 0^o, ASA = 22^o, EoA = 0^o and ESA = 7^o. The power values with the modified uniform power method are the same and not shown in the Figure.

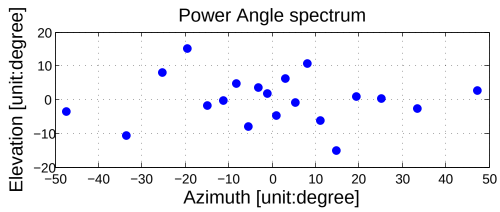

Figure 4. An illustration of one realization of the random pairing of azimuth and elevation angles. The target spatial cluster is with AoA = 0^o, ASA = 22^o, EoA = 0^o and ESA = 7^o.

$(N \ll M)$ sinusoids with largest power values are selected. The amplitudes of the remaining unselected $(M - N)$ sinusoids are set to 0s. An illustration of the method is shown in Figure 3 (right).

3) Random pairing method. This method is currently under consideration in [8], where only 20 sinusoids are adopted. The power values are the same for the twenty sinusoids, while the angular locations are obtained by randomly pairing the twenty different azimuth angles and twenty elevation angles. An illustration of one realization of the random pairing method is shown in Figure 4. With the random pairing method, there is a concern whether the generated channel model is ergodic, as different realizations of the PAS are different. This issue is investigated in detail in Section IV.

IV. Simulation Results

The target spatial cluster adopted in the simulation is with AoA = 0^o, ASA = 22^o, EOA = 0^o and ESA = 7^o, unless otherwise stated in the paper. The simulation setups for different angular sampling methods are detailed in Table I. The discrete PASs with the modified uniform power and modified uniform angular sampling methods are shown in Figure 3. Eighty sinusoids are used in the uniform power and uniform angular methods, while only twenty sinusoids are used for the random pairing methods.

Table I
Simulation setups for different angular sampling methods

Method	Number of sinusoids
Modified uniform power method	$20 \times 4 = 80$
Modified uniform angular method	$M = 40 \times 40$ with $N = 80$
Random pairing method	$M = 20$

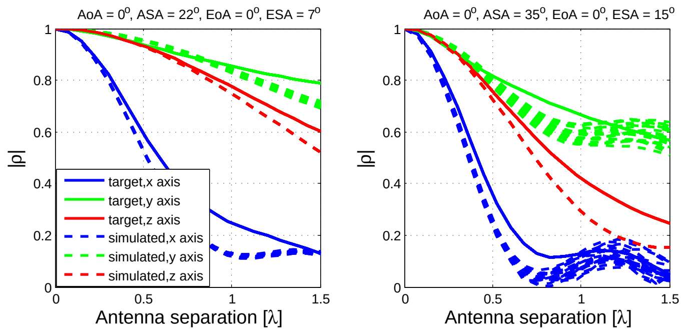

Figure 5. Spatial correlation results over $\bar{x}$, $\bar{y}$, and $\bar{z}$ axes for the 20 realizations of the generated spatial channel models with the random pairing methods for two different clusters. Note that the target curves are different for the two different clusters.

A. Different realizations for random pairing methods

To investigate the impact of different realizations of random pairing method on the ergodicity of the generated channels, two channel models are considered. One with a small ESA (ESA = 7^o), and the other one with a large ESA (ESA = 15^o). 20 realizations of the generated channels in terms of spatial correlation and temporal correlation are shown in Figure 5 and Figure 6, respectively. As we can see, the spatial correlations of the generated channels follow the tendency of the target channels well for both cases over the $\bar{x}$, $\bar{y}$, and $\bar{z}$ axes. The difference among realizations for the cluster with small ESA is negligible, with a variation up to 0.02 in terms of spatial correlation with antenna separation up to 1.5λ, while a deviation up to 0.11 can be observed for the cluster with a large ESA. Similarly, difference in terms of temporal correlation is larger for the cluster with a large ESA. The deviation among different realizations is expected to be even larger for clusters with wider ESAs. As different realizations of the random pairing method present significant difference in terms of spatial correlation and temporal correlation for clusters with large ESAs, the random pairing method would fail in this case. As discussed earlier, small ESAs are generally considered in the literature, where the problem is small. For larger ESA's the variation among realizations may be reduced by increasing the number of sinusoids. One realization of the random pairing method is compared with other angular sampling methods in Section IV-B for the target cluster with a small ESA.

B. Angular sampling method comparison

1) Spatial correlation for different sampling methods: The spatial correlation of generated channel models is shown in

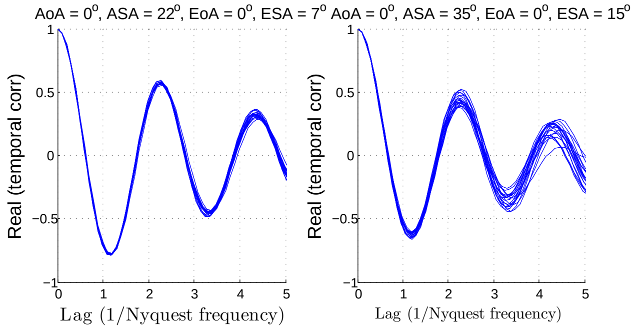

Figure 6. Temporal correlation results for the 20 realizations of the generated spatial channel models with the random pairing methods for two different clusters. Note that the target curves are different for the two different clusters. The direction of travel is DoT = $[30^o, 0^o]$.

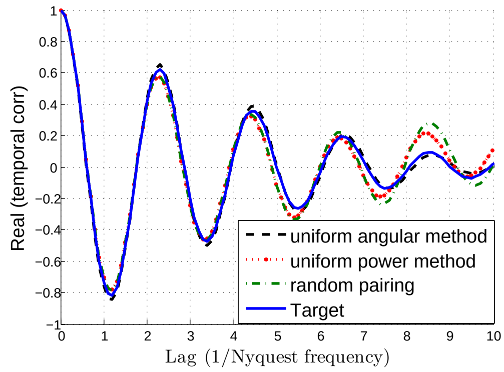

Figure 8. Temporal correlation of the generated channel models with different angular sampling methods. The direction of travel is DoT = $[30^o, 0^o]$.

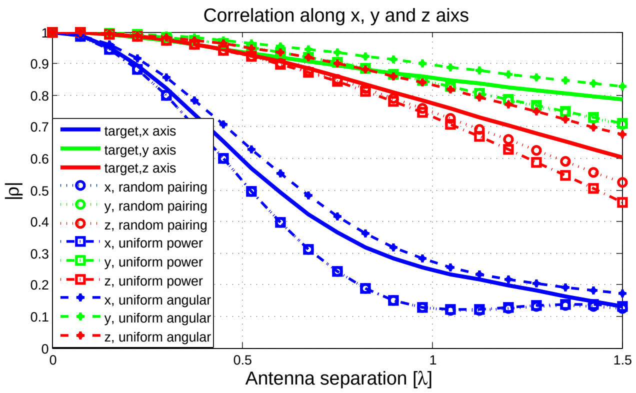

Figure 7. Spatial correlation of generated channel models with different angular sampling methods.

Figure 7 for different angular sampling methods. The three proposed methods generally follow the target well over the $\bar{x}$, $\bar{y}$ and $\bar{z}$ axes. The deviation in spatial correlation between target model and generated models with different angular sampling methods is due to the fact that only limited number of sinusoids are utilized to generate the channel. The curve with uniform power method follows very well the curve with random pairing method, as a result of the small ESA.

2) Temporal correlation for different sampling methods: The temporal correlations of the generated channel models with different angular sampling methods are shown in Figure 8. The generated channels with different methods generally follow the target well in terms of temporal correlation. The achieved result with the modified uniform angular method matches the target very well.

V. Conclusion

In this paper we discussed the impact of different angular sampling methods on the accuracy of the 3D spatial-temporal channel models. We presented three angular sampling methods to generate 3D spatial channel models (1) modified uniform power, (2) modified uniform angular and (3) random pairing methods. The random pairing method is currently being considered in the standards. The simulation results in the paper demonstrate that it presents good match with the target channel models in terms of spatial correlation and temporal correlation with a small number of sinusoids when the cluster elevation spread is small. However, the generated channel will be non-ergodic for clusters with large elevation spreads. The uniform power and uniform angular sampling methods provide good results as well, though more sinusoids are required than the random pairing method in generating the channels.

Acknowledgment

This work has been supported by the Danish High Technology Foundation via the VIRTUOSO project. Part of this work was performed in the framework of the FP7 METIS project. The authors appreciate the assistance from colleagues in Anite Telecoms Oy, Finland, especially from Mr. Pekka Kyösti.

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