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The Improvement of Geometrically Based 3-D Wave Scattering in MIMO OFDM Mobile Communication Systems

Suzi Seroja Sarnin, Siti Maisurah Sulong, Azlina Idris, Norsuzila Ya'acob

Faculty of Electrical Engineering,UiTM Shah Alam, 40000 Selangor, Malaysia

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ABSTRACT

The paper focuses on the signal cross correlation in 3D scattering MIMO channel. An improved geometrically-based 3-D wave scattering MIMO channel model is developed. The fading cross-correlation in vertically (ε=90°) and horizontally (ε=0°) separated antenna array at the MS was investigated in terms of the antenna element spacing, AoA distributions, and the angular spread of the arrival angle in the vertical plane. An extended geometrically-based MIMO channel model in 3-D wave scattering is developed and general formulas for joint spatial-temporal correlation, spatial correlation, and temporal correlations are derived and numerically evaluated. Then the effect of this correlation on MIMO channel capacity is investigated under assumption of uniform and Laplacian angular energy distributions and for uniform linear array (ULA) and uniform circular array (UCA) using MATLAB simulation environments.

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INTRODUCTION

MIMO channel capacity increases linearly with number of antennas provided that the environment is rich scattering, but in practice however correlated MIMO channel are expected, which may significant reduce the theoretically promised MIMO capacity. Channel propagation is the principle contributed to many of the problems and limitations that severely effect on the performance of wireless communication system, the wireless channel must be characterized and a reliable model must be established. K. Yu and B. Ottersten (2002) said that it is critical to characterize and model the MIMO channel for different conditions in order to predict, simulate, and design high performance MIMO systems, with more accurate channel models that incorporate the spatial characteristics, the performance of the wireless communication systems can be predicted better.

The high capacity promised by MIMO systems is greatly determined by the propagation conditions. Though the assumption of horizontal travel of electromagnetic waves (2-D) may provide an acceptable approximation for certain environment (e.g., for rural areas), it does not seem appropriate for built up areas or urban environments. In such environments, the mobile antenna is often located in close proximity to and lower than the surrounding buildings, thus the propagated waves are also spread in the elevation plane as a result of diffraction and scattering from the tops of buildings, reflection from the ground, or other vertically disposed objects. Therefore, J. D. Parsons (2000) proved that it is more general and appropriate to adopt a 3-D scattering mechanism to describe the arrival of waves at the receiver. The previous experiment conducted by W. C. Y Lee and R. H. Brandt (1973) has confirmed that the scattered signals arriving under NLoS conditions indeed are spread over a wide elevation angle (EA). As an example, with a large portion of signals outside 16°, and the EA for scattered signals received in urban areas is greater than that in suburban areas also reported by W.C. Y. Lee (1995). T. Aulin (1979) later proposed a 3-D model by introducing a nonzero elevation angle for the incidence of waves in addition to the azimuthal angle. While the azimuthal angle had been assumed to be uniformly distributed within (0, 2π), a particular form of the PDF for the EA was proposed for the purpose of obtaining a closed-form expression for the PSD. However, the obtained PSD may be useful only when the EA is very small, since it has an unrealistic flat (constant) section near the maximum frequency end. J. D. Parsons (2000) recently suggested a PDF for the EA in order to overcome this problem. However, compared with T. Aulin (1979) model, the associated PSD has no analytical solution anymore. The concept of 3-D model has been proposed and well-studied for SISO link, however, there still a lack of theoretical analysis and investigations regarding the distribution

Corresponding Author: Siti Maisurah Sulong, Faculty of Electrical Engineering, UiTM Shah Alam, 40000, Selangor Malaysia
E-mail: sitimaisurah91@gmail.com

of the AoA, scatterer distribution, PSD of and antenna configuration for links with multiple antennas at both ends.

In this research, the 2-D Clarke's-channel model is extended into 3-D wave scattering MIMO channel model and the proposed model incorporates, in addition to the signal amplitude and Doppler shift, both the azimuthal and elevation AoAs. Using the developed model, analytical expressions for the joint spatial-temporal correlation, spatial correlation, and temporal correlation are derived, for a uniform linear array (ULA) and uniform circular array (UCA) at the mobile station (MS). The correlation functions of the special case of single-input multiple-output (SIMO) model are obtained. The effects of antenna elements spacing, AoAs statistics, motion of the receiver, and antenna array directions are investigated.

Methodology:

A general MIMO system with M_t transmit antenna array and M_r receive antenna array. The MIMO channel is typically represented as a complex matrix H(t) of dimensions M_r x M_t where the component h_{pq} of the matrix is the channel impulse response between the pth transmit antenna to the qth receive antenna that can be written as

$$h_{pq}(m) = [h_{pq}(m.0), h_{pq}(m,1), \ldots. h_{pq}(m,L-1)]^T \quad (1)$$

With m is the OFDM symbol. The 3-D scattering MIMO channel geometry is depicted in Fig. 1 for a macrocell environment. For simplicity, only two antenna elements of the transmitter (BS) and the receiver (MS) are shown. The scattering scenario is based on single ring model, which is non-site specific and mathematically derivable. In this scenario, we assume that L independent local scatterers are fixed in positions and uniformly distributed around the mobile station on a circular cylinder with radius R. We assume that from each scatterer only one path is scattered in the direction of the receiving antenna. The lth path has an amplitude β_l, a phase shift ϕ_l, and spatial AoAs in the azimuth and elevation planes θ_l and α_l respectively. The parameters $\beta_{l,}$ $_{\phi l}$, θ_l, and α_l are all random and statistically independent, and their distributions depend on the type of environment. The base station is assumed to be placed higher than the surrounding buildings and objects and therefore not obstructed by local scattering.

Under the assumption of narrowband or flat Fading MIMO channel and NLoS component exists, the channel impulse response of the link between the pth antenna of the BS and the qth antenna of the MS can be represented in a similar way proposed by A. Abdi and M. Kaveh (2002) as

$$h_{qp}(t) = \lim_{L\to\infty} \frac{1}{\sqrt{L}} \sum_{l=1}^{L} \beta_l e^{j\phi_l} e^{-j2\pi f_{D,l} t} e^{-j\frac{2\pi}{\lambda}(\varsigma_{lp}+\varsigma_{ql})} \quad (2)$$

The antenna elements numbering at the MS and BS follows the convention $0 \le n \le (M_r - 1)$ and $0 \le m \le p \le (M_t - 1)$, respectively. Z_{lp} and ζ_{ql} are the distances shown in Fig.1, and λ is the wavelength. $F_{D,l}$ is the Doppler shift in the lth path resulted due to the receiver motion and is given by

$$f_{D,l} = v/\lambda \cos(\theta_l - \gamma) \cos(\alpha_l) \quad (3)$$

Where v is the mobile velocity in the horizontal plane in a direction making an angle γ to line connected between the antenna centers of the BS and MS, and the quantity represents the maximum Doppler shift. If the transmitted signal is narrowband, then we can assume that all the received component waves will be subjected to the same Doppler shift as finds by J. D. Parsons (2000). According to A. Abdi and M. Kaveh (2002), based on the statistical properties of the channel, the central limit theorem states that h_{qp} (t) is a lowpass zero-mean complex Gaussian random process. Therefore, the envelope $|h_{qp}(t)|$ is a Rayleigh-fading process. The path loss can be incorporated in (2) as a function of the inverse of the traveled distance. The path delay is calculated as

$$\tau_i = (\zeta_{lm} + \zeta_{nl}) / c \quad (4)$$

with c is the velocity of the light. Assume that the difference between the height of the BS and the mean height of the scatterers is small so that we can approximate the line joining the BS antenna center and the center if the scatterer's circle by the distance D. Further, assume that D >>R >> max ($d_{nq}^{(MS)}$, $d_{mp}^{(BS)}$), this implies that Δ and Ω are small, and the angle δ is approximately equal to the angle $\varkappa$. Referring to Fig.1, we can obtain

$$\zeta_{nl} - \zeta_{ql} \approx d_{nq}^{(MS)} \cos(\chi) \quad (5)$$

$$\cos(\varkappa) = \cos(\alpha)\cos(\varepsilon)\cos(\theta - \eta) + \sin(\alpha)\sin(\varepsilon) \quad (6)$$

The circular scattering region is illuminated by the BS antenna with a maximum spreading angle Δ which is measured from the line joining the center of the BS antenna and the center of the illuminated scatterer's circle. We use the approximations $\sin(\omega) \approx 1$, when ω is small. Thus, $\sin\Delta \approx \Delta \approx (R/D)$, and it can be shown that

$$\zeta_{lm} - \zeta_{lp} \approx d_{nq}^{(MS)} \cos(\varphi - \Omega) \approx d_{nq}^{(MS)} [\cos\varphi\cos\Omega + \sin\varphi \sin\Omega] \quad (7)$$

Where $\sin\Omega \approx (R\sin\theta) / D \approx \Delta\sin\theta$ and $\cos\Omega \approx 1$. A similar methodology for calculating some of the above parameters in 2-D scattering scenario can be found in D. S. Shiu (2000).

Simulation Results:

R. H. Clarke (1968) assumption was followed that an isotropic scattering is occurred, and the scattered waves arrive uniformly at the mobile station from all directions over the azimuth angle θ with equal probability. In such a case, the PDF for statistical distribution of θ is approximated by (3), and the statistical distribution of the elevation angle α is assumed to follow the PDF. In this section, the cross-correlation between signals received at two antenna elements of a uniform linear array is numerically evaluated. The result can be evaluated on cross-correlation of horizontally and vertically seperated antenna elements. It is also evaluated the effects of vertically separation on spatial fading signal correlation and crosss-correlation between the signals received at two elements of horizontally separated ($\varepsilon = 0^0$) antenna elements, $\eta = 0^0$.

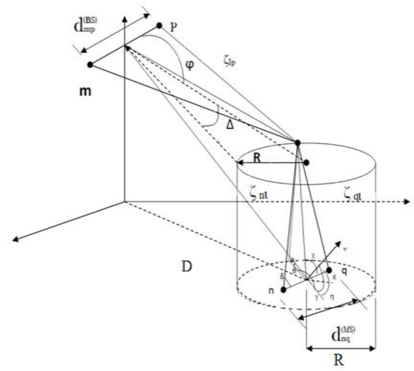

Fig. 1: Geometry of MIMO channel model with 3-D scattering.

Horizontal fading cross-correlation

The cross-correlation between fading signal received at a pair of antenna elements is shown in Fig 2, as a function of the antenna element spacing and for various values of α_m when the antenna array of a MS is horizontally placed (e.g. $\varepsilon = 0^0$). It can be noted that the first minimum in the envelop correlation occurs at d = 0.4λ. However, when d > 0.4λ, the decrease in the correlation coefficient becomes much slower even with increasing of α_m. From the plotted graph it can be seen that the correlation coefficient decreases as the antenna spacing increases and the correlation is almost the same for the different values of a α_m.

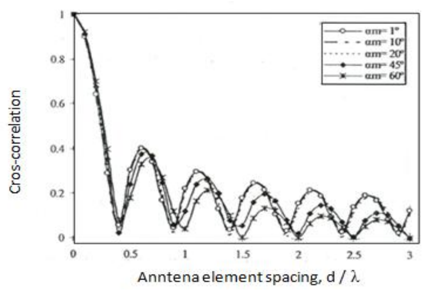

Fig. 2: Cross-correlation between signals received at two elements of horizontally separated ($\varepsilon = 0^0$) antenna elements, $\eta = 0^0$.

It can be concluded that reasonable decorrelation can be achieved using a spatial spacing of less than λ/2 because the correlation coefficient is less than 0.4 for a minimum antenna spacing of 0.4λ and in the case of the MS antenna array is horizontally placed, channel models based on two-dimensional scattering are sufficient and accurate.

Vertical fading cross-correlation:

The cross-correlation between signals received at two antenna elements of a uniform linear array is shown in Fig.3, as a function of the antenna elements spacing λ/2 and for various values of α_m when the antenna elements are vertically separated (i.e.,ε = λ/2),. From the figure we can say that the antenna spacing required to achieve a given correlation coefficient decreases rapidly as α_m increases, and the first minimum in the correlation occurs at the smaller antenna spacing. It is concluded that these results depend mainly on the angle of arrival spreading in the vertical plane α_m and they also show that as α_m increases, the antenna element spacing required for independent fading between two antenna elements decreases. In Fig.3, as a function of the BS and MS antenna spacing, the cross-correlation between two paths of a 2x2 MIMO channel when the MS antenna is vertically placed is shown and the maximum angular spread in the elevation plane was put to 20^0.

Vertical Separation Effect on Spatial Fading Signal Correlation:

The cross-correlation is plotted in Fig.3, as a function of the antenna spacing for different values of separation angles in the vertical direction and it tells us that the correlation coefficient decreases more rapidly as ε decreases and we can conclude that the antenna spacing required to achieve a given correlation coefficient in the case of the horizontally placed antenna array is much smaller than that in case of vertically spaced antenna array.

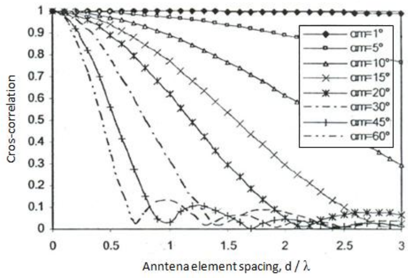

Fig. 3: Cross-correlation between signals received at two elements of vertically separated ($\varepsilon = 90^0$) antenna array, $\eta = 0^0$.

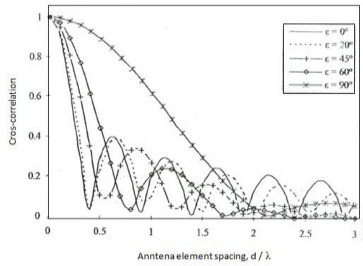

Fig. 4: Cross-correlation versus antenna spacing for various values of ε, and when $\alpha = 20^0$ and $\eta = 0^0$.

Signal Temporal Autocorrelation in 3-D Scattering MIMO Channels:

The autocorrelation of signals arriving in 3-D scattering at a mobile moving in xy-plane in terms of the normalized spatial separation fdτ and the angle spread in the elevation plane is shown in fig.5. From the plotted graph it can be seen that the correlation coefficient decreases as the spatial separation (Doppler spread and/or time-delay) increases and its value is less 0.4. Only slightly different in the correlation coefficients occurred for small values of α_m.

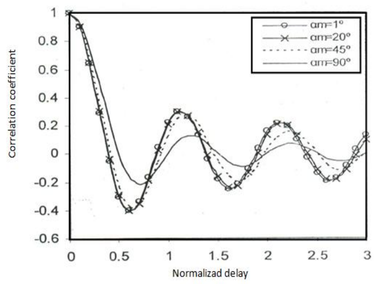

Fig. 5: Autocorrelation of the real part of a fading as a function of the normalized delay.

Conclusion:

Extended geometrically three-dimension MIMO channel model is presented which incorporates the effects of the AoAs and the receiver motion. The fading cross-correlation in vertically and horizontally separated antenna array at the MS was investigated in terms of the antenna element spacing, AoA distributions, and the angular spread of the arrival angle in the vertical plane. It was found that the correlation coefficient decreases as the antenna spacing increases. However, in case of the vertical separation, the correlation decreases much faster with increasing the antenna spacing and α_m compared with the situation when the antenna elements are horizontally separated where the decrease in correlation becomes much slower with increasing α_m and for the antenna spacing of greater than 0.3λ. The temporal correlation decreases as the spatial separation $f_D\tau$ increases while a slight difference occurred in the correlation coefficients for small values of α_m. The accurate MIMO channel can assist in the choice of efficient modulation schemes under different scenarios and the system performance can be accurately predicted.

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