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Impact of 3D Propagation on Wi-Fi Performance in MIMO System

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Abstract− One of the research activities in 5G communication systems is the extension of the MIMO processing from the 2D to the 3D plane by exploiting the elevation dimension which gives an additional degree of freedom to meet the high capacity demands. Despite the growing researches concerning 3D space propagation, there are few studies that evaluate the impact of 3D propagation on MIMO performance at the PHY level and the capacity gained from exploiting the elevation component. The aim of this paper is to evaluate, quantify and compare the downlink BER performance experienced by users in an urban environment in cases of 2D and 3D channel models, where the impact of the 3D component on MIMO performance is evaluated. Results indicate that 3D modelling implies lower correlation between MIMO spatial streams and consequently lower BER. Therefore, the full benefits of MIMO cannot be accurately predicted in 2D model where high correlated MIMO spatial streams are observed. The study also compares two different orientations of linear MIMO arrays (horizontal and vertical). In this study, we are also implementing our enhanced 3D channel model which is an extension of the well-known 3GPP/ITU channel model.The proposed channel model is made available to the public through SourceForge.

Keywords—Wi-Fi; IEEE802.11n; 3D Ray tracer; 3D/2D channel modelling; MIMO.

I. Introduction

Data traffic demands in cellular networks are growing rapidly and the International Mobile Telecommunication (IMT) vision towards 2020 and beyond requires future 5G systems to deliver 10 Gbps peak rate. To fulfill such high spectral efficiency demands, many researches are interested to generate a complete three dimensional (3D) channel model that takes into consideration propagation in the elevation plane and a wide variety of channel propagation statistics in order to extend the Multiple Input Multiple Output antenna system (MIMO) gain from the azimuth to the elevation plane [1]-[4]. Examples of mechanisms exploiting the elevation dimension are vertical sectorization, Full Dimension (FD) MIMO and per user 3D beamforming. Exploiting the 3D spatial dimensions (azimuth and elevation) of MIMO channels is critical in improving the spectral efficiency and the reliability of the radio link. The assumption of 2D modelling results in inaccurate estimation of system level performance and ergodic capacity as discussed in [4][5], especially in environments where the assumption of 2D propagation breaks downs because the elevation spread is significant.

The discussion on the conspicuous advantages of 3D MIMO systems must be combined with the observation that it is the orthogonality of the sub-channels constituting the MIMO system that determines the extent of the multiplexing gain that can be realized. Large capacity gains can only be realized when the sub-channels are potentially de-correlated. However in realistic propagation environments, the promised theoretical gains are not realized due to the significant spatial correlation present in the MIMO channels. Our observations in [5] show that the 2D model clearly overestimates the correlation, which is a consequence of ignoring the directivity of antennas and the propagation of multi-paths in the elevation. Assuming the radiation of energy from all the antennas to be in the same fixed direction in the elevation will cause the antennas to appear more correlated [6].Therefore exploiting the channel's degrees of freedom in the elevation can further enhance the system performance by benefiting from the richness of real channel which consequently results in lower MIMO spatial correlation. The deployment of the 3D channel model requires an implementation of 3D antenna pattern in the channel generation process to take into consideration the directivity of the antenna.

In this paper we evaluate the impact of 3D channel modelling on Bit Error rate (BER) in a Wi-Fi system assuming the IEEE802.11n physical baseband system [7] operating in the ISM band since this standard supports MIMO processing. A comparison is made between the 2D and 3D channel models and for horizontal and vertical linear arrangements of MIMO elements. It's worth mentioning that, it's only because we are implementing a 3D channel model, we are capable of exploiting the elevation dimension in the vertical arrangement of the MIMO system. In this paper, we will implement our proposed 3D channel model by extending the current 2D 3GPP ITU generic channel model in [8] using 3D channel statistics generated from a 3D ray tracing engine described in [9]. It's worth mentioning that the authors have relevant contribution in 3D channel modelling, where large set of wireless channel parameters have been modelled (Large Scale Parameters (LSPs)) [10] and an open source code of the developed model is published at: ***http://sourceforge.net/projects/enhanced-3d-itu-channel-model/***

The remainder of this paper is organized as follows: section II illustrates the modelling of the 3D wireless channel. List of implemented systems parameters are presented in section III, while results are analyzed in section IV and conclusion drawn in section V.

II. Modelling of 3D Wireless Channel

In this study, the existing two-dimensional (2D) 3GPP/ITU channel model [8], which only focuses on propagation in the azimuth plane, is enhanced by extending the channel LSPs using a 3-dimensional (3D) ray tracer engine which is validated in [10]. Our 3D channel modelling implementation considers both propagation in the azimuth and elevation plane based on point-to-point predictions from each AP to every UE location for each site-specific urban databases, which results in a more accurate estimation of channel capacity, spatial correlation and system level performance as shown in our previous work in [5]. An isotropic antenna was deployed in the stage of channel generation in order to provide a generic channel model with no impact from the antenna system. At a later stage of the system level study, any type of transmit and receive antenna patterns can be applied as a spatial-phase-polarization convolution process. The implemented ray tracer parameters when generating the channel predictions are summarised in Table I. Please note that an urban environment is considered in this paper.

TABLE I. 3D CHANNEL MODELLING PARAMETERS

Parameter	Value
Environment	Urban (Bristol & London)
Carrier Frequency	2.4 GHz (802.11n)
Number of APs	100
AP heights (m)	Range of 5-15 m above ground
Total UE (ITU model)	10000 (100 UE/AP)
Total UE (3D ray tracer)	4600 (200 UE/AP)
UE height (m)	1.5
UE locations	50-1000m from AP
AP transmit power (dBm)	30

In detail, our 3D channel modelling calculates the mean (μ) and the variance (σ) of the log of all LSPs. Table II shows the best fit normal and lognormal LSPs statistics for the urban environment. Note that the urban statistics are obtained by averaging channel predictions generated in both *London* and *Bristol* cities, United Kingdom. In the table, the term *RMS DS* refers to the root mean square (RMS) of the delay spread, while *ASD*, *ASA*, *ESD* and *ESA* refer to the RMS angular spread of departure azimuth angles, arrival azimuth angles, departure elevation angles and arrival elevation angles respectively. The *K-factor* is calculated as the ratio of the power of the dominant component to the power of scattered components. While, *SF* is the shadow fading measured in dB.The presented 3D statistics are imported directly into the 3GPP/ITU generic channel code [9] to generate a set of 1000 channel realizations to ensure suitable averaging over the fading process. It's worth mentioning that, the authors generated different set of the 3D channel statistics from our previous work in [11], taking into considerations the practical range of AP heights which impact the channel LSPs statistics mentioned previously. Our model also considers the cross correlation of the LSPs which presented in Table III. The cross correlation between the LSPs represent the inter-dependence of these parameters which eventually results in more accurate modelling of these parameters specially in multi-link environment.

TABLE II. URBAN ENVIRONMENT BEST FIT NORMAL AND LOG NORMAL PARAMETERS

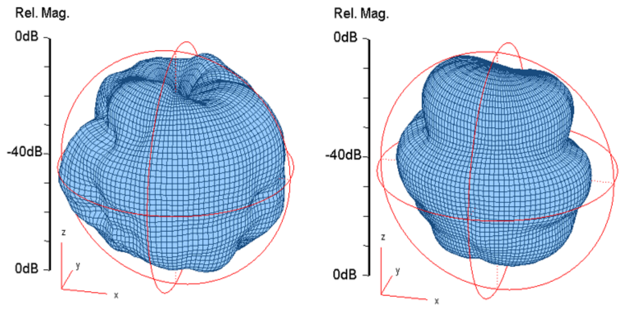
Parameter		2.4 GHz	
		LOS	NLOS
SF (dB)		8.6	11.3
K factor (dB)	μ	12	1.7
	σ	6.3	6.14
RMS DS $\log_{10}$(ns)	μ	-8	-6.97
	σ	0.78	0.51
ASD $\log_{10}$(Degree)	μ	-0.16	0.83
	σ	0.75	0.65
ASA $\log_{10}$(Degree)	μ	1.24	1.66
	σ	0.57	0.43
ESD $\log_{10}$(Degree)	μ	-0.7	-0.11
	σ	1.14	0.68
ESA $\log_{10}$(Degree)	μ	0.29	0.77
	σ	1.25	0.47

TABLE III. URBAN ENVIRONMENT CROSS-CORRELATION PARAMETERS

Parameter	2.4 GHz	
	LOS	NLOS
ASD_DS	0.563415	0.57893
ASA_DS	0.72292	0.45535
ASA_SF	-0.24736	0.03313
ASD_SF	-0.45507	-0.2674
DS_SF	-0.47357	-0.30675
ASD_ASA	0.33796	0.21901
ASD_K	-0.48396	-0.3780
ASA_K	-0.5346	-0.48483
DS_K	-0.46299	-0.4465
SF_K	0.464841	0.06441
ESD_DS	0.680461	0.436081
ESA_DS	0.52538	0.164592
ESA_SF	-0.04904	-0.04303
ESD_SF	-0.1905	-0.1106
ESD_ESA	0.86701	0.20201
ESD_ASD	0.520107	0.63957
ESD_ASA	0.562515	0.18929
ESA_ASA	0.617272	0.54398
ESA_ASD	0.243337	0.11031
ESD_K	-0.29507	-0.41186
ESA_K	-0.26689	-0.4002

III. SYSTEM MODEL

In this paper, the system level simulation of a detailed IEEE802.11n downlink physical channel simulator is implemented depending on the physical channel processing described in [7]. The simulator is used to evaluate the performance in terms of packet error rate for 3D and 2D models. In this study a pilot based Minimum Mean Square Error (MMSE) channel estimator is used. The study considers the downlink performance for the cases of SISO and 2x2 MIMO systems in an urban environment. The MIMO system assumes spatial multiplexing processing where the linear antenna spacing at the AP side is $\mathbf{10\lambda}$ placed at two orientations (horizontal and vertical), while the spacing at the UE side is $\mathbf{0.5\lambda}$ at the horizontal plane only. The bit level simulation is held for the cases of 2D channel modelling and 2D antenna patterns, 3D channel model (considering elevation plane) and 3D antenna radiations. Fig.1 shows the antenna radiations used in this study which have been measured in the anechoic chamber, University of Bristol.



a) AP Dipole antenna b) UE handset Antenna

Fig. 1. Total measured radiation power

The presented 3D statistics in section II are imported directly into the 3GPP/ITU model for generating a set of uncorrelated channel realizations to ensure suitable averaging over the fading process, which are then used in the bit level simulator. The channel realizations generated by the extended 3GPP/ITU model are normalized and an Additive White Gaussian Noise (AWGN) noise is then added to the channel. Table IV lists the system parameters, where the NLOS and LOS conditions are assumed when generating the channel matrix. The spatial correlation of the communication channel can be defined in terms of the AP and UE spatial correlation parameters, α and β respectively. The parameters α and β are calculated from the channel matrix as explained in [12]. In order to justify the difference in the correlation between the two models, the correlation between the MIMO antenna elements patterns used at later stage for both to justify the differences between the 2D and 3D results. It's worth mentioning that this study shows the difference in BER between the 2D and 3D model and does not investigate the impact of varying the elevation spread on BER performance which can be considered in future work.

TABLE IV. SYSTEM PARAMETERS

Parameter	Values
Wi-Fi Standard	IEEE802.11n
Bandwidth	20MHz
Number of Antenna elements	SISO, 2X2 MIMO (linear arrangement)
MIMO antenna spacing	BS (10λ (horizontal & vertical)) , UE (0.5λ)
Antenna type	Measured Pattern
Carrier Frequencies	2.4 GHz
Wireless Channel Model	Extended 3D 3GPP/ITU channel model
Mobility speeds	static
Channel Estimation	MMSE
Packet Size	500 Bytes
LOS condition	NLOS/LOS

IV. RESULTS AND ANALYSIS

A. Comparison of 2D and 3D in SISO system

This section analyses the BER performance of the IEEE 802.11n Wi-Fi system for Single Input Single Output (SISO) case where a comparison is made between the 2D and 3D channels models. Fig.2 shows the BER as function of bit level energy (EbNo) for some MCS (modulation and coding schemes) schemes, as the conclusions drawn the figure are applicable to other MCSs modes. Note that, for the 2D model, all rays arriving in the 2D plane interpolated at elevation angle of 0 degree (of the deployed 3D pattern) at the AP side (assuming rays arrival in horizontally only), and elevation angle of +66 degree (of the deployed 3D pattern) at the UE side (this elevation plane gives highest gain where UE is perfectly aligned to the AP for best performance). As shown in Fig.2, slight differences are observed between the two models in the context of BER and this is justified by the differences in k-factor obtained in the 3D model which results in lower BER, given that the K-factors are -2 and 3.5 for the 2D and 3D models respectively. The differences in all MCS modes are less than one dB in EbNo to satisfy 10% BER.

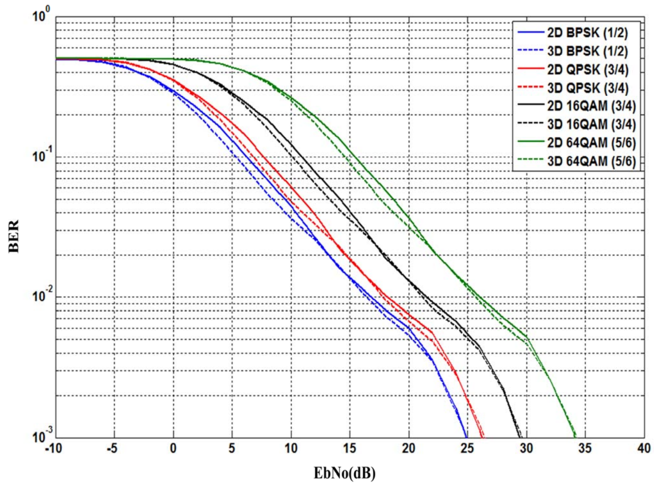
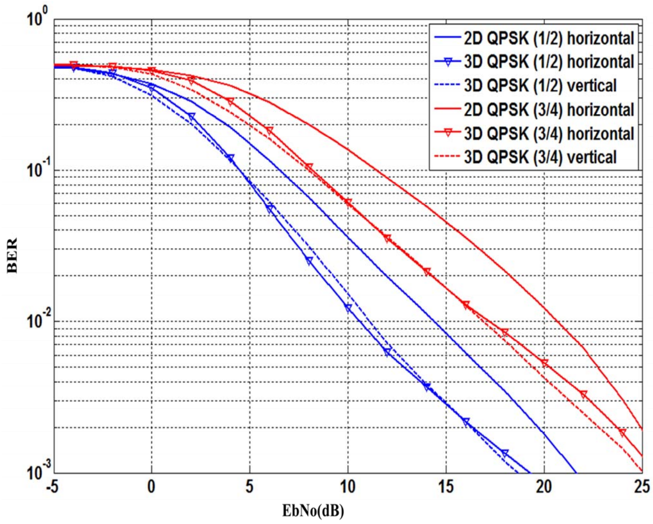


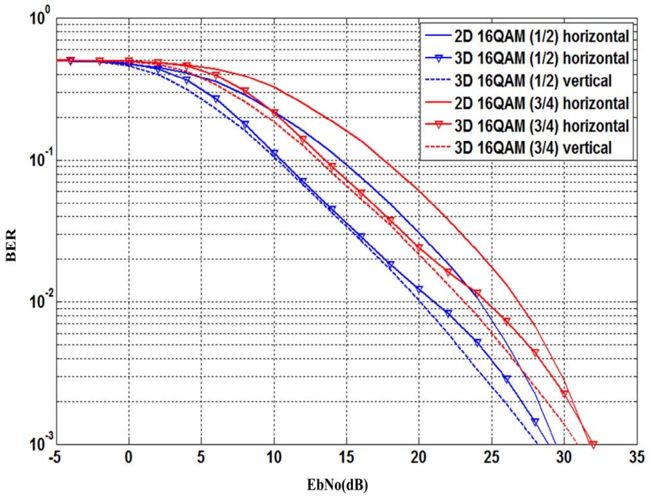
Fig. 2. Comparison of bit-level BER in 2D and 3D channel models in SISO

B. Comparison of 2D and 3D in MIMO system

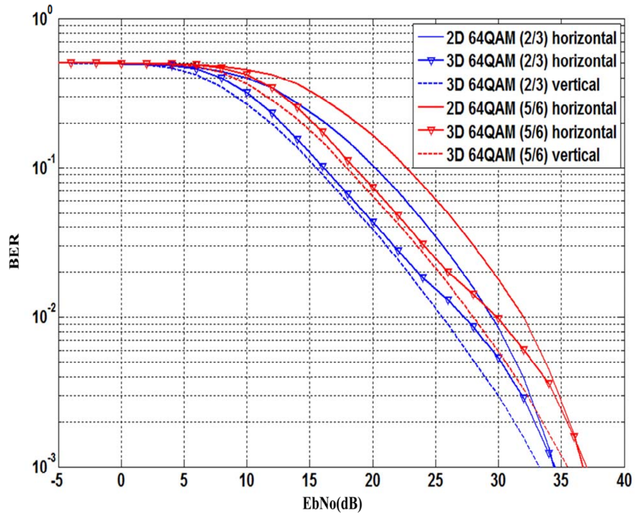
In this section the physical layer performance of the Wi-Fi physical layer is evaluated for two different MIMO antenna orientations exploiting both horizontal and elevation planes and for the propagation conditions of NLOS and LOS. The results for NLOS case are presented in Fig.3 for different modulation schemes (QPSK, 16QAM, 64 QAM).Comparing the results to the SISO presented previously; larger differences are observed between the 2D and 3D models, where the 3D model results in lower BER. It's observed that the 2D model requires an additional EbNo of 2dB for QPSK and 4 dB for 16QAM and 64 QAM to achieve a BER of 10% as compared to the 3D model (horizontal case). In order to justify the better performance of the 3D model, we compare the 2D QPSK (1/2) (coding rate of ½) in Fig.3a with the 3D QPSK (1/2) for the horizontal case. The 3D model results in lower BER, and this is justified by the lower spatial correlation observed at the UE side for the 3D model, where the correlation between the MIMO spatial streams at the UE side (β) are 0.38 and 0.85 for the 3D and 2D models respectively which implies 55% reduction in the correlation. This is also applicable to the vertical arrangement of antenna elements. The obtained results are also due to the differences in the correlation between the 3D and 2D antenna elements radiations, given that for the horizontal MIMO arrangement, the correlation between AP antenna elements radiations are: 0.01, 0.1 for the 3D and 2D respectively, while the correlation at the UE side is reduced by 39% in the 3D model (0.48) as compared to the 2D model (0.79). Therefore, the lower correlation between the MIMO elements radiations results in lower correlation between the MIMO spatial streams and therefore better performance in the 3D model. The differences in the correlation between the MIMO streams are expected to increase in scenarios where the elevation spread is higher (like UE positions close to AP), which results in lower correlation at the UE side given that the elevation spread decreases as the distance increases between the UE and AP [13]. Larger angular spread including the elevation spread will results in uncorrelated spatial streams and therefore they are more beneficial for the performance of MIMO system.



a) QPSK modulation scheme



b) 16QAM modulation scheme



c) 64QAM modulation scheme

Fig. 3. Comparison of bit-level BER in 2D and 3D channel models in MIMO (NLOS).

On the other hand, when comparing the 3D BER performance for the MIMO horizontal arrangement with the vertical one, we observe that the vertical case results in lower BER since lower correlation is observed at the AP side, while the correlation at the UE side is almost the same. For example, when comparing the 3D 16QAM(3/4) horizontal and 16QAM(3/4) vertical we observe that the vertical results in lower BER, where the AP MIMO spatial streams correlation (α) are 0.53 and 0.2 for the horizontal and the vertical arrangements respectively. It's worth mentioning that the differences in performance between the horizontal and vertical MIMO arrangements decreases when increasing the EbNo.

For the case of LOS propagation condition, the BER performance for the MCS modes considered are shown in Fig.4. In this case, the AP MIMO antenna elements are placed horizontally and spaced by $\mathbf{10\lambda}$. We observed that the differences between the two models are lower compared to the NLOS (horizontal) shown in Fig3, and this is justified by the presence of strong LOS multipath component, which increases the correlation between the MIMO spatial streams and therefore reduces the performance. The spatial correlations of MIMO spatial streams are α=0.98 & β=0.89 for AP and UE sides in the 2D model, while the correlations for the 3D model are: α=0.95 and β=0.91 for the AP and UE respectively. The MIMO correlation levels are higher than the ones observed in NLOS condition and therefore higher BER is obtained. Further analysis to the LOS show that, the 2D model requires an additional 2 dB for the BPSK, 1 dB for the QPSK (3/4), 16 QAM (3/4) and 64 QAM (5/6) MCS modes to achieve a BER of 10% as compared to 3D model. These differences are lower compared to the NLOS case discussed previously.

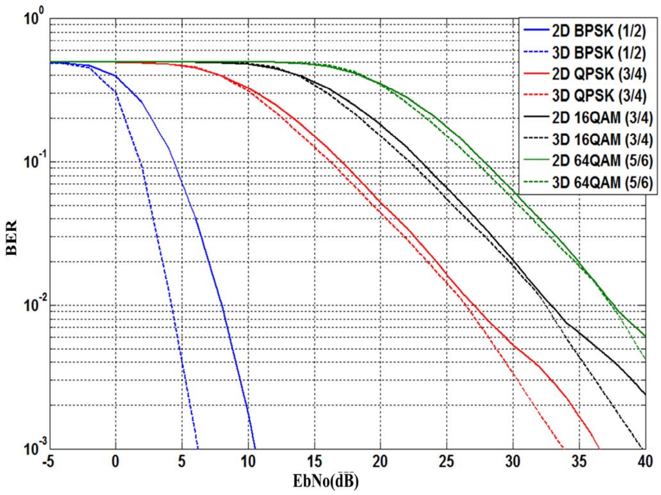


Fig. 4. Comparison of bit-level BER in 2D and 3D channel models in MIMO (LOS).

V. Conclusions

In this paper we have presented a quantitative analysis of the IEEE 802.11n PHY performance in terms of PER in a 3D and 2D ITU/3GPP channel models. The paper investigated the performance differences between the 2D and 3D channel assumptions in terms of BER for SISO and MIMO scenarios where in case of MIMO two different antenna arrangements (horizontal and vertical) are considered. Simulations results show that for MIMO, the 3D model results in lower BER compared to the 2D model. In addition, placing the antenna elements in the elevation plane results in lower BER compared to the horizontal arrangement. Add to that, in LOS conditions, the BER differences obtained between the 2D and 3D channel models are lowered compared to the NLOS case due to the presence of LOS component. The lower spatial correlation observed between the MIMO streams the in 3D model is due to the richness of the multipath components in real channels when considering elevation plane, and the lower correlation resulted from phase-polarization convolution with antenna pattern in the 3D planes.

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