A Proposed 3D Extension to the 3GPP/ITU Channel Model for 800 MHz and 2.6 GHz Bands

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***Abstract*—Recently there have been many proposals to generate a complete channel model that covers wide range of carrier frequencies and take into consideration different aspects of channel propagation statistics. Many of these models focus on two dimensional propagation, i.e. propagation in the azimuth plane only. The assumption of 2D propagation may lead to inaccurate estimation of channel capacity and system level performance. In addition, few studies have focused on the propagation characteristics in the 800 MHz band. In this paper a complete 3D channel model is generated and examined through 3D ray tracer tool. The paper proposes detailed channel related parameters for urban macro and micro-cell environments at carrier frequencies of 800 MHz and 2.6 GHz. The paper analyzes the channel in terms of best-fit normal parameters for large scale parameters, path loss models, cross-correlation of large scale parameters, and de-correlation distance for both line-of-sight and none line-of-sight conditions. The paper uses the generated statistics to extend the current 2D 3GPP/ITU channel model to 3D model and compare the propagation statistics generated by this model with the ray tracer predictions.**

***Index Terms*—3D Channel Model, 3GPP/ITU, Large Scale Parameters, De-correlation Distance.**

I. INTRODUCTION

Data traffic demands in cellular networks are growing rapidly and an accurate channel modelling is now required to obtain accurate system level performance evaluation. Therefore, in order to achieve high capacities when designing such communication systems, the propagation characteristics of operating frequency bands have to be carefully considered. These include the impact of wireless channel, the base station (BS) and user equipment (UE) antennas.

LTE-Advanced is one of the 4G wireless cellular communication standards which designed to operate in evolved universal terrestrial radio access (E-UTRA) frequency bands in the range of 699 MHz to 3.8 GHz [1]. E-UTRA low frequency operating bands, 5, 8, 12, 13, 14, 17, 18, 19, 20, are considered attractive bands due to their enhanced propagation characteristics. These bands are considered as good candidates for M2M applications [2] and inter-band carrier aggregation [3]. The current 3GPP/ITU channel model covers a frequency range of (2 GHz– 6 GHz) only [4]. Therefore we aim at proposing an extension to the existing 3GPP/ITU model to include the E-UTRA low frequency bands mentioned above.

This paper presents a range of urban macro-cell and micro-cell propagation statistics derived from state of-the art 3D ray tracing predictions. The paper focuses on two frequency bands which are the 800 MHz and 2.6 GHz. In this work, we propose a 3D extension to the current 3GPP/ITU channel model. The proposed extension provides complete set of propagation statistics which can be easily incorporated in the 3GPP/ITU model, given that the current channel model is a 2D model which lacks the availability of the elevation plane statistics [4]. The assumption of 2D modelling leads to differences in channel propagation characteristics and inaccurate estimation of channel capacity and MIMO spatial correlation as explained in section IV. Ray tracing is used to generate a vast propagation data set, then used to fit the stochastic channel model parameters for each frequency band and cell type.

The first set of the modelled propagation parameters are the large scale parameters (LSPs) which are considered as an average over a typical channel segment i.e. distance of some tens of wave-lengths [4]:

- Delay spread and distribution.
- Angle of departure spread and distribution.
- Angle of arrival spread and distribution.
- Shadow fading standard deviation.
- Ricean K-factor.

First three of the large scale parameters are used to control the distributions of delay and angular parameters. Add to that, some other support parameters which are necessary to generate channel realizations are also calculated such as cross-correlation and de-correlation distances of LSPs.

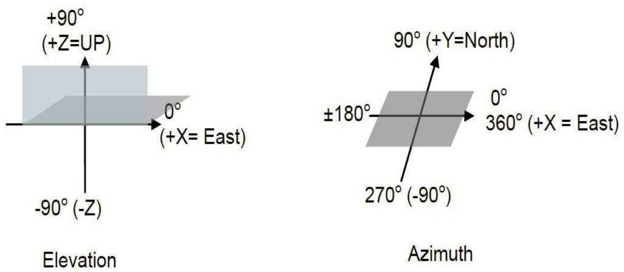
II. RAY TRACER MODELLING PARAMETERS

The propagation channel between each BS and UE is modelled as a set of spatial and temporal multipath components using state-of-the-art 3D ray tracing tool. The ray tracing identifies all possible ray paths between the BS and UE based on site specific database, given that the database includes terrain, buildings and foliage related information. A validation study of the tracer predictions and accuracy as compared to field measurements are presented in [5].

The tracer engine capture rays (see Fig. 1a) and provides information on the amplitude, phase, time, delay, angle-of-departure (AOD) at BS and angle-of-arrival (AOA) at UE for each multipath component (MPC). Fig. 1b shows the coordinate system of the ray tracing tool. The ray tracing is performed in the cities of London (143 km^2) and Bristol (17.6 km^2), United Kingdom. In both cities two types of cell sizes were considered, urban macro and micro-cells. 23 BSs were randomly scattered in each of the above mentioned cities with a total number of 900, and 500 UEs per BS in the macro and micro cell respectively.

Table I summarizes the ray tracing system modelling parameters. In all cases, an isotropic antenna was deployed to allows any type of transmit and receive antenna pattern to be applied later as part of system level study.

a) Captured rays between a transmitter and a receiver



b) Ray Tracer coordinate system

Fig. 1: Captured rays and coordinate system of the ray tracer.

TABLE I
RAY TRACER PARAMETERS

Parameter		Value
Carrier Frequency (MHz)		800 , 2600
Number of BS		23
Number of Sectors		3
Number of UE per Sector		300
UE height (m)		1.5
BS height (m) [above ground]	Micro-cell	10 – 25
	Macro-cell	10 – 120
UE locations (m)	Micro-cell	50 – 500
	Macro-cell	50 – 1000
BS transmit power (dBm)	Micro-cell	39
	Macro-cell	43

III. ANALYSIS OF PROPAGATION STATISTICS

A. Best fit normal and lognormal parameters

The ray-tracing predictions are used in this paper to generate path loss models, angle spread statistics, and calculates the mean (μ) and the variance (σ) of the log of all LSPs. The path loss equation in (1) is expressed in terms of variables A, B, and the distance in meters (d). Table II and Table III show the best fit normal and lognormal channel parameters statistics for macro and micro cells respectively(to be consistent with the ITU channel model) ,which are obtained from averaging all channel predictions generated in both London and Bristol cities for macro and micro cells. The presented statistics can be imported directly into 3GPP/ITU process for generating 3D channel realizations [6][4]. Note that, the RMS DS refers to the 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 at the ratio of power of the dominant component to the power of scattered components. SF is the shadow fading measured in dB.

$$Pathloss = A \cdot \log_{10}(d) + B \quad (1)$$

TABLE II
MACRO-CELL BEST FIT NORMAL AND LOG NORMAL PARAMETERS

Parameter		800 MHZ		2.6 GHz	
		LOS	NLOS	LOS	NLOS
Path loss(dB)	A	20	29	19	26
	B	31	30	41	51.9
SF (dB)		8.4	15.3	10.7	11.2
K factor (dB)	μ	10	2.54	11.64	2.2
	σ	6.5	6.25	6.95	6.2
RMS DS $\log_{10}$(ns)	μ	-7.88	-6.95	-7.95	-6.96
	σ	0.88	0.54	0.96	0.55
ASD $\log_{10}$(Degree)	μ	-0.26	0.62	-0.35	0.56
	σ	0.84	0.75	0.89	0.76
ASA $\log_{10}$(Degree)	μ	1.21	1.62	1.18	1.61
	σ	0.613	0.47	0.65	0.49
ESD $\log_{10}$(Degree)	μ	-1.13	-0.47	-1.15	-0.49
	σ	1.39	0.84	1.48	0.86
ESA $\log_{10}$(Degree)	μ	-0.121	0.65	-0.1	0.61
	σ	1.6	0.58	1.69	0.58

TABLE III
MICRO-CELL BEST FIT NORMAL AND LOG NORMAL PARAMETERS

Parameter		800 MHZ		2.6 GHz	
		LOS	NLOS	LOS	NLOS
Path loss(dB)	A	19	28	16	25
	B	32	33	42	53
SF (dB)		6.6	14.8	8.6	11.3
K factor (dB)	μ	11.2	2.1	12	1.7
	σ	5.89	6.2	6.3	6.14
RMS DS $\log_{10}$(ns)	μ	-7.9	-6.98	-8	-6.97
	σ	0.73	0.51	0.78	0.51
ASD $\log_{10}$(Degree)	μ	-0.09	0.82	-0.16	0.83
	σ	0.69	0.64	0.75	0.65
ASA $\log_{10}$(Degree)	μ	1.27	1.68	1.24	1.66
	σ	0.55	0.39	0.57	0.43
ESD $\log_{10}$(Degree)	μ	-0.67	-0.11	-0.7	-0.11
	σ	1.1	0.68	1.14	0.68
ESA $\log_{10}$(Degree)	μ	0.27	0.81	0.29	0.77
	σ	1.2	0.49	1.25	0.47

B. Cross-correlation of LSPs

LSPs are used as control parameters when generating the small-scale channel parameters. The large set of channel predictions generated by the tracer engine, show that different MSs being at the same spatial position will experience correlated LSPs. In multi-link simulations, spatial correlations of channel parameters are important. In order to establish accurate correlations between links at system level, the cross-correlation of LSPs have been calculated and presented in Table IV and Table V for both macro and micro cells.

For single position of radio-stations (one link), the inter-dependence of multiple LSPs can be described with correlation coefficient matrix. The cross-correlation of LSP is calculated using (2) [4]:

$$\rho_{xy} = C_{xy} \Big/ \sqrt{C_{xx} . C_{yy}} \qquad (2)$$

C_{xy} in (2) is the cross-covariance of LS parameters x and y. The correlation between MSs connected to the same BS is the interest of this paper.

TABLE IV
MACRO-CELL CROSS-CORRELATION PARAMETERS

Parameter	800 MHZ		2.6 GHz	
	LOS	NLOS	LOS	NLOS
ASD_DS	0.52	0.54	0.57	0.53
ASA_DS	0.69	0.50	0.71	0.50
ASA_SF	-0.22	0.01	-0.27	0.06
ASD_SF	-0.45	-0.30	-0.52	-0.18
DS_SF	-0.43	-0.31	-0.49	-0.21
ASD_ASA	0.25	0.18	0.29	0.20
ASD_K	-0.42	-0.37	-0.48	-0.37
ASA_K	-0.50	-0.48	-0.52	-0.45
DS_K	-0.44	-0.46	-0.49	-0.46
SF_K	0.41	0.13	0.52	0.08
ESD_DS	0.67	0.41	0.70	0.40
ESA_DS	0.50	0.21	0.54	0.19
ESA_SF	-0.11	-0.06	-0.11	0.02
ESD_SF	-0.21	-0.14	-0.23	-0.05
ESD_ESA	0.88	0.17	0.89	0.16
ESD_ASD	0.44	0.59	0.48	0.60
ESD_ASA	0.60	0.16	0.62	0.16
ESA_ASA	0.64	0.57	0.65	0.57
ESA_ASD	0.19	0.08	0.21	0.08
ESD_K	-0.28	-0.38	-0.29	-0.38
ESA_K	-0.26	-0.42	-0.25	-0.38

TABLE V
MICRO-CELL CROSS-CORRELATION PARAMETERS

Parameter	800 MHZ		2.6 GHz	
	LOS	NLOS	LOS	NLOS
ASD_DS	0.51	0.57	0.56	0.58
ASA_DS	0.71	0.46	0.72	0.46
ASA_SF	-0.21	-0.02	-0.25	0.03
ASD_SF	-0.38	-0.34	-0.46	-0.27
DS_SF	-0.40	-0.36	-0.47	-0.31
ASD_ASA	0.31	0.20	0.34	0.22
ASD_K	-0.43	-0.38	-0.48	-0.38
ASA_K	-0.50	-0.52	-0.53	-0.48
DS_K	-0.41	-0.45	-0.46	-0.45
SF_K	0.37	0.13	0.46	0.06
ESD_DS	0.66	0.46	0.68	0.44
ESA_DS	0.51	0.19	0.53	0.16
ESA_SF	-0.04	-0.12	-0.05	-0.04
ESD_SF	-0.14	-0.19	-0.19	-0.11
ESD_ESA	0.86	0.22	0.87	0.20
ESD_ASD	0.51	0.64	0.52	0.64
ESD_ASA	0.57	0.21	0.56	0.19
ESA_ASA	0.63	0.56	0.62	0.54
ESA_ASD	0.24	0.12	0.24	0.11
ESD_K	-0.27	-0.44	-0.30	-0.41
ESA_K	-0.27	-0.44	-0.27	-0.40

C. De-correlation distance

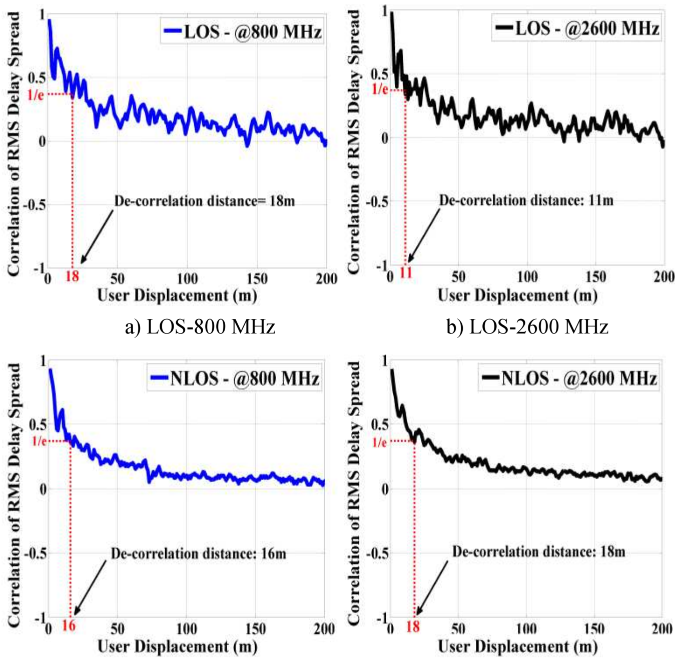
As a correlation measure, cross-correlation coefficient calculated in (2) shows that, for one link (single position of MS) inter-dependence of multiple control parameters can be described with correlation coefficient matrix. Additionally if parameters of intra-site links are correlated according to distance between MS positions, then correlation matrix gets additional dimension that describes changes in correlations over distance, and can be described as:

$$\rho_{xy} = C_{xy} \cdot d_{MS} \Big/ \sqrt{C_{xx} . C_{yy}} \qquad (3)$$

In (3), d_{MS} is the UE displacement in (m). This distance represents the maximum UE displacement which causes the LSPs to be highly correlated. The correlation distance is determined based on a correlation threshold of e^{-1} as considered in 3GPP/ITU channel model and other related standards such as WINNER/WINNER+ channel models [7]. Fig.2 shows how the auto-correlation of RMS DS decays exponentially as function of distance according to (4) in macro-cell, at both 800 MHz and 2.6 GHz bands,

$$\rho(d) = \alpha . \left[e^{\frac{-d_{MS}}{\gamma}} \right] \qquad (4)$$

The values of α and γ are dependent on the propagation condition (LOS/NLOS) and environment type. Table VI and Table VII show the de-correlation distances calculated for different LSPs for macro and micro cells. These values averaged between two cities topologies which are Bristol and London.



a) LOS-800 MHz
b) LOS-2600 MHz
c) NLOS-800 MHz
d) NLOS-2600 MHz

Fig. 2: Correlation of RMS delay spread versus distance for different cases.

TABLE VI
MACRO-CELL DE-CORRELATION DISTANCES

Parameter	800 MHZ		2.6 GHz	
	LOS	NLOS	LOS	NLOS
DS_lambda	18	16	11	18
ASD_lambda	36	40	38	44
ASA_lambda	17	19	14	32
ESD_lamda	28	24	25	35
ESA_lamda	7	38	5	28
KF_lambda	23	16	22	17

TABLE VII
MICRO-CELL DE-CORRELATION DISTANCES

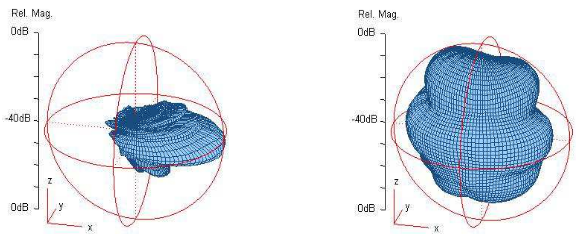
Parameter	800 MHZ		2.6 GHz	
	LOS	NLOS	LOS	NLOS
DS_lambda	11	24	5	25
ASD_lambda	63	43	49	24
ASA_lambda	4	33	3	30
ESD_lamda	37	25	5	25
ESA_lamda	12	23	3	28
KF_lambda	6	22	4	18

IV. RAY TRACER AND 3D ITU CHANNEL STATISTICS COMPARISON

The LSP statistics presented in section III are used to extend the software implementation of the existing ITU channel models of [7], which is a 2D model. In [6], the authors have presented the propagation differences that occur when considering 3D modelling and its impact on the channel capacity, MIMO spatial correlation and large/small channel propagation parameters. The channel statistics for both Bristol and London cities generated from the extended 3D ITU code [6] are compared to the ray tracer predictions to validate the generated parameters. The ITU channel statistics for each city is generated by considering cities specific path loss models in the C2 ITU scenario (Urban Macro). The comparison is performed for the case of macro-cell at the centre frequency of 2.6 GHz. Readers may refer to [6] for detailed explanation of the required changes to the existing 2D ITU model to incorporate the elevation angles statistics in the process of generating channel realizations. To assess the performance of the derived 3D ITU channel in comparison to the 3D ray tracer, same system parameters are applied for both the ray tracer and ITU model. The system modelling parameters include city specific path loss equations derived from the 3D ray tracer engine, BS and MS heights, number of sectors, and transmission power levels. Details of the used antenna patterns are presented in subsection A. While subsection B presents the configuration parameters applied to the 3D ITU channel model software to generate channel statistics.

A. Measured 3D Antenna pattern

The radiation patterns of the macro-cell BS antenna and the UE antenna used in this study were measured in an anechoic chamber at the University of Bristol [8]. All patterns are 3D and include full phase and polarization information. The total power radiation patterns are shown in Fig. 3. Table VIII summarizes the antenna patterns parameters. The antenna patterns are applied to the tracer generated statistics and imported in the ITU channel modelling process.



(a) Macro BS antenna (b) UE handset antenna

Fig. 3: Total power measured radiation patterns.

TABLE VIII
3D ANTENNA PATTERN PARAMETERS

Parameter		Value
BS Antenna Type		Uniform linear array with 6 dual polarised patches
UE Antenna Type		NOKIA mobile phone antenna (omni-directional)
Antenna 3dB Azimuth /Elevation Beamwidth	BS	65°/15°
	UE	360°/36°
BS antenna downtilt		10°

B. 3D ITU Channel Model Parameter

The communication channel between the BS and UE is generated using the generic ITU channel model. The ITU channel model is a stochastic model that requires two levels of randomness to model different BS-UE links. First, large-scale (LS) parameters like shadow fading, delay proportionality factor and angular spreads are drawn randomly from tabulated distribution functions. Then the SS parameters like cluster delays, cluster powers, and directions of arrival and departure are drawn randomly according to tabulated distribution functions. The ITU channel model is based on clustered delay line (CDL) [4]. A cluster is comprised of the vector sum of multi path components (MPC), that all have the same or close to the same delay. It is worth mentioning that clusters with ratios less than 25 dB compared to the maximum cluster power are removed. A third level of randomness is also required to generate different realization of each individual link through selecting different phases for the scatters [7]. Table IX list the system parameters assumed in the ITU related statistics.

TABLE IX
ITU CHANNEL MODEL PARAMETERS

Parameter		Value
Carrier Frequency		2.6 GHz
Number of BS		100
Number of Sectors		3
Number of UE per Sector		100
BS heights (m) [above ground]	Bristol	7-77
	London	8-122
Total Number of UE's	Bristol	10000
	London	10000
UE height (m)		1.5
UE locations (m)		50-1000 from BS within the BS antenna 3dB beamwidth
BS transmit power (dBm)		43

C. Propagation Statistics Analysis

Fig. 4 presents the propagation statistics results in terms of received power, K factor, RMS delay spread and Angle-of-Departure/Angle-of-Arrival (AOD/AOA) RMS azimuth and elevation spreads (departure refers to the side of the BS and arrival at the user). The mentioned statistics are compared between both ray tracer predictions and ITU generated statistics. In order to provide further validation of the proposed channel parameters presented in previous section, the channel propagation characteristics such as DS, K factor, and RMS angular spread for AOA and AOD for both azimuth and elevation are compared to the ray tracer statistics. The figures show slight differences between the implemented 3D ITU model and the ray tracer predictions in Bristol and London which support our proposed channel models for macro and micro cells that have been generated from large set of channel predictions. The 3D ITU statistics shown in Fig.4 are generated by the 3GPP/ITU software tool [7] after modifying the existing tabulated statistics and adding the elevation extension to generate complete 3D channel model. Therefore, the proposed channel parameters can be incorporated in the 3GPP/ITU channel modelling process to generate accurate channel models for macro and micro-cells.

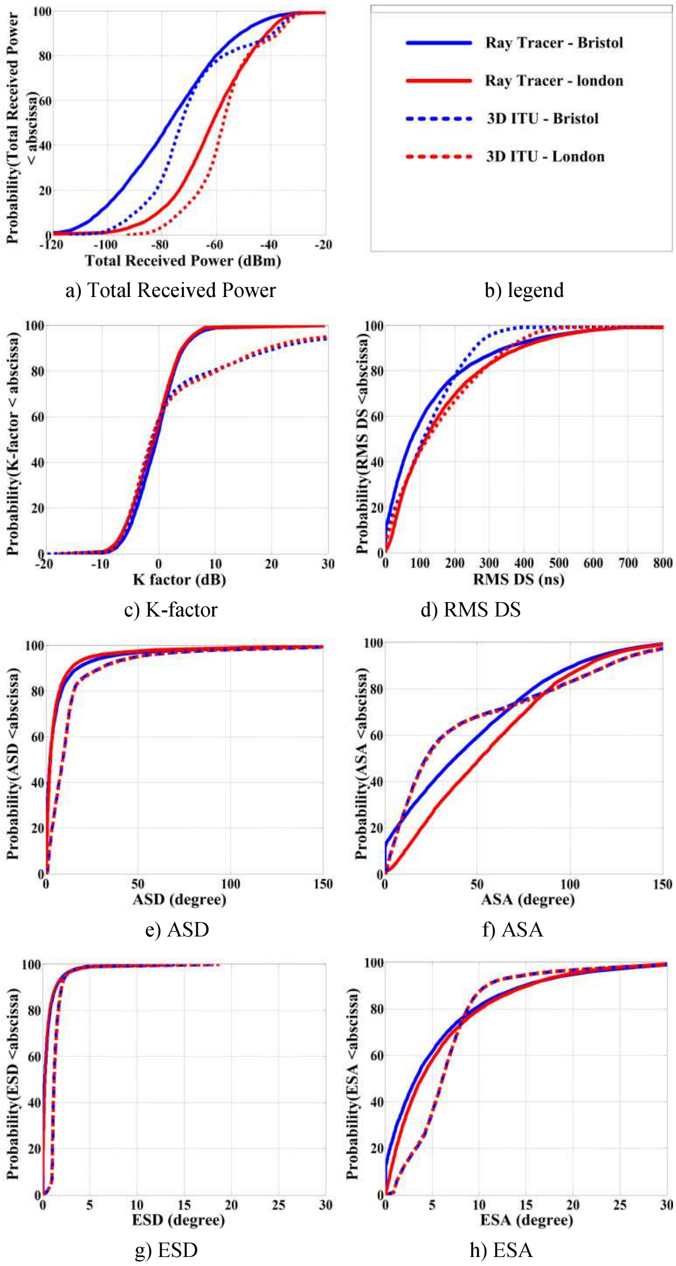


Fig. 4: Channel statistics of Macro-cell at carrier frequency of 2.6 GHz.

V. CONCLUSIONS

This paper has presented a set of novel urban micro-cell and macro-cell propagation statistics derived from 3D ray tracing tool for scenarios in the center of Bristol and London cities, United Kingdom. The paper also presented the propagation differences between the legacy 2.6 GHz band and the recently adopted 800 MHz band. The paper analyzed the channel in terms of best fit normal parameters for large scale parameters, path loss models, cross-correlation of large scale parameters and de-correlation distances for both LOS and NLOS conditions. The paper provided CDFs of channel's small scale parameters for both the extended 3D ITU and ray tracer channel statistics. Comparison was performed between the 3D ray tracer used and the implemented 3D ITU channel models to validate the modifications made to the ITU model when considering the elevation plane and the other statistics proposed in this paper, where it has been shown that the channel statistics generated by the 3D ITU maintain good match with the ray tracer statistics. The proposed statistics can therefore be incorporated in the 3GPP/ITU channel modeling process to generate the channel realizations to be used in link and system level performance evaluations.

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