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LSAA-Based Wireless Coverage for 5G Millimeter-Wave Mobile Communication Systems

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Abstract: Millimeter-wave (mm Wave) communications will be used in 5G communication system, but they have experienced several path losses and having high sensitivity to physical objects, leads to smaller cell radii and complex network architectures. A coverage extension scheme using large-scale antenna arrays (LSAAs) has been advised and theoretically proven to be cost-efficient in combination with ultra-dense minor cell networks. To examine and enhance the LSAA-based network deployments, a comprehensive survey of recent advances in statistical mm Wave channel modeling is presented in terms of channel parameter estimation, large-scale path loss models, and small-scale cluster models. Next, the measurement and modeling results at two 5G candidate mm Wave bands (e.g., 28 GHz and 39 GHz) are reviewed and compared in several outdoor setups, where the propagation characteristics make essential contributions to wireless network designs. Finally, the coverage behaviours of systems employing many antenna arrays are conversed, as well as some implications on future mm Wave cellular network designs.

Keywords: Fifth generation (5G), Channel modelling, Large-scale antenna array (LSAA), millimetre wave (mm Wave) communications, Radio propagation measurements, Wireless coverage.

I. INTRODUCTION

To support various emerging applications for fifth-generation (5G) mobile communication [1] devices, a multi-Gbps user experience information rate with lower latency and complicated reliability is needed. Consideration has been given to the candidate mm Wave bands (e.g. 24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 Hz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz, and 81-86 GHz). The candidate mm Wave bands (e.g., 24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 Hz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz, and 81-86 GHz) have been taken into consideration for the 5G mobile service within the World Radio communication Conference 2015 (WRC-15) [2] and can finally be determined in WRC-19 supported technical and economic concerns. Meanwhile, with the speedy development of frequency (RF) hardware techniques [3-4], the implementation of many technologies (e.g., large multiple-input and multiple-output (MIMO), hybrid beam forming mistreatment miniaturized high-density large-scale antenna arrays (LSAAs) and low-power complementary metal–oxide–semiconductor (CMOS) circuits) is potential for mm Wave communications [5, 6]. However, there are a unit still many challenges and necessities within the preparation of LSAA primarily based mm Wave systems with massive coverage. Due to severe attenuation and path loss between transmitters (TXs) and receivers (RXs), LSAA-based mm Wave mobile communication systems area unit necessary to increase the coverage up to many hundred meters, with the rise within the variety of array components victimization directional Transmissions [6, 11, 12]. Traditional single-directional beams should be steered either electronically or automatically to discover optimized links, and communication is broken once the transceivers area unit moving or no LoS path exists. Due to the utilization of multi beam or beam-steerable antenna arrays (e.g., passive multi beam antenna, the lens-based beam-switching antenna system, and the active phased array), these arrays will overcome the on top of shortcomings and supply robust beam alignment [13]. Combined with large MIMO techniques, the systems mistreatment multi beam arrays and advanced beam forming pre-coding give tremendous will increase in spectral potency and anti-interference capability at base station (BS) sides [3]. With relevancy potential beam forming architectures, totally digital beam forming needs one dedicated RF chain per antenna part, which is restricted by hardware constraints, together with price, unaffordable energy power consumption, and integrated size [6]. Hence, many hybrid analog-digital beam forming architectures have been designed to cut back the quantity of RF chains, leading to fewer information streams and reduced power consumption [15]. Even a lot of therefore, with the event of the substrate-integrated conductor (SIW) technique, a totally digital beam forming MIMO system is feasible once

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employing a superior mm Wave transceiver front-end [16]. To support multiple users within the mm Wave cellular network, multiple-access techniques area unit necessary to take advantage of the abstraction resolution, spectral potency, and property density, that need correct channel state info (CSI) and smart backward compatibility with different mm Wave physical layer-enabled techniques [3]. From a wireless networking perspective, multitier cooperative cell preparation, combined with LSAA-based little cells, is predicted to be a key enabler to immensely boost 5G mm Wave radio network coverage and capability with lower energy consumption and networking prices [10]. Recently, a oval low-latency heterogeneous network (HetNet) mistreatment AN reconciling low-latency strategy was developed, wherever the cooperative network among the mm Wave macro cells, little cells, and wireless backhaul improved the general space coverage and system outturn at the same time [17, 18]. In this article, we have a tendency to target the coverage and property analysis of LSAA-based mm Wave communication systems from radio channel modeling and wireless networking perspectives. The motivation is to indicate the impact of large-scale and small-scale channel characteristics on a 5G mm Wave system style. Specifically, we have a tendency to discuss progressive characteristics in terms of mm Wave applied math channel modeling supported field mensuration data, together with channel parameter estimation and channel model standardization. On the other hand, a site-specific analysis of the angular unfolds and therefore the corresponding statistics area unit conferred for the optimization of LSAA-based mm Wave transmission schemes. As a reputable approach, propagation measurement-based network style and preparation considerably reduce the outage chance and supply an affordable trade-off between the network complexity and coverage sweetening of 5G mm Wave mobile communications. The rest of the article is organized as follows. We start with a brief review of the recent advances in mm Wave channel modeling and discuss the impacts of path losses, blockages, and temporal/spatial dispersions on network deployment using the LSAA in section II. Then, a comparison of the field measurement results in three typical outdoor access scenarios (e.g., urban microcell (UMi), urban macro cell (UMa), and rural macro cell (RMa) is presented in section III. Finally, the conclusions are drawn in section IV.

II. MMWAVE CHANNEL CHARACTERIZATION AND MODELING

Mm Wave applied mathematics channel models principally target feature extraction from field channel activity information or ray-tracing simulation information. The involved channel parameters are wont to model large-scale path loss and characterize small-scale multipath effects, which additional impact channel generation and network preparation.

A. Distance-Dependent Path Loss Models

As the basis of link budget and interference calculations, distance-dependent path loss models offer realistic insights into the large-scale propagation characteristics of radio channels, that confirm the coverage of cellular and backhaul networks. The link budget in mm Wave channel measurements is given by

$$P_t = P_r + G_r - L_p + G_t + G_s \qquad (1)$$

here *Pt* represents transmitted power in the RF output port; *Gt* and *Gr* represent the gain of the transmit and receive antennas, respectively; and *G* s represents the system gain considering the external RF amplifier gain, which can be calculated through back-to-back calibration to accurately compute the path loss *LP* in (1) , it is essential to obtain the received power *Pr* through a power delay profile (PDP), which reflects the decay of multipath components (MPCs) with propagation delay and is also the foundation of channel parameter\estimation. For an omni directional channel, the PDP is synthesized with overlapping directional PDPs when using narrow beam width antennas with the directional scanning sounding method. For example, Fig. 1 shows a synthesized PDP measured within the urban NLoS situation, wherever the beginning of the surplus delay t_0 is that the initial time that the PDP is on top of the detection level, with a fifteen ns margin of safety, as against the delay of the trail with the biggest received power because of a lacking LoS path. Note that random noise could exceed the detection level with an outsized propagation delay, which isn't a detectable multipath, as shown in figure 1. Therefore, we tend to style a slippery window with a selected period to figure the quantitative relation of effective MPCs to all or any received paths from the tip of the PDP on top of the detection threshold. If the quantitative relation is larger than the default, the present delay represents t_1 in (3). Here, we tend to advocate the employment of this credible PDP estimation methodology in future mm Wave channel modeling activities. Path loss models square measure usually sculptural as a perform of the 3D propagation distance, whereas those with fewer parameters, that indicate physical meanings and straightforward expressions, square measure desirable for application in future 5G mm Wave channel models. Here, we tend to summarize the 3 varieties of distance-dependent path loss models operational.

B.Additional large-scale path loss

The distance-dependent path loss models describe the received signal decay with propagation distance, whereas the presence of blockages (e.g., buildings, trees, and human bodies) results in further power attenuation. For O2I situations, the BEL provides a applied mathematics expression of the extra loss thanks to a terminal being within the building. Note that the log-normally distributed shadow attenuation related to buildings is completely different from the BEL, which might be thought-about as a random variation in received power at the alternative face of the building. Otherwise, penetration loss is outlined because the transmission loss through an artifact, that is calculated by the ability distinction between the transmitted signal outside the lit face and also the received signal outside the alternative face. This loss is used for assessing the impacts of artifact properties and structures on radio wave propagation, that may be a operate of in operation frequency and incident direction. For the QLoS path, the received signals blocked by humans and foliage include many copies of the carrying signal generated by optical phenomenon and scattering. Additionally, the characterization of auto penetration loss at the mm Wave bands has recently received much interest attributable to the event of intelligent transportation systems. Hence, the overall large-scale path loss models ought to consider the extra loss additional to the fundamental distance-dependent models.

C.BEL Model

The BEL determines the flexibility of the mm Wave radio system to supply continuous coverage. A projected BEL model in 3GPP TR 38.900 is given by [20]

$$LL_{BE} = L_{npi} - 10\sum_{i=1}^{N_{material}}\left(P_i 10^{\frac{L_{material}}{-10}}\right) + N\left(0, \sigma_p{}^2\right) \quad (2)$$

where L_{npi} represents the correction term accounting for the impact of the incidence angle on the BEL; P_i represents the proportion of *ith* materials and satisfies

$$\sum_{i=1}^{N_{Material}} P_i = 1; \qquad L_{material} = a_{material} + b_{Material} \quad (3)$$

f_c represents the penetration loss of the i^{th} material at *fc* (GHz); σp represents the standard deviation in the penetration loss; *N material* represents the number of materials and N (μ ,σ^2) represents the normal distribution, with a mean of μ and a variance of σ^2. Meanwhile, a log-frequency single-slope model is used to describe the penetration loss in mm Wave, which has a natural advantage when combined with the ABG path loss model.

D. Human, Foliage, and Car Blockages

Several double knife-edge optical phenomenon (DKED)-based models are developed to describe the characteristics of physique shadowing, like the changed DKED half-breed model, that assumes that a personality's blocker is delineate as a screen with four sides or associate degree infinitely vertical screen with 2 sides; a multiple-edge optical phenomenon model, with the additional general assumption of a geometrical model of the physique; and Vogler's multiple knife-edge model, that has over one person moving on the LoS path between the Texas and RX. The simulation results show sensible agreement with the measure leads to completely different human blockage eventualities, as well as human blockers moving on the LoS link and frontally or laterally crossing the LoS link. In made scattering environments, foliage or vegetation obstructions cause terribly giant foliage attenuation and larger angular unfold.

E. Small-scale channel models

The mm Wave propagation is sensitive to close objects, wherever the methods square measure sufficiently separated in time, space, and polarization. The interaction among the copies of the transmitted signal traveling on totally different methods, that square measure combined at the RX antenna

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in amplitude and part, causes speedy fluctuation within the signal strength over a short propagation distance or period.

Multipath attenuation provides natural blessings for extending the coverage of mm Wave systems in NLoS eventualities with the event of beam forming and beam combining techniques.

In made scattering environments, the larger rank of the channel matrix indicates the rise within the data rate. Thus, it's vital to model small-scale spatiotemporal channel characteristics, as well as the Rician K issue, Christian Johann Doppler shifts, time dispersion, angular dispersion, and their correlations. Measurement-based analyses reveal that mm Wave signals square measure received in finite clusters, that square measure outlined assets of MPCs with some constant directions and delays from specific close objects (also referred to as scatters).

F. LoS Probability Model

LoS propagation offers a reputable association in mmWave communications, which might be used for backhauling links among tiny cells and also the association between microwave and mm Wave BSs in HetNet combined with directional transmission. However, in NLoS scenarios, LoS propagation exhibits totally different propagation mechanisms, wherever reflections and diffractions cause difficulties in absolute propagation delay measurements and numerous angular dispersion characteristics. For users in LoS situations with shorter TX-RX separation distances, it's affordable to use widebeam antennas, whereas multibeam high-gain array antennas ar needed to boost and track multipaths in NLoS situations. A basic LoS likelihood model higher than half-dozen gigacycle per second follows associate degree exponential-like distribution as a operate of the 2nd distance d2D, i.e.

$$\begin{cases} 1, & d_{2D} \le d_1 \\ e^{-\left(\frac{d_{2D}-x_1}{\beta_1}\right)}, & d_1 < d_{2D} \le d_2 \\ \gamma e^{-\left(\frac{d_{2D}-x_1}{\beta_1}\right)}, & d_2 < d_{2D} \end{cases} \quad (4)$$

where modeling parameters square measure layout-related and frequency-independent. However, the model needs modification in densely buildup urban environments. In [9], recent advances in mmWave LoS chance models for UMi and UMa situations square measure reviewed, that have similar expressions however totally different breakpoint distances.

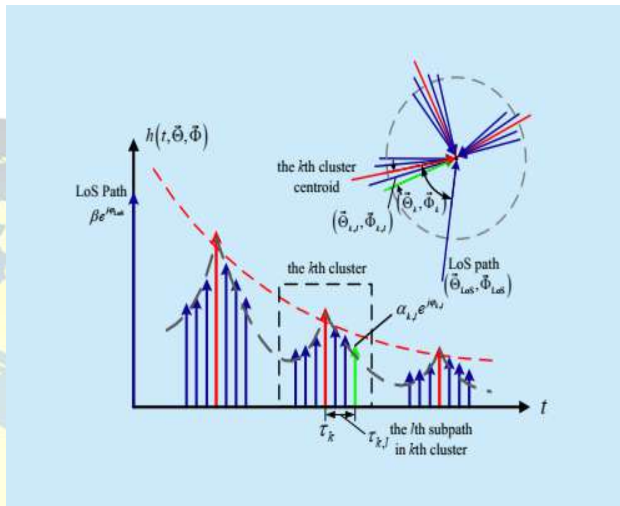

Figure 1. Cluster-level representation of the mmWave wideband channel in the time and angular domains

III. Performance Evaluation And Analyses

Understanding propagation characteristics is prime to mmWave system deployments. This section reviews many recent out of doors mmWave channel measure and modeling results in numerous out of doors eventualities, highlight the associated network preparation issues to change coverage. Examples embrace antenna configurations, transceiver sittings, and measure environments

A. Outdoor access

Three typical out of doors situations area unit taken into thought. In UMi, BSs area unit mounted below upper side levels of close buildings with smaller widths, indicating that seamless coverage are often complete below the O2I condition. In UMa, larger inter-site distances, with BS heights higher than twenty five m, area unit expected because of the made scattering environments. In RMa, directional transmission will catch up on the big attenuation caused by vegetation blockage, though this state of affairs

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has not been totally investigated within the 3GPP TR thirty eight.900 models [20]. Omnidirectional and directional CI path loss models in UMi and UMa area unit conferred, as delineate by the parameters in Table 1, where we tend to primarily specialize in the 2 most potential 5G mmWave bands (e.g., the twenty eight rate and thirty eight rate bands). For convenience, the activity configurations of the TX and RX heights, activity areas, and antenna scanning ranges also are given in Table one. the most conclusions from these studies area unit as follows: i) a general increase within the PLE versus frequency below a similar activity condition, ii) significantly lower PLEs and shadowing factors for LoS links over NLoS links, and iii) higher BS positions comparable to coverage scaling. additionally, the cases with PLEs smaller than a pair of solely seem for directional propagation once victimization slim beam width horn antennas scanned in 3D area to sight the strongest path.

TABLE I
TABLE I. LARGE-SCALE CHANNEL PARAMETERS IN PATH LOSS AND SHADOW FADING MODELS IN UMI AND UMA SCENARIOS

Area	Scen.	f	h_T	h_R	Range	TX	RX	PLE	σ_{CI}	R
	Measurementconditions							CI model		
	LoS	28/38	5	1.7	14-113	horn	horn	2.7/3.1	4.2/4.0	[3]
	NLoS	38	8/23/36	1.5	>200	horn	horn	3.3	12.3	
UMi Street Canyon	LoS	28	7/17	1.5	31-54	horn	Omni	2.1	3.5	[4]
	NLoS	28	7/17	1.5	61-186	horn	Omni	3.4	9.7	
	LoS	29	6.5	1.5	35-256	Omni	Omni	2.2	4.4	[6]
	NLoS	29	6.5	1.5	35-256	Omni	Omni	3.1	8.2	
UMi Downtown	NLoS	28	40	1.5	110-135	sector	Omni	4.1	7.1	[8]
UMa Downtow n	LoS	28	8/17	NA	55-207	sector	Omni	2.1	3.36	[7]
UMa Open Area	LoS	29	NA	NA	35-256	Omni	Omni	2.7	5.7	[6]
	NLoS	29	NA	NA	35-256	Omni	Omni	3.4	8.0	
UMa	LoS	29	NA	NA	35-256	Omni	Omni	2.9	21.0	[6]

Supported a lot of elaborate study of the beam area illustration of the channel parameters, it's efficient to use giant arrays with wider beams for user instrumentality (UE) on the brink of the BS and multiple slim beams for cell-edge users.

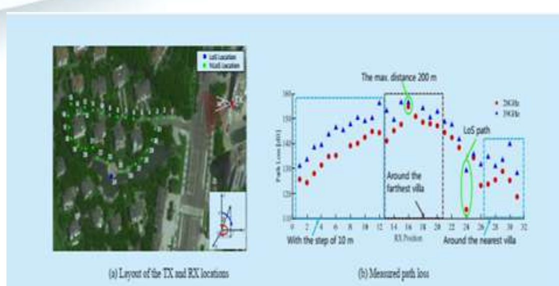

Figure 2. Channel measurements in a UMa modern business center and PAPs with different sector coverages in the LoS link.

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Figure 2 depicts the measured PAPs in the UMa modern business center using wide-beam antenna with two different pointing angles for sector coverage. The cooperation between adjacent sectors reduces the outage proba- bility of the dense mmWave networks. In the UMa residential area, the height of the BS is above 50 m, which is much higher than that of the surrounding buildings, indicating that the diffraction over the rooftops and corners of buildings increases the distance of NLoS links. As shown in Figs. 3 reflection from the ground is negligible, while the paths from the opposite building are reason- able for eliminating the blindness area (e.g., RX 1 and RX 5 to RX 36).

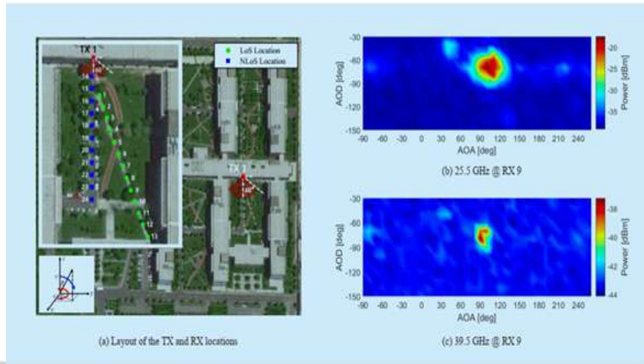

Figure 3. Channel measurement in a UMa residential area and time-spatial propagation analyses in coverage blind spots.

TABLE II.

STATISTICS OF THE COMPOSITE DELAY AND ANGULAR SPREAD FOR THE UMI AND UMA SCENARIOS

	Measurementcondition		Delayspread[$\log_{10}$([s])]				Angular Spread[$\log_{10}$([°])]			
Area	Scen.	f [GHz]	Min	Max	Mean	Std	Min	Max	Mean	Std
UMi Street canyon	LoS	25.5	-7.82	-7.08	-7.44	0.23	0.63	1.43	0.98	0.25
	LoS	39.5	-7.73	-7.03	-7.22	0.23	0.63	1.20	0.92	0.22
	NLoS	25.5	-7.41	-7.07	-7.19	0.13	1.04	1.80	1.47	0.26
UMa Modern business center	LoS	28	-7.42	-6.36	-6.73	0.26	1.45	2.04	1.84	0.20
	LoS	39	-7.42	-6.32	-6.81	0.33	0.73	2.05	1.77	0.30
	NLoS	28	-7.53	-6.77	-7.00	0.24	1.14	2.08	1.76	0.30
	NLoS	39	-7.63	-6.77	-7.28	0.23	0.69	2.12	1.71	0.34
UMa Residential area	Both	28	-7.67	-6.35	-6.87	0.29	1.06	2.21	1.84	0.27
	Both	39	-7.55	-6.35	-6.96	0.34	0.73	2.21	1.78	0.43
RMa Villas district	Both	28	-7.98	-6.77	-7.32	0.28	0.45	2.20	1.89	0.41
	Both	39	-7.79	-6.69	-7.38	0.27	1.20	2.22	1.97	0.29

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IV. CONCLUSION

LSAA-based 5G mmWave communications ar expected to produce users with Ultrahigh data rates, ultralow latency, and higher wireless coverage. An outline of the rising challenges and needs in mmWave ultra dense network deployments has been given. Supported the observations of recent mmWave channel models from varied normal bodies and activity activities, acceptable large-scale path loss models and small-scale cluster models of LSAA-based mmWave systems are given, severally. The channel activity leads to 2 5G candidate bands have shown that, victimization directional transmissions and high-gain antennas, mmWave systems will give stable connections and accomplish good ranges up to many meters. The mmWave transmission and downlink budgets are combined with the projected outside path loss models to optimize RF system configurations. What is more, it's clear that there's a requirement to adaptively choose huge MIMO transmission schemes supported the angular unfold characteristics.

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