African Journal of Engineering & Technology (AJET)
AJET 3 (2023) 1 http://doi.org:10.47959/AJET.2021.1.1.12

Research Article

Evaluation of Cell Coverage Percentage of Millimeter Waves Propagation for the 5th Generation Cellular System

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Received 14th June 2022
Accepted for publication 4 November 2022
Published 30th January 2023

Abstract

This paper evaluates the cell coverage percentages of millimeter waves for the 5th generation cellular system. First, a survey on the recent pioneering works and results for channel model characterizations and development for 5th generation systems were conducted, and then a theoretical formula for calculating the cell coverage area was developed. The cell coverage percentage was evaluated for the 28 GHz, 38 GHz, and 73 GHz propagation channel models. The obtained results reflected an increase in the path loss due to increased frequency and densification of the urbanization structure.

Keywords: 5th Generation cellular system; millimeter waves; cell coverage percentages; wireless channel propagation model.

1. Introduction

Since the deployment of the first generation cellular mobile communication systems four decades ago, the wireless communications industry has seen a great expansion and increase in terms of system capacity, coverage, application support, level of service, and quality of service [1-4]. The main factors determining the cellular system's network performance are capacity design and coverage design. The capacity design of the cellular network or network segment determines the maximum number of customers that can be served by the whole network or network segment at any given time [5, 6]. On the other hand, coverage planning, and design determine quality of service and the level of service provided by the network in any given area. A network with excellent coverage planning is going to have fewer dark areas (areas under deep shadowing) inside the system, which accordingly leads to fewer dropped

 https://doi.org/10.47959/AJET.2021.1.1.12

calls and connections. To improve the network coverage, an excellent understanding of signal propagation in the cellular system is required. There has been a lot of work proposed in the literature on large-scale signal propagation and channel characterization [6-10].These studies statistically determine the effects of signal attenuation due to path loss and shadowing as the distance between the transmitter and receiver increases in typical urban and suburban settings

2. Survey on the Propagation Channel Measurement for the 5th Generation Cellular System

To address the emerging bandwidth needs of the future internet of people and internet of things, the use of millimeter-wave at the 30 GHz-300 GHz band is proposed [11-14]. The available spectrum in this band is 200 times greater than the whole current cellular spectrum allocated to the wireless systems of today. This large spectrum clearly contributes to the overall system data rate **R**, which upper bounded by the capacity **C** relation[15] as shown in equation (1).

$$\mathbf{R} \leq \mathbf{C} = \mathbf{m}\left(\frac{\mathbf{W}}{\mathbf{n}}\right)\mathbf{log_2}\left(\mathbf{1} + \frac{\mathbf{S}}{\mathbf{I + N}}\right) \quad (1)$$

Where: **R** represents the cellular system's upper-bound data rate, **m** represents the system's spatial multiplexing gain factor, which increased with the use of multiple antennas [16, 17], **n** is the system load factor, which reduced with the increase in network densification. ***w*** Represents the total bandwidth or the system allocated spectrum and **S**, **N**, **I** represent the desired signal power, noise power and total interference power. The total system interference of the next generation wireless cellular system will be greatly reduced by making use of excellent and intelligent power control and channel and resource scheduling strategies.

Electromagnetic signal at the millimeter wave band tends to have reasonably small wave length, which enables the deployment of larger numbers of antennas which is called massive multiple input multiple output (massive MIMO) technology in a small area [18-20]. This feature also represents an additional surplus point in the system design according to the relation explained in equation (1).

Recently, several specialized research groups have been working on channel characterization and developing channel models at the millimeter wave band. These groups include: METIS2020, COST IC1004, ETSI mm Wave SIG, 5G mm-Wave Channel Model Alliance, MiWEBA, mm-Magic, and NYU WIRELESS [11, 21-25]. The developed empirical models (based on extensive channel measurement and statistical characterization on the millimeter wave), advocate that perfect channel path loss and shadowing parameter can be perfectly predicted. Thus, these models can be used for system design, prototyping and performance testing at this stage for the next generation system design. Also some talented results in this area shows that the deployment of intelligent self configuration algorithms can compensate the path loss and shadowing effect at high data rate [15].

The reported NYC channel models developed from the channel measurement data collected from the city centre of New York at 28 GHz, and 73 GHz and at UT at 38 GHz, showed a comparable pattern and characteristics [11]. These channel measurements and characterizations also point toward the fact that the smaller wavelengths introduce an increased sensitivity of the channel propagation models to the scale of the environment and show some frequency dependence of the path loss as well as an increased occurrence of signal blockage. Additionally, the penetration loss is highly dependent on the material and tends to increase with frequency. On the other hand, shadowing fading and angular spread parameters are larger, and the boundary between line-of- Sight (LOS) transmission and None-line-of-

Sight (NLOS) transmission depends not only on transmit antenna heights but also on the local communication environment (urbanization elements in the communication environment) [26]. The small-scale wireless fading characteristics of the channel such as delay spread and angular spread and the multipath richness is somewhat similar over the frequency range, which is encouraging result for enlarging the available on hand 3GPP models to the wider frequency range at the millimeter wave band[18, 24].

The measurements and channel modelling conducted by the NYU and UT research groups report that the none-line of sight channel at 28 GHz, 38 GHz and 73 GHz has a general path loss $\mathbf{P_L}$ relation of the form[11]

$$\mathbf{P_L = \alpha + 10\beta \log_{10}(d) + \xi[dB]} \quad (2)$$

With the parameter values shown in table (1). These results are reported in this work purposely to be used to evaluate cell coverage percentages in typical a cellular system as shown in section 3.

Table 1:Path loss models as reported in[11, 27]

Channel Propagation model	Model Parameter values		
	28 GHz	38 GHz	73 GHz
$\mathbf{P_L = \alpha + 10\beta \log_{10}(d) + \xi[dB]}$ $\mathbf{\xi \sim \mathbb{N}(0, \sigma^2)}$, **d in meters**	$\mathbf{\alpha = 72, \beta = 2.92, \sigma = 8.7dB}$	$\mathbf{\alpha = 64, \beta = 3.2, \sigma = 11.6dB}$	$\mathbf{\alpha = 82.7, \beta = 2.69, \sigma = 7.7dB}$

Recently, a lot of attention has been paid to the underused frequency spectrum in the millimeter wave range. This is because there isn't a lot of carrier bandwidth in the wireless communication system. The latest channel measurements and investigations confirm that typical wireless systems of today will work at these ranges of frequencies. This paper evaluates the cell coverage percentage at 28 GHz, 38 GHz, and 73 GHz. Understanding cell coverage percentages for these different bands is vital information for system designers and operators of future 5th generation cellular systems.

3. Materials and Method

In this section, we develop the formula for the coverage percentage which will be used in the simulation to evaluate cell coverage percentage at different frequencies. The concept of the cell coverage percentage is defined as the percentage of the cell area that has some received power $\mathbf{P(d)}$ greater than or equal to some predefined threshold value $\mathbf{P_{thr}}$. The derivation of cell radius inaccuracy developed in [28] is purposely reintroduced in this work to mathematically define the concept of cell coverage percentage.

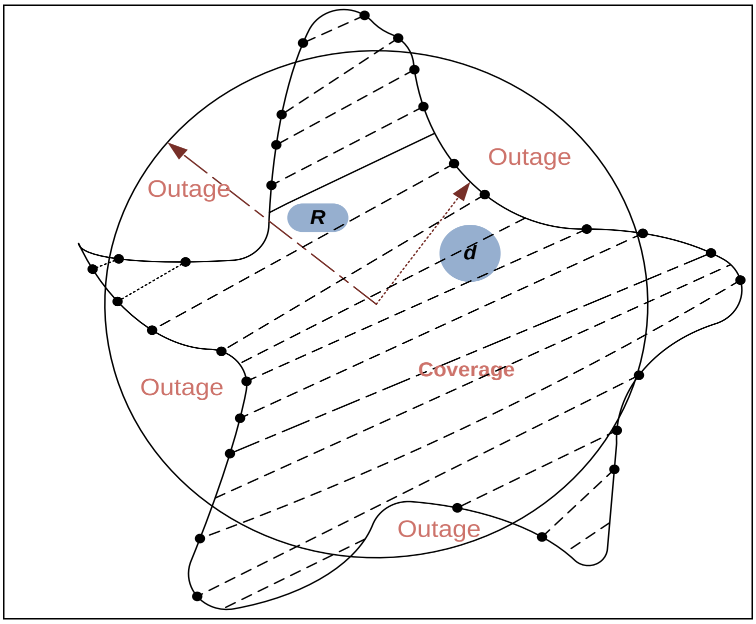

Figure 1: Illustration of cell coverage area and outage

For typical cellular system cell as shown in figure 1. We define the received power at some distance $\mathbf{P(d)}$

$$\mathbf{P(d) = P_t - \alpha - 10\beta log_{10}(d) + \xi} \quad (3)$$

Where: $\mathbf{P(d)}$ represent the received signal power at distance $\mathbf{d}$ from the base transmitter unit and $\boldsymbol{\xi}$ is a normally distributed random variable with variance$\boldsymbol{\sigma^2}$. From figure 1, the percentage of the covered area is the area over the contour of radius $\mathbf{d}$ where

$$\mathbf{P(P(d) \geq P_{thr}) = 1 - F\left(\frac{P_{thr} - P(d)}{\sigma}\right) = Q(\frac{P_{thr} - P(d)}{\sigma})} \quad (4)$$

And we can evaluate the coverage area percentage$\mathbf{cov}$ by integrate the indicator probability function of the form:

$$\mathbf{cov = \frac{1}{\pi R^2}\int_0^{2\pi}\int_0^R P(P(d) \geq P_{thr})\, rdrd\theta = \frac{2}{R^2}\int_0^R rQ(a + b\ln\frac{r}{r})dr} \quad (5)$$

By considering $\mathbf{a = \frac{P_{thr} - P(R)}{\sigma}}$, $\mathbf{b = \frac{10\beta log_{10}e}{\sigma}}$ and $\mathbf{R \geq r, d = r}$ the expression in (5) yields the flowing closed form solution given by:

$$\mathbf{cov = Q(a) + exp\left(\frac{2 - 2ab}{b^2}\right) Q(\frac{2 - ab}{b})} \quad (6)$$

Furthermore, mathematically we can define the cell outage probability **cell outage** as:

$$\mathbf{cell\ outage = 1 - cov} \quad (7)$$

Which intuitively define the percentage of the area inside the cell where the received power is less than the threshold value $\mathbf{P_{thr}}$

 https://doi.org/10.47959/AJET.2021.1.1.12

4. Results and Discussion

The channel models reported in Table 1. were evaluated and compared with the theoretical formula for wave propagation equation was used to evaluate the path loss as function of frequency and distance in idealized conductions (free space propagation environment).

$$\mathbf{PL(f,d)} = \mathbf{20log_{10}}(\sqrt{\mathbf{G_L}}\frac{\boldsymbol{\lambda}}{\mathbf{4\pi d}}) \quad (8)$$

Where $\boldsymbol{\lambda}$ is the transmitted signal wavelength, $\mathbf{d}$ is the distance between the transmitter and receiver and $\mathbf{G_L} = \mathbf{G_t G_r}$ is the total transmit and receive antenna gain.

Figure 2. shows the evaluation of the developed propagation models as given in Table 1 compared with the idealized path loss model for the free space channel. At 28 GHz, 38 GHz, and 73 GHz bands, there are an average of 30 dB differences between the free space channel and the urbanization channel. Thus, a typical system designer should consider the free space as a minimum Path loss value plus 30 dB typical urbanization effect for outdoor propagation in addition to an average of 20 dB loss for indoor systems and 1.4 dB rain loss in special cases.

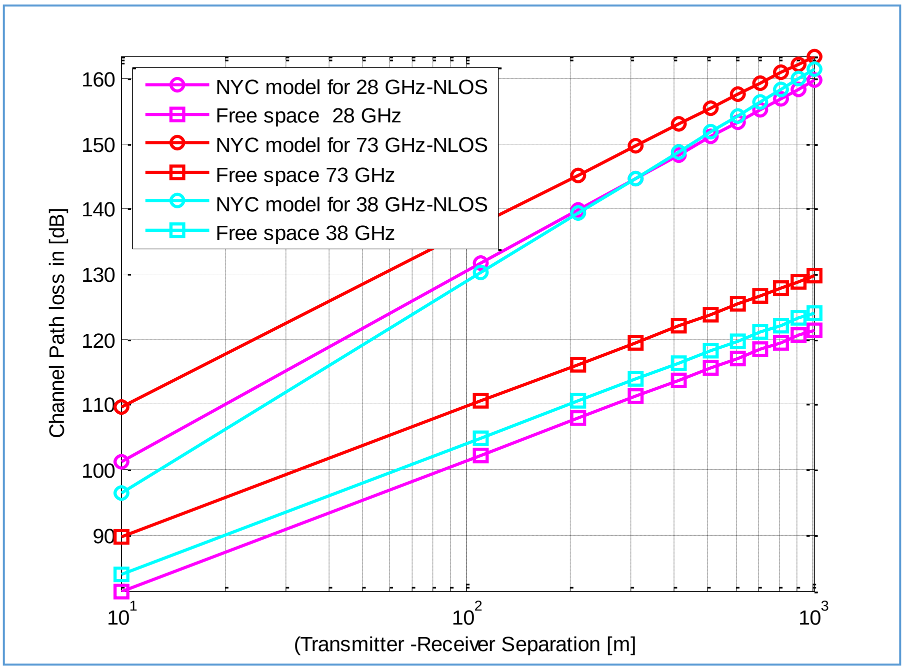

Figure 2: Path loss model evaluation at 28 GHz, 38 GHz and 73 GHz Vs the idealized free space model

Figure 3. shows the evaluation of cell coverage percentage area at 28 GHz, 38 GHz and 73 GHz Vs the distance between the transmitter and receiver, taking into account $\mathbf{P_{thr}} = \mathbf{-110dB}$ and $\mathbf{P_t} = \mathbf{35dB}$. As shown Figure 3, there is a frequency dependency on the coverage area percentage, which can be reasoned back to the dependency of the shadowing and path loss exponent parameters on the frequency range. Given that the measurements on 28 GHz and 73 GHz are both conducted using similar conditions at NYU (propagation environment, transmit antenna height, receive antenna height, types of antenna, and antenna gain), it shown that at 200 m we have 74% cell coverage at 73 GHz while having 88% cell coverage at 28 GHz. This result clearly point out the frequency dependency of cell coverage percentage

http://doi.org:10.47959/AJET.2021.1.1.12

on the frequency band on millimeter waves range and suggest that the system designer should consider this variation when consider design handover and system adaption algorithms (adaptation in data rate, modulation, coding, power control, interference control …etc).

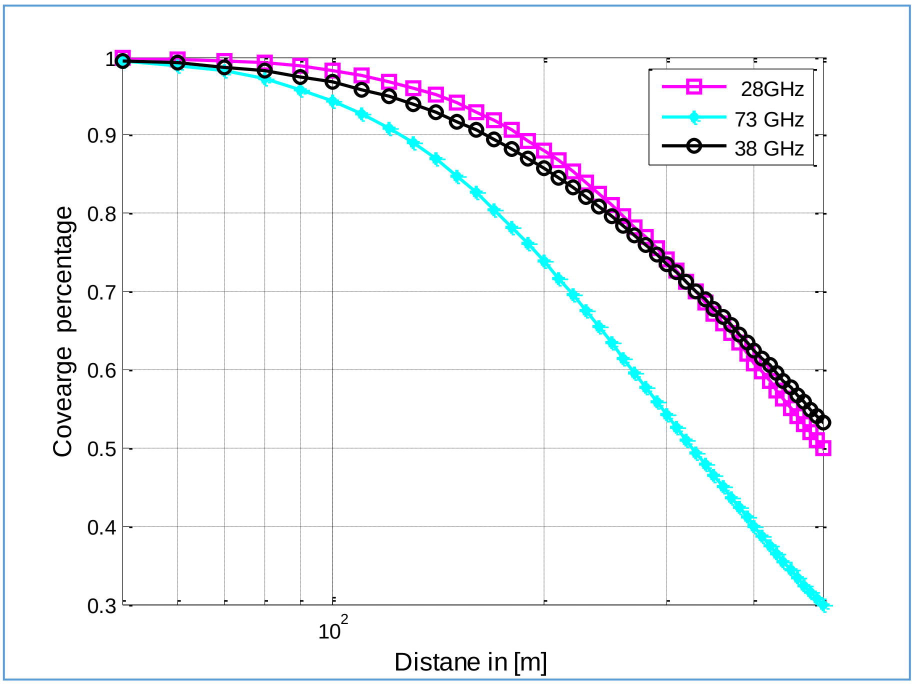

Figure 3: Cell coverage area percentage evaluation at 28 GHz, 38 GHz and 73 GHz

Figure 4, shows the cell outage evaluation at the 28 GHz, 38 GHz and 73 GHz frequency vs the distance between the transmitter and the receiver taking into account $\mathbf{P_{thr} = -110dB}$ and $\mathbf{P_t = 35dB}$. As shown Figure 4, there is a frequency dependency on the outage probability, which can be articulate to the dependency of the shadowing and path loss exponent parameters on frequency range. It shown that at 200 m we have 26% outage at 73 GHz while having 12% outage at 28 GHz. This result suggests that the engineering optimization should consider this variation.

https://doi.org/10.47959/AJET.2021.1.1.12

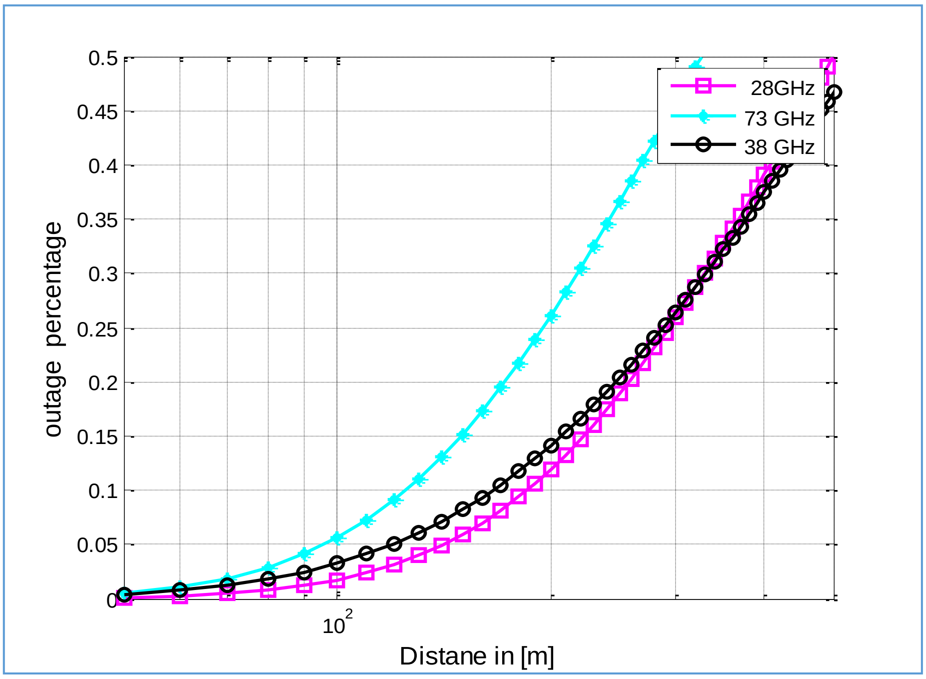

Figure 4 : Cell outage evaluation at 28 GHz, 38 GHz and 73 GHz

5. Conclusion

In this work, we compared the developed empirical path loss models at millimeter waves with the basic idealized reference model for free space channel. We found that there is a 30 dB difference between the free space channel model and the developed urbanization channel at 28 GHz, 38 GHz and 73 GHz. Furthermore, we evaluate and compare the cell coverage percentage for the developed models. It has been shown that at 200 m, we have 74% cell coverage at 73 GHz while having 88% cell coverage at 28 GHz. Both results suggest that there is a large range of channel variation in the millimeter wave band due to path loss and shadowing in a typical urban area. This variation should be considered in the system adaptation and interference control algorithm design for the future 5th generation cellular systems.

6. References

[1] C. Cox, *An Introduction to LTE, LTE-advanced, SAE, VoLTE and 4G Mobile Communications*, Second Edition ed.: John Wiley & Sons, Ltd, 2014. https://onlinelibrary.wiley.com/doi/book/10.1002/9781118818046

[2] J. Parikh and A. Basu, "LTE Advanced: The 4G Mobile Broadband Technology," *International Journal of Computer Applications*, vol. 13, pp. 17-21, January 2011. https://doi.org/10.5120/1776-2449

[3] E. Dahlman, S. Parkvall, and J. Sköld, *4G LTE/LTE-Advanced for Mobile Broadband*, 1 ed.: Academic Press of Elsevier, 2011. https://doi.org/10.1016/C2010-0-66332-2

[4] E. Saeid and W. Osman, "5th Generation Cellular Communication Systems Enabling Technologies and Challenges," *International Journal of Innovative Technical and Applied Sciences*, vol. 1, pp. 19-25, 2017.

[5] G. L. Stüber, *Principles of Mobile Communication*, Second ed.: Kluwer Academic Publishers, 2002. https://doi.org/10.1007/978-3-319-55615-4

[6] N. Shabbir, M. T. Sadiq, H. Kashif, and R. Ullah, "Comparison of radio propagation models for long term evolution (LTE) network," *International Journal of Next-Generation Networks*, vol. 3, p. 2741, sept 2011. https://DOI:10.5121/ijngn.2011.3303

[7] H. M., "Empirical formula for propagation loss in land mobile radio services," *IEEE Transactions onVehicular Technology*, vol. 29, pp. 317 - 325, Aug 1980. https://**DOI:** 10.1109/T-VT.1980.23859

[8] C. A. 231, "Digital mobile radio towards future generation systems, final report," European Communities,1999.

[9] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, A. A. Julius, and R. Bianchi, "An empirically based path loss model for wireless channels in suburban environments," *EEE Journal on Selected Areas in Communications*, vol. 17, pp. 1205-1211, July 1999. https://**DOI:** 10.1109/49.778178

[10] G. Wölfle, R. Wahl, P. Wertz, P. Wildbolz, and F. Landstorfe, "Dominant Path Prediction Model for Indoor Scenarios," presented at the German Microwave Conference, Ulm, Germany, 2005. http://www.eurasip.org/Proceedings/Ext/IST05/papers/242.pdf

[11] M. R. Akdeniz, Yuanpeng Liu, M. K., Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation," *IEEE Journal on Selected Areas in Communications*, vol. 32, pp. 1164-1179, June 2014. https:// **DOI:** 10.1109/JSAC.2014.2328154

[12] M. Peter, R. J. Weiler, B. s. Göktepe, W. Keusgen, and K. Sakaguchi, "Channel Measurement and Modeling for 5G Urban Microcellular Scenarios," *Sensors*, vol. 16, pp. 1-13, June 2016. **https://doi.org/10.3390/s16081330**

[13] Y. L. Yong Niu, D. Jin, L. S. , and A. V. Vasilakos, "A Survey of Millimeter Wave (mmWave) Communications for 5G: Opportunities and Challenges," 2015. https://doi.org/10.1007/s11276-015-0942-z

[14] E. Saeid, V. Jeoti, and B. B. Samir, "Precoding for Multiuser MIMO," in *Developments in Wireless Network Prototyping, Design and Deployment: Future Generations"*, M. A. Matin, Ed., ed USA: IGI Global, 2012. https://DOI: 10.4018/978-1-4666-1797-1

[15] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Teja, Sukhavasi, C. Patel, and S. Geirhofer. (2014, Feb) Network Densification: The Dominant Theme for Wireless Evolution into 5G. *IEEE Communications Magazine*. 82-89. . https://doi.org10.1109/MCOM.2014.6736747

[16] E. Saeid, V. Jeoti, and B. B. Samir, "On MU-MIMO Precoding Techniques for WiMAX," in *Selected Topics in WiMAX*, D. G. Pasolini, Ed., ed: InTech, 2013. https:// DOI: 10.5772/56034

[17] A. Saad, M. Ismail, and N. Misran, "Capacity of MIMO channels at different antenna configurations," *Journal of Applied Sciences*, vol. 8, pp. 4595-4602, December 2008. https:// **DOI:** 10.3923/jas.2008.4595.4602

[18] S. Wu, "Massive MIMO Channel Modelling for 5G Wireless Communication Systems," PhD, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, 2015. http://hdl.handle.net/10399/2889

[19] H. Q. Ngo, "Massive MIMO: Fundamentals and System Designs," PhD, Department of Electrical Engineering, Linköping University,, Linköping 2015. http:// DOI: 10.3384/lic.diva-112780

[20] E. G. Larsson, ISY, O. Edfors, F. Tufvesson, and T. L. Marzetta. (2014, Feb) Massive MIMO for Next Generation Wireless Systems. *IEEE Communications Magazine*. 186-196. 5. http://**DOI:** 10.1109/MCOM.2014.6736761

[21] M.-I. E. project. (2017, 27 Jan). EU project METIS-II Available: https://metis-ii.5g-ppp.eu/

[22] ETSI. (2017, 27 Jan). *Millimetre Wave Transmission*. Available: http://www.etsi.org/technologies-clusters/technologies/millimetre-wave-transmission

[23] NIST, "5G Millimeter Wave Channel Model Alliance," N. C. T. Laboratory, Ed., ed. U.S: NIST Wireless Networks Division,, 2015. https://www.nist.gov/system/files/documents/ctl/5G-Millimeter-Wave-Channel-Model-AllianceV2.pdf

[24] ICT FP7 MiWEBA project #608637, 'Deliverabl, "D5.1 channel modeling and charactrization Public deliverable, Intel editor," June 2014.

[25] S. Salous, "COST IC1004 White Paper on Channel Measurements and Modeling for 5G Networks in the Frequency Bands above 6 GHz," C. IC1004, Ed., ed, 2016. https://www.researchgate.net/publication/283447443_COST_IC1004_White_Paper_on_5G

[26] M. K. Samimi and T. S. Rappaport, "3-D Statistical Channel Model for Millimeter-Wave Outdoor Mobile Broadband Communications," presented at the IEEE International Conference on Communications, 2015. http://**DOI:** 10.1109/ICC.2015.7248689

[27] T. S. RAPPAPORT, S. SUN, R. MAYZUS, H. ZHAO, Y. AZAR, K. WANG, G. N. WONG, J. K. SCHULZ, M. SAMIMI, and F. GUTIERREZ, "Millimeter Wave Mobile Communications for 5G Cellular: " *IEEE Access Practical innovation*, vol. 1, pp. 335-349, 2013. http://doi.org /10.1109/ACCESS.2013.2260813

[28] P. BERNARDIN, M. YEE, and T. ELLIS, "Cell Radius Inaccuracy: A New Measure of Coverage Reliability," *IEEE Transactions on Vehicular Technology*, vol. 47, pp. 1215-1226, 1998. http://**DOI:** 10.1109/25.728510