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HUMIDITY EFFECT TO 5G PERFORMANCES UNDER PALEMBANG CHANNEL MODEL AT 28 GHZ

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Abstract -- *The telecommunication has a tremendous improvement in terms of data rates and bandwidth requiring sufficient frequency allocation and wideband spectrum availability. The millimeter-wave frequency band is one of the solutions to these requirements. However, communications in this band are facing new challenges on the climate effect to the channel propagation. In this paper, we propose a 5G channel model considering the effect of humidity based on the characteristic of the natural environment of Palembang city. The channel model is represented by power levels and delay called a Power Delay Profile (PDP and is derived based on a series of computer simulations using parameters of nature in Palembang. The 5G channel model is important to further derive the outage performance to be used as the theoretical performance of 5G in Palembang since the Shannon Channel Capacity Theorem is involved in the derivation. We conduct a series of computer simulations to evaluate the validity of the proposed channel model and its characteristics. We found that humidity affects the performances, where high humidity makes the performances of outage and BER slightly worse, although the effect may be ignored for some applications. The results of this paper are expected to be the references for the development and implementation of 5G Networks especially at the mm-Wave band in Palembang.*

Keywords: *Channel Model; PDP; Outage Performance; BER; FER*

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INTRODUCTION

Some factors motivate the study and development on wireless communication for the future, such as the increasing need for the internet data, the faster data rate, and the solution for the bandwidth limitations [1, 2, 3]. The fifth telecommunication generation (5G) network technology of the future is expected to provide a data rate of 1 Gbps at lower, mid, and high band, where 28 GHz is part of the high band for 5G. This situation indicates an increase in speed to be faster than the previous mobile communications technology [4]. The increase in data rate is currently in line with the rapid growth of communication devices and the increase of data traffic [5, 6, 7].

The network technology of 5G requires a wider frequency band than that of the previous wireless technology. The frequencies of < 6 GHz have been used by other technological applications and are already too dense [8, 9, 10]. The millimeter-wave band answers some challenges related to the requirements of broadband frequency usage. Millimeter waves still have sufficient bandwidth for the upcoming wireless technology implementation [11], where .28 GHz is one of the frequency candidates for the implementation of 5G network technology [12, 13, 14].

The utilization of millimeter-wave frequency is susceptible to the influence of the atmosphere and climate [15] [16]. One of the climate factors that are susceptible to influence is the air humidity factor [17]. The results of the study conducted by the US Department of Commerce [18] revealed that air humidity causes the slowing of the spread of radio waves. The use of higher frequencies results in shorter wavelengths and high attenuation propagation causing lower signal reception.

The channel model is probably depending on certain area parameters. The Channel Model is a combination of the received signal level obtained from the channel propagation results with the reception delay time (PDP) [19]. In this paper, we use real-field parameters as the input for instantaneous PDP generated by NYUSIM Wireless. This software was developed based on real measurements in the field using millimeter-wave frequencies performed under various outdoor conditions [20]. Each region has different atmospheric and climatic conditions from those of other regions, so they have different channel models that need to be developed independently to get the best network performances [21] [22]. It is necessary to know that the channel model of an area can be used as a reference to minimize data transmission errors and to optimize network performances.

The theoretical performance of communications can be obtained either by mathematical derivation or by making computer simulations to obtain the outage performance. The outage performance is a curve expressing the probability of a system being in outage because the channel capacity C is dropping under the channel coding rate R, which is expressed in mathematics as

$$P_{\{outage\}} = \Pr(R > C)$$

Anwar and Matsumoto [23] evaluated channel model simulations with real measurements in the real field and found similar performance trends, where the Outage Probability is derived by using the Shannon Capacity Theorem approach. Anwar, *et al*. [24] [25] use and implemented Outage Performance using the Shannon Capacity Theorem approach. The simulations using a 5G BPSK block system with CP-OFDM were also conducted to verify the performance results to get the performance value of FER and BER [26].

This study considers the humidity effect in the Palembang region. The reason is the fact that the city of Palembang can provide representation Sumatera, while most of the regions in Indonesia are low-lying areas, especially the regions outside of Java. The humidity levels are being compared was the humidity value at maximum conditions (*H-max*) and minimum conditions (*H-min*). The objective of this study is to evaluate the effects of humidity on the channel model and its effect on the performances of the channel model at the 28 GHz mm-Wave frequency in the Palembang region.

METHOD

This paper compares the performance of the channel model, considering two different humidity levels in Palembang. Based on the input parameters of the real-field environment, we generate instantaneous PDP using New York University (NYU) Wireless Simulator. We generate more than 1000 instantaneous *PDPs* generated for each level of humidity. 1000 Instantaneous PDPs are then processed to be represented by 1 representative PDP called as the final channel model of 5G using technique of 90% cumulative distribution function as well as techniques provided by the 3GPP TR 38,810 standard.

The proposed channel model is then used to derive the outage performance, such that the model can also be evaluated by using the Frame Error Rate (FER) performances via a practical transmission scheme like the cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) with binary shift keying (BPSK) modulation.

Palembang Humidity Profile

This subsection discusses the humidity levels, where two different humidity values, i.e., the maximum and minimum values are considered. The value is fluctuating in Palembang for 10 year-period, as shown in Figure 1. The climate data were obtained from the Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) for disclosing the characteristics of the Palembang region.

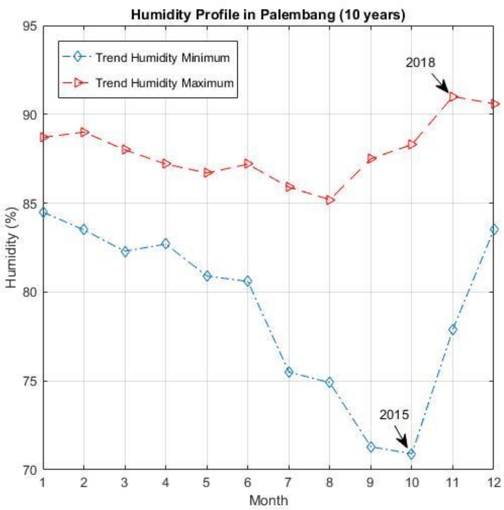


Figure 1. Humidity profile in Palembang for 10 years.

Figure 1 shows the maximum and minimum humidity trends within ten years. The maximum humidity value (*H-max*)of 91% occurred in November 201, while the minimum humidity value (*H-min*) of 70.9% occurred in October 2015. Indonesia is a tropical region, of which the humidity fluctuations are stable, while air humidity in coastal areas and guinea savannah is fluctuating [27]. The two humidity values were used as input for simulation to get the channel model and the two performances were compared to disclose the effect of humidity on the channel model.

In addition to air humidity, other climatic characteristics that were used as software input were barometric pressure, temperature, and rain rate obtained from BMKG of Palembang City. The characteristic of the climate in Palembang is listed in Table 1.

Table 1. Climate Characteristic in Palembang

Parameters	Value(s)
Air pressure	1009.947 mbar
Temperature	27.5ºC
Rain Rate	50.194

NYU Wireless Simulator software also required several data channels as input, namely:

- Frequency = 28 GHz
- RF Bandwidth = 400 MHz
- Scenario =U-Mi (Urban Micro)
- Environment = NLOS (Not Line Of Sight)
- T-R Separation Distance = 200 m
- TX-Power = 30 dBm
- Polarization = Circular

Instantaneous PDP

Instantaneous PDP is the result obtained from NYU Wireless Simulator Software. Instant PDP is a sample channel model that is received by the receiver at a certain distance from the transmitter. The PDP data used in this study were Omnidirectional PDP, in which it was assumed that the transmitter used an antenna with an omnidirectional radiation pattern that radiated in all directions. Instant PDP received had a different value because of the effects of large scale fading and small scale fading.

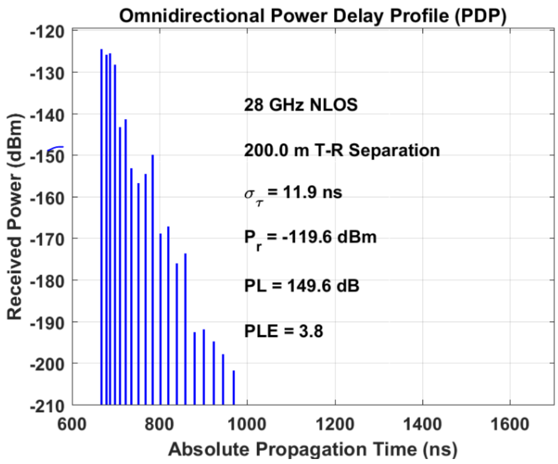


Figure 2. An example of instantaneous PDP resulted from NYU Wireless Simulator.

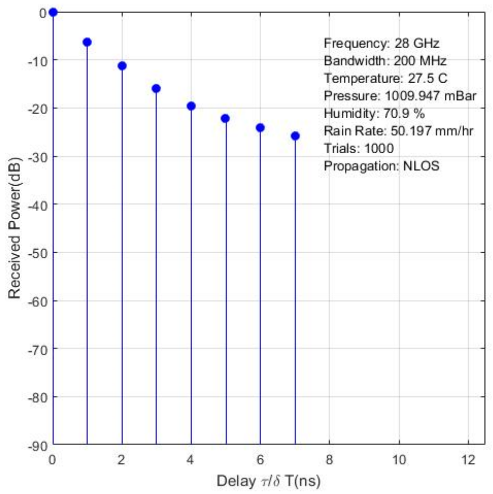
Figure 2 is an instantaneous PDP generated by the NYU Wireless simulator with a frequency of 28 GHz and air humidity (*H-min*) of 70.9%. The distance between the transceiver and the receiver was 200 m, which resulted in a propagation delay of 11.9 ns with Path Loss Propagation of 149.6 dB. There were as many as 1000 samples of Instant PDP to represent the real conditions of Palembang so that a more accurate PDP representative as a channel model representative was obtained.

PDP Representative

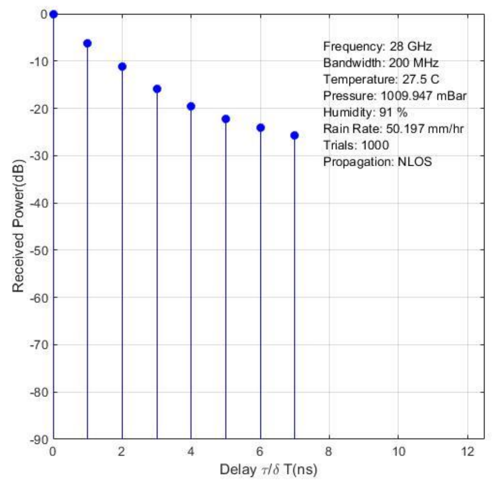
PDP Representative is a representative of several Instant PDP that shows a channel model. The method of representative taking was done by simplifying the grid delay with a distance of 1 / BW. The value of power on each grid delay in the Instant PDP is rounded to the nearest equidistant delay grid. In the equidistant delay grid that has the smallest power value, it is simplified to a value of 0. The sum of the received power for each equidistant delay grid refers to the recommendation of 3GPP [28]. A number of path PDP are adjusted with the number of CP Length, which calculated from FFT size. In this research, it uses FFT 128 with CP duration 0.57 and OFDM Sym. Duration of 8.33. The PDP values are calculated using a CDF with 90 percentiles. The final step is to get the PDP Representative by giving the smallest threshold value of -140 dBm in which only the power above the threshold is used. The threshold is assumed to be the minimum acceptable power value.

PDP Representative is produced under two conditions, namely the minimum humidity conditions (*H-min*) and the maximum humidity conditions (*H-max*).

In Figure 3, the PDP representative under the *H-min* condition has eight paths (a), while the PDP Representative under the *H-max* condition has eight paths (b). The number of paths normalization depends on CP duration, OFDM Symbol, and FFT Size. This value-based on numerology that is used. In [29] simulated humidity using 3 GHz frequency and produced 13 PDP Representative paths. The different number of trajectories was caused by different working frequencies, numerology, bandwidths, and also different regional characteristics conditions.



(a)



(b)

Figure 3. The proposed channel model obtained from representative PDP with (a) minimum humidity and (b) maximum humidity.

RESULTS AND DISCUSSIONS

At this stage, the channel model performance was evaluated using three parameters, namely Outage Performance, Frame Error Rate (FER), and Bit Error Rate (BER). The Outage Performance used the Shannon Capacity Theorem calculation method. The Outage Performance was verified using a transmission block simulation on the CP-OFDM system with FER and BER parameters. This simulation used Matlab software as shown in Figure 4.

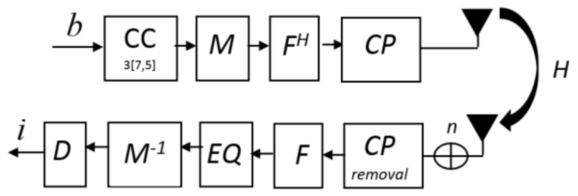


Figure 4. CP-OFDM structure to evaluate the performance of the 5G channel model in Palembang.

Outage Performance

The outage performance expresses the probability of outage for every different rate with the signal-to-noise power ratio (SNR). The outage condition is a condition when the channel capacity drops below the channel coding rates. This condition causes the bits sent to be lost or error in the process of sending information bits. Outage probability is a comparison between the outage condition and the total transmission of information bits. Outage probability is calculated using the Shannon Capacity described as [30]

$$C \approx \frac{B}{2N}\sum_{n=1}^{N}\log_2\left(1+2\cdot\left|\psi_n\right|^2\cdot m\cdot R\cdot\frac{N}{N+Q}\cdot\frac{Eb}{No}\right) \tag{1}$$

In which N is block length, B is the bandwidth (MHz), ψ is the eigenvalue representing the equivalent link quality, m is modulation index, R is a coding rate, Eb/No is the energy bit per noise power ratio, and Q is the length of CP.

This paper simulated two scenarios with two different humidity conditions. The System model simulated was with R = 1 and R = 1/2. Since the simulation used the frequency of 28 GHz, it was included in neurology-3 with CP duration of 0.57 µs and OFDM symbol duration of 8.33 µs. The modulation used in this study was BPSK modulation with the m-index equal to m = 1. The block length used was 128 with Equivalent CP. It was calculated on 2 Humidity conditions, namely the Humidity maximum of 90% and the Humidity minimum of 60.9%. The results of the Outage performance are presented in Figure 5.

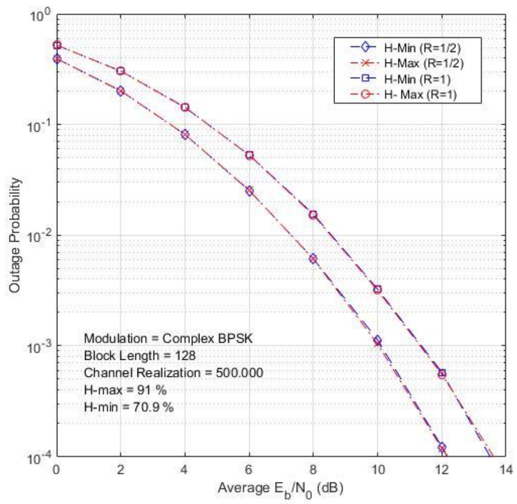


Figure 5. Outage performances of the 5G channel model with different humidity levels

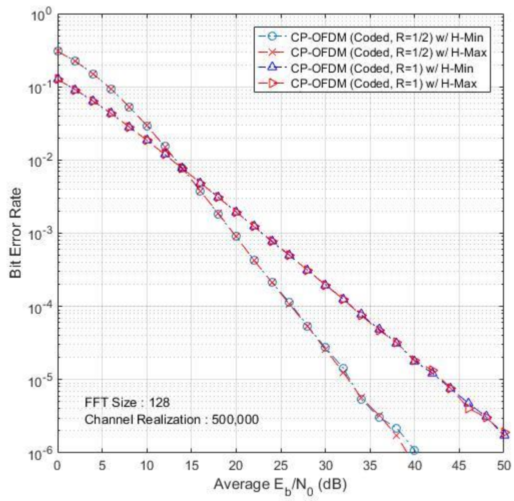


Figure 6. BER performances of CP-OFDM with different humidity conditions

Figure 5 shows the results of the outage performance at R = 1 and R = ½. In the use of R = 1, when the Eb / No condition is 10 dB, the Outage probability at the *H-max* condition is 3.98 x 10^{-3}, whereas the *H-min* condition is 3.19 x 10^{-3}. The difference between the Outage probability value is only 7.92 x 10^{-4}. Likewise, when using the coding rate = ½, when the Eb / No condition is 10 dB, the Outage probability at the *H-max* condition is 1.26 x 10^{-3}, whereas the *H-min* condition is 1.13 x 10^{-3}. The difference in value between the two conditions is 1.34 x 10^{-4}.

The Outage probability values constantly indicate that the *H-max* condition has a greater Outage probability value on all Eb / No values. Based on the results of this analysis, it can be concluded that the effect of humidity may be ignored since it does not have a significant influence on the channel model and its performance.

BER Performance under Palembang channel model

Outage Performance is evaluated using BER parameters generated by simulations using the CP-OFDM communication system block with Complex BPSK for modulation. The BER value is also shown in 2 different conditions, namely the conditions of *H-min* and *H-max* with conditions without Coding (R = 1) and using Coding (R = 1/2).

Figure 6 shows the result of BER performance under the condition of Coded (R = 1/2) and Uncoded (R = 1). In the condition of CP-OFDM with Coded (R = 1/2), when the Eb / No condition is 10 dB, BER performance at the *H-max* condition is 3.096 x 10^{-2}, whereas the *H-min* condition is 2.93 x 10^{-2}. The difference between the Outage probability value is only 1.66 x 10^{-3}. Likewise, in the condition of CP-OFDM Complex BPSK with Uncoded (R = 1), when the Eb / No condition is 10 dB, BER performance at the *H-max* condition is 1.89 x 10^{-2}, whereas the *H-min* condition is 1.85 x 10^{-2}. The difference in value between the two conditions is 4.14 x 10^{-4}.

Based on the results, it shows that the *H-max* condition has a greater BER performance or worse than *H-min* condition and constantly on every Eb / No value. The difference in BER value between *H-max* and *H-min* is below 10^{-3}. It concludes that the humidity can be ignored since it does not have a significant influence on BER performance.

FER Performance under Palembang channel model

The simulation used the CP-OFDM system to produce FER performance values using the PDP Representative results as the system input. The simulation also used two conditions, namely condition without coding (R = 1) and condition using coding (R = 1/2), in which each condition was simulated in the *H-max* and *H-min* conditions.

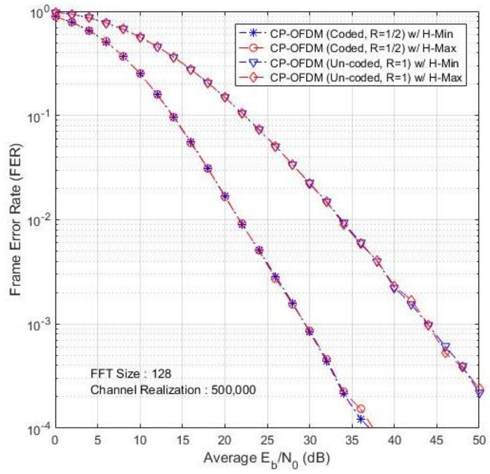


Figure 7. FER performances of CP-OFDM with different humidity conditions

Figure 7 shows the result of FER performance under the condition of Coded (R = 1/2) and Uncoded (R = 1). In the condition of CP-OFDM with Coded (R = 1/2), when the Eb / No condition is 10 dB, FER performance at the *H-max* condition is 2.268 x 10^{-1}, whereas the *H-min* condition is 2.52 x 10^{-1}. The difference between the Outage probability value is only 4.814 x 10^{-3}. It shows that the *H-max* condition has a greater FER performance than the *H-min* condition. But, it has different results for Eb / No more than 14. When the Eb / No condition is 20 dB, FER performance at the *H-max* condition is 1.75 x 10^{-2}, whereas the *H-min* condition is 1.728 x 10^{-2}. *H-max* condition has a less FER performance than the *H-min* condition.

In the condition of CP-OFDM Complex BPSK with Uncoded (R = 1), when the Eb / No condition is 10 dB, BER performance at the *H-max* condition is 5.594 x 10^{-1}, whereas the *H-min* condition is 5.632 x 10^{-1}. The difference in value between the two conditions is 4.814 x 10^{-3}, but it is not constantly in every Eb / No.

Based on the results, it shows that FER performance not inline with humidity, and the different FER performance value is below only 10^{-3}. It indicates that the humidity does not have a significant impact on FER performance.

Comparison between Bandung Reference Channel Model and Palembang Channel Model

The results of the channel models in Palembang are compared with the reference channel models in Bandung [29]. The Bandung channel model represents the characteristics of the highland region, while the Palembang channel model represents the lowland region, as listed in Table 2.

Table 2. Path of the representative PDP comparison.

Path	PLM_28_Hmin (dBm)	BDG_3.3_Hmin (dBm)	Delay
1	0	0	0
2	-6.225709997	-7.272397425	1
3	-11.2718182	-9.645932337	2
4	-15.9564956	-14.34220044	3
5	-19.50501296	-19.60945153	4
6	-22.20707657	-20.75650924	5
7	-24.12302637	-24.43368052	6
8	-25.75943488	-24.12721151	7
9	-	-	8

Representative PDP for both models has the same number of paths, which are eight paths. For the path profile above, it can be seen that at the same delay, the received signal power in the Palembang channel model is lower than that of the Bandung channel model, although at path delay 1 and 4, it has a higher received signal.

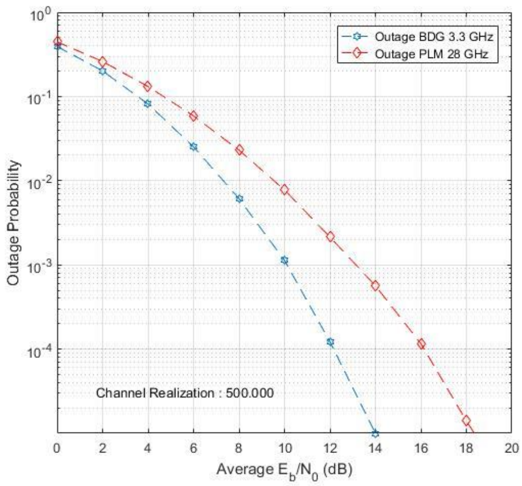


Figure 8. Outage Performance Comparison

Figure 8 shows a comparison of the performance of the channel model presented in the Outage Performance between the Bandung Channel Model Reference and the Palembang Channel Model. Bandung Channel Model has better performance than that of Palembang. The situation is because the Bandung Channel Model Reference still uses the frequency of 3.3 GHz, whereas the working frequency of the Palembang Channel Model uses 28 GHz. In addition to this, different climatic factors of the two regions also affect the resulting channel conditions, in which the Bandung Channel Model Reference has the characteristics of the highlands and mountainous regions, whereas the Palembang Channel Model has the characteristics of the lowlands.

CONCLUSION

This paper has evaluated the humidity effect of 5G performances under the Palembang channel model at the operating frequency of 28 GHz. We have conducted a series of computer simulations with the input parameters of real-field natural parameters in Palembang. We have proposed a 5G channel model obtained from the PDP Representative, of which the number of paths at H-max and H-min is 8. The results show that the difference in 5G performance with high and low humidity in Palembang is not significant. The higher humidity levels make the performance of Outage and BER performances slightly worse, where the effect may be ignored especially for some insensitive applications. This paper has also made a performance comparison to the 5G channel in Bandung. The difference in land characteristics is found in the impact to channel model and performance due to the different climate.

REFERENCE

[1] G. R. MacCartney, Junhong Zhang, Shuai Nie, and T. S. Rappaport, “Path Loss Models for 5G Millimeter Wave Propagation Channels in Urban Microcells,” *2013 IEEE Global Communications Conference (GLOBECOM)*, Atlanta, GA, 2013, pp. 3948-3953.DOI: 10.1109/GLOCOM.2013.6831690

[2] T. S. Rappaport et al., “Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!,” *IEEE Access,* vol. 1, pp. 335-349. DOI: *10.1109/ ACCESS.2013.2260813*

[3] S. Singh and M. Chawla, “A review on Millimeter Wave Communication and Effects on 5G System,” *International Advanced Research Journal in Science, Engineering and Technology,* vol. 4, no. 7, pp. 28-33, July 2017. DOI: 10.17148/IARJSET.2017.4705

[4] T. S. Rappaport et al., “Wideband Millimeter-Wave Propagation Measurement and Channel Models for Future Wireless Communication System Design,” *IEEE Transactions on Communication*, vol. 63, no. 9, pp. 3029-3056, September 2015. DOI: 10.1109/TCOMM.2015.2434384

[5] S. Sun et al.,” Propagation Path Loss Models for 5G Urban Micro- and Macro-Cellular Scenarios,” In *IEEE 83rd Vehicular Technology Conference (VTC2016-Spring)*, Nanjing, China, 2016, pp. 1-6. DOI: 10.1109/VTCSpring.2016.7504435

[6] Z. F. Nossire, N. Gupta, L. Almazaydeh, and X. Xiong, “New Empirical Path Loss Model for 28 GHz and 38 GHz Millimeter Wave in Indoor Urban under Various Conditions,” *Applied Sciences*, vol. 8, no. 11, pp: 1-14, November 2018. DOI: 10.3390/app8112122

[7] G. R. MacCartney and T. S. Rappaport, “Rural Macrocell Path Loss Models for Millimeter-Wave Wireless Communications,” *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 7, pp. 1663-1677, July 2917. DOI: 10.1109/JSAC.2017.2699359

[8] G. R. MacCartney et al.,” Millimeter-Wave Wireless Communications: New Results for Rural Connectivity,” Presented in *the 5th Workshop on All Things Cellular: Operations, Applications and Challenges*, New York, October 2016, pp. 31-36. DOI: 10.1145/2980055.2987353

[9] S. Sun et al., “Investigation of Prediction Accuracy, Sensitivity and Parameter Stability of Large-Scale Propagation Path Loss Models for 5G Wireless Communications,” *IEEE Transaction on Vehicular Technology*, vol. 65, no. 5, pp. 2843-2860, May 2016. DOI: 10.1109/TVT.2016.2543139

[10] T. S. Rappaport, S. Shu, and M. Mansoor, “Investigation and Comparison of 3GPP and NYUSIM Channel Models for 5G Wireless Communications,” Presented at *IEEE 86th Vehicular Technology Conference (VTC Fall)*, Toronto, Canada, September 2017. DOI: 10.1109/VTCFall.2017.8287877

[11] S. Nie, G. R. MacCartney, S. Shun and T. S. Rappaport, “28 GHz and 73 GHz Signal Outage Study for Millimeter Wave Cellular and Backhaul Communications,” *2014 IEEE International Conference on Communication (ICC),* Sydney, NSW, 2014, pp. 4856-4861. DOI: 10.1109/ICC.2014.6884089

[12] Y. Azar et al., “28 GHz Propagation Measurements for Outdoor Cellular Communications Using Steerable Beam Antennas in New York City,” Presented in *2013 IEEE International Conference on Communications (ICC)*, Budapest, 2013, pp. 5143-5147. DOI: 10.1109/ICC.2013.6655399

[13] M. K. Samimi and T. S. Rappaport, “Statistical Channel Model with Multi-Frequency and Arbitrary Antenna Beam-width for Millimeter-Wave Outdoor Communications,” Presented in *2015 IEEE Global Communication Conference, Exhibition & Industry Forum (GLOBECOM) Workshop*, San Diego, CA, 2015, pp. 1-7. DOI: 10.1109/GLOCOMW.2015.7414164

[14] M. K. Samimi and T. S. Rappaport, “3-D millimeter-wave statistical channel model for 5G wireless system design,” *IEEE*

Transaction on Microwave Theory and Techniques, vol. 64, no. 7, pp. 2207-2225, July 2016. DOI: 10.1109/TMTT. 2016.2574851

[15] S. J. Dudzinsky, "Atmospheric Effects on Terrestrial Millimeter-Wave Communications," Presented *at 4th European Microwave Conference,* Montreux, Switzerland, 1974, pp. 197-201. DOI: 10.1109/EUMA.1974.332040

[16] ITU-R, "Attenuation by atmospheric gases," *Recommendation ITU-R P.676-11*. 2019.

[17] J. Luomala and I. Hakala, "Effects of Temperature and Humidity on Radio Signal Strength in Outdoor Wireless Sensor Networks, "Presented in *2015 Federated Conference on Computer Science and Information Systems (FedCSIS)*, Lodz, 2015, pp. 1247-1255. DOI: 10.15439/2015F241

[18] H. J. Liebe, K. C. Allen, G. R. Hand, R. H. Espeland, and E. J. Violette, *Millimeter-Wave Propagation in Most Air: Model versus Path Data*. U.S. Department of Commerce, Malcolm Bridge, US.1985.

[19] T. Jost, W. Wang, M. Walter, "A Geometry-Based Channel Model to Simulate Averaged-Power-Delay-Profile. *IEEE Transactions on Antennas and Propagation,* vol. 65, no. 9, pp. 4925-4930, September 2017. DOI: 10.1109/TAP.2017.2722864

[20] S. Sun, G. R. MacCartney, and T. S. Rappaport, "A novel millimeter-wave channel simulator and applications for 5G wireless communications," Presented at *2017 IEEE Int. Conf. on Comm (ICC),* Paris, 2017, pp. 1–7. DOI: 10.1109/ICC.2017.7996792

[21] E. M. Alfaroby, N. M. Adriansyah, and K. Anwar, "Study on Channel Model for Indonesia 5G Networks," *The 2018 International Conference on Signals and Systems (ICSigSys)*. Bali, Indonesia, 2018, pp. 125-130. DOI: 10.1109/ICSIGSYS.2018.8372650

[22] A. A. Budalal, M. R. Islam, M. H. Habaebi and T. A. Rahman, "Millimeter Wave Channel Modeling – Present Development and Challenges in Tropical Areas," In *2018 7th International Conference on Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, Malaysia, 2018, pp. 23-28. DOI: 10.1109/ICCCE.2018.8539324

[23] K. Anwar, T. Matsumoto, T. (2013, March) Field Measurement Data-based Performance Evaluation for Slepian Wolf Relaying Systems. Paper presented at *IEICE General Conference 2013*, Gifu, Japan, 2013, pp. s33-s34.

[24] K. Anwar and T. Matsumoto, "Accumulator-assisted distributed turbo codes for relay systems exploiting source-relay correlation," IEEE *Communications Letters,* vol. 16, no. 7, 1114–1117, July 2012. DOI: 10.1109/LCOMM.2012.050112.120629

[25] Anwar, K and T. Matsumoto, "Low-complexity Time-concatenated Turbo Equalization for Block Transmission: Part 1 - The Concept," *Wireless Personal Communications*, vol. 67, no. 4, pp. 761–781, March 2012. DOI: 10.1007/s11277-012-0563-0

[26] X. He, X. Zhou, K. Anwar and T. Matsumoto, "Estimation of Observation Error Probability in Wireless Sensor Networks, "*IEEE Communication Letters*," vol. 17, no. 6, pp. 1073-1076, June 2013. DOI: 10.1109/LCOMM.2013.042313.130361

[27] 3GPP TR 38.810 v16.0.0, *Technical Specification Group Radio Access Network*, Release 16, 2018-2019.

[28] K. D. Adedayo, "Statistical analysis of the effect of relative humidity and temperature on radio refractivity over Nigeria using satellite data," *African Journal of Environmental Science and Technology*, vol. 10, no. 7, pp. 221-229, July 2016. DOI: 10.5897/AJEST2016.2095

[29] R. D. Wahyuningrum and K. Anwar, "Outage Performances of 5G Channel Model Considering Humidity Effects," Presented in *2nd Symposium of Future Telecommunication and Technologies (SOFTT)*, 2018.

[30] C. Schlegel and L. Perez, L. *Trellis and Turbo Coding*. John Wiley & Sons, 2013.