



# Indonesia 5G Channel Model Under Foliage Effect

## *Model Kanal 5G Indonesia dengan Pengaruh Dedaunan*

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### ABSTRAK

Kinerja sistem komunikasi ditentukan oleh kanal, sehingga pengetahuan model kanal suatu negara menjadi penting. Makalah ini mengusulkan (i) model kanal telekomunikasi generasi ke-lima (5G) Indonesia dan (ii) kerangka kerja untuk menghitung model kanal di lokasi lain di Indonesia. Model kanal dalam makalah ini diciptakan untuk bandwidth 40 MHz pada frekuensi 3,3 GHz dengan parameter riil lapangan. Makalah ini juga menampilkan teori outage performance yang diperoleh dari model kanal 5G Indonesia, kemudian memvalidasi teori outage performance tersebut menggunakan block error rate (BLER) pada cyclic-prefix orthogonal frequency division multiplexing (CP-OFDM) numerology zero dengan complex binary phase shift keying (C-BPSK) standard 5G dan Polar coding. Semua hasil numerik diperoleh dari simulasi komputer menggunakan parameter riil lapangan untuk alam Indonesia. Makalah ini menemukan bahwa kanal 5G Indonesia dapat dimodelkan power delay profile (PDP) dengan 17 path untuk kanal tanpa efek dedaunan dan kurang dari 15 path untuk kanal dengan dedaunan. Hasil tersebut menunjukkan bahwa redaman daun menyebabkan penurunan kinerja, yang ditandai dengan penurunan jumlah path dan memburuknya outage performance. Kurva outage performance yang diperoleh dari model kanal 5G Indonesia diharapkan menjadi referensi untuk implementasi sistem 5G di Indonesia dalam pengembangan 5G di Indonesia secara optimal, terutama untuk lokasi yang memiliki dedaunan lebat.

### ABSTRACT

The performance of communications is determined by the channel, therefore knowledge of channel model of a country is important. This paper proposes (i) the fifth telecommunication generation (5G) Indonesia channel model and (ii) a framework to derive the channel model of any locations in Indonesia. We consider operating frequency of 3.3 GHz with bandwidth of 40 MHz with real-field parameters of several cities in Indonesia. We also present a theoretical outage performance evaluated for the proposed Indonesia 5G channel model validated by block error rate (BLER) performances of cyclic-prefix orthogonal frequency division multiplexing (CP-OFDM) numerology zero with 5G complex binary phase shift keying (C-BPSK) and Polar coding scheme. Sub-optimal Polar codes are used in this research, where better performances are expected in the future. We found that the Indonesia 5G channel model has 17 paths for the case of without foliage effect and has less than 15 paths for the case of with foliage effect. The results show that foliage attenuation causes performance degradations indicated by smaller number of paths and worse theoretical outage performances. The obtained outage performances from the proposed Indonesia 5G channel model in this paper are expected to be a reference for 5G implementations in Indonesia.

Keywords:

5G

Model Kanal

Efek Dedaunan

## 1. Introduction

### 1.1 Background

Mobile data traffic is expected to increase exponentially with the increasing number of wireless applications and users supported by the latest advanced wireless technologies. The continual demand for

mobile data traffic in wireless systems has led the emergence of the fifth generation mobile communication New Radio (5G NR) (Ericsson, 2011). The objective of 5G NR is to support the different use cases of mobile communication systems characterized from International Telecommunication Union (ITU) triangle, i.e., (i) enhanced mobile broadband (eMBB), (ii) massive machine type communication (MMTC), and (iii) ultra-reliable low latency communication (URLLC) (ITU-R, 2015). The performances of 5G NR are depending on the propagation channel. Therefore, channel models are important to predict the realistic and high-quality radio propagation to design an optimum system, including Indonesia. With a high accurate channel state information (CSI), parameters at transmitter and receiver can be set optimally to be suitable with environment in Indonesia such that the high quality and efficient radio transmission are achieved (Alfaroby et al., 2018).

A channel can be represented by a power delay profiles (PDP) as a signal power received with precise delay and receive power observations such that the signals can be mapped using time vs power mapping. There are several existing and on-going researches worldwide targeting on the 5G channel measurement and modelling, e.g., European telecommunication standards institute (ETSI) mmWaveSIG (ETSI, 2015), mobile and wireless communication enablers for twenty-twenty (2020) information society (METIS) 202 (Nurmela, V. et al., 2015), millimetre-wave evolution for backhaul and access (MiWEBA) (Inter Corporation, 2011), 5G mm-Wave channel model alliance (NIST, 2016), New York University (NYU) wireless (Sun, S. et al., 2017), and millimetre-wave based mobile radio access network for fifth generation integrated communications (mmMagic) (mmMagic, 2017). Each model has their own characteristic, benefit, and strengths depending on where the channels were developed.

Foliage is a common aspect in suburban or urban outdoor mobile communication environments that affects to the quality of 5G NR system propagation in Indonesia. Since Indonesia is a tropical country having several types of foliage, understanding and calculating the foliage effect to the propagation channel is vital for future 5G NR communication and implementation in Indonesia. This research focuses on foliage effect to the Indonesia 5G channel model based on the green space percentage in several cities in Indonesia.

Study on foliage effect on the attenuation for the propagation channel has been widely developed around the world. The effect of foliage attenuation to the propagation channels in mango and oil plantation using frequency of 0.4 – 7.2 GHz is measured and compared to the ITU-R, Weissberger, COST235, and Fitted ITU-R model (Ndzil, D. et al., 2012). Comparison of foliage attenuation between simulation and empirical models, e.g., ITU-R, Weissberger, and FITU-R are evaluated in (Rahim, H. et al., 2015). Foliage attenuation effect on 73 GHz outdoor wideband is evaluated using a channel sounder in (Rappaport, T. S., 2015). Research about Indonesia channel model is presented in (Alfaroby et al., 2018), where foliage attenuation is not considered. More complete channel models have been proposed in (Christy, E., et al., 2018) for 5G channel model taken from Telkom University campus considering foliage depth based on the real environment parameters.

This paper tries to solve the problem above by proposing (i) Indonesia 5G channel model under the foliage effect and (ii) a framework to calculate the channel model based on real-field parameters in a specific location. Compared to (Christy, E., et al., 2018), this paper considers different research method and input. Real environment parameter of the several cities in Indonesia are used to increase the accuracy of the Indonesia 5G channel model results. Foliage effects are also categorized into level of 20%, 40%, 60%, and 80%, depending on the real condition of several cities in Indonesia. In this paper paper, we provide the channel model that is suitable to parameters of several cities in Indonesia. The outage performances of Indonesia 5G channel model under foliage effect are also presented and expected to be good references for 5G system implementations in Indonesia such that the optimal performances of 5G system implementation in Indonesia are achieved.

## 1.2 Problem Formulation

Implementation of 5G in Indonesia without knowing the channel model may cause high inefficiency either in terms of power or spectrum efficiency. An optimal design is required, since channel model will be one of the most important solution. However, since channel model may be different location-by-location, a framework of channel model calculation is required. When the channel model is obtained, many performances can be predicted as well as the optimal parameter settings for the infrastructure.

## 1.3 Objective and Contributions

The objective of this paper is to obtain the representative PDP of Indonesia 5G channel model under the foliage effect. The contributions of this paper are summarized as follows:

1. The proposed Indonesia 5G channel model under foliage effect and its performance evaluations in terms of outage and bit-error-rate (BER) performances.
2. The proposed framework to calculate the channel model based on real-field parameters of any locations in Indonesia.

The rest of this paper is organized as follows. Section 2 explains the basic concepts utilized in the derivation of the Indonesia 5G channel model. Section 3 describes the system model and the proposed framework. Section 4 presents the result and analysis. Finally, Section 5 concludes this paper with some concluding remarks.

## 2. Basic Concepts

### 2.1. Wireless Channels

A mobile device signal transmitted through a wireless channel will suffers random fluctuations in time because of signal reflection and attenuation between transmitter and receiver. Wireless channel model is needed to make an optimum design of wireless system implementation. The wireless channel can be categorized based on the bandwidth used into frequency selective fading channel and non-selective or “flat” fading channels. If the coherence channel bandwidth  $B_c$  is smaller than the transmission bandwidth  $B$ , we have frequency selective fading channel. Thus, we need an equalizer or orthogonal frequency division multiplexing (OFDM) to process the received signal with minimum inter-symbol interferences (ISI). On the other hand, if the coherence channel bandwidth  $B_c$  is larger than the transmission bandwidth  $B$ , we have frequency-flat fading channel (Goldsmith, A., 2005). ISI does not occur in frequency-flat fading channel, however, the diversity is also not achieved.

#### 2.1.1. Narrowband Channels

The communication using transmission bandwidth  $B$  within the coherence bandwidth  $B_c$  is referred to as narrowband communications. Narrowband channels are formulated when there is only one received signal at the receiver side. Many application that need long-range and low-power tend to use narrowband transmission because it has lower noise bandwidth, better sensitivity, and also higher range.

#### 2.1.2. Broadband Channels

A channel with transmission bandwidth  $B$  exceeding the coherence bandwidth  $B_c$  is referred to as broadband channel. The utilization of wide bandwidth causes the effect of multipath fading indicated by fact

that there are more than one received signals at the receiver side at a time instant. Applications requiring high data-rate tend to use broadband transmission leading to a result that the channels have a high capacity (Jiao, Z., 2013).

## 2.2. Power Delay Profile

Power delay profile (PDP), also called as the the multipath intensity profile, is defined as the auto-correlation  $A_c(\tau)$  expressed as (Goldsmith, A., 2005)

$$\Delta t = 0 : A_c(\tau) \triangleq A_c(\tau, 0). \dots\dots\dots 1)$$

where  $\tau$  is a propagation delay.

### 2.2.1. Mean Excess Delay

Mean excess delay  $\mu T_m$  is a representation of the substantial delay weighted proportional to the received signal power from entire delay in a PDP. Mean excess delay is expressed as (Goldsmith, A., 2005)

$$\mu T_m = \frac{\sum_{k=0}^K A_c(\tau_k) \cdot \tau_k}{\sum_{k=0}^K A_c(\tau_k)}, \dots\dots\dots 2)$$

where  $A_c(\tau_k)$  is a signal power received in time  $\tau_k$ . In mean excess delay, high multipath components contribute more to delay spread rather than weak components.

### 2.2.2. Root Mean Square Delay

Root mean square (RMS)  $\sigma T_m$  delay spread is a standard deviation of mean excess delay weighted proportionally to the received signal power expressed as (Goldsmith, A., 2005)

$$\sigma T_m = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}, \dots\dots\dots 3)$$

where  $\overline{\tau^2}$  is expressed as

$$\overline{\tau^2} = \frac{\sum_{k=0}^K A_c(\tau_k) \cdot \tau_k^2}{\sum_{k=0}^K A_c(\tau_k)}. \dots\dots\dots 4)$$

## 2.3. Channel Capacity and Outage Performance

The capacity of the channel  $C$  is a maximum mutual information between the transmitted and received messages, where the probability of error close to zero if the channel coding rate  $R$  is below  $C$ . While outage probability  $P_{out}$  is a probability when the capacity  $C$  is dropped under the coding rate  $R$  (He, X., 2013)

$$P_{out} = P_r(R > C). \dots\dots\dots 5)$$

Transmission failure happened because it violates the Shannon coding theorem, where the inequality  $R < C$  should be satisfied.



#### 2.4.4. Coding Rate

Coding rate  $R$  is the ratio between the message and encoded message. As an example, code rate  $\frac{m}{n}$  shows that for every  $m$  bits of message, the encoder generates a total  $n$  bits of encoded message, with  $n - m$  redundant bits. As the number of coding rate  $R$  is increased close to one, bit error rate (BER) is worse but the spectrum efficiency is increases. When the coding rate  $R$  decreases close to zero, BER performance is better but the spectrum efficiency is decreases.

#### 2.4.5. Polar Codes

Polar codes are invented by Erdal Arikan using a channel polarization concepts (Arikan, E., 2009). Channel polarization is a technique that construct  $N$  polarized channels (also called as bit-channel) out of  $N$  similar independent copies of channels. Polar codes transmit only through selected good bit-channel, this selection is called as Polar code construction.

#### 2.4.6. Convolutional Codes

Convolutional code is one of channel coding scheme which is simple and use widely in wireless communication systems. A hard-decision Viterbi decoding is used to keep the simplicity in both simulation and analysis. The performance of convolutional codes will be compared to Polar codes on this research.

#### 2.4.7. 5G Binary Phase Shift Keying Modulation

The 5G modulation mapper takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols as output. 5G binary phase shift keying (BPSK) produces real and imaginary value symbol rather than just produce real-value symbol on its predecessor. In case of 5G complex BPSK modulation, bit  $b(i)$  are mapped to complex-valued modulation symbol  $x$  according to (3GPP, 2017) as

$$x = \frac{1}{\sqrt{2}} [(1 - 2b(i)) + j(1 - 2b(i))]\dots\dots\dots(7)$$

#### 2.5. Foliage Attenuation

Foliage attenuation is one of the key impairments in 5G propagation channels. Foliage attenuation is affected by foliage depth, tree types, frequency, leaf size, foliage thickness, leaf density, trunks, humidity, branch, path length through foliage, and also height of the tree compared to the antenna heights. There are several foliage attenuation calculation and model, i.e., Weissberger model, international telecommunication union-radiocommunication (ITU-R), and Fitted ITU-R. We consider ITU-R model in this research, because ITU-R foliage model estimates the diffracted components from top, ground, and around of the vegetation.

#### 2.6. New York University Wireless Simulator

New York University (NYU) wireless simulator is an open source for 5G channel model simulator software generating a realistic spatial and temporal wideband channel impulse response, which is suitable in 3GPP and standard bodies simulations. NYU wireless simulator has a wide range frequency of 0.5 – 100 GHz and bandwidth of 0 – 800 MHz.

### 3. System Model and The Proposed Framework

#### 3.1. System Model

This simulation considers frequency  $F_c$  of 3.3 GHz and bandwidth  $B$  of 40 MHz based on OFDM numerology zero and the regulation from the ministry of communication and informatics of Indonesia about broadband wireless access in Indonesia (KEMKOMINFO, 2016). We consider omnidirectional antenna in transmitter and receiver to generate the PDP from a real-field environments in Indonesia. We consider the distance between transmitter and receiver of 50, 100, 150, and 200 m. The maximum distance between transmitter and receiver are based on the maximum coverage radius of 5G systems in urban macro area. Moreover, the foliage attenuation are calculated using ITU-R foliage attenuation model with the tree depths are 20%, 40%, 60%, and 80% of transmitter and receiver distance. This percentage are expected to represents several cities in Indonesia which have different number of foliage. Metropolitan cities tend to have a small percentage of foliage in the city, while the non-metropolitan cities tend to have a high percentage of foliage in the city.

#### 3.2. The Proposed Framework

We propose a framework to obtain Indonesia 5G channel model and analyze the foliage effect to the Indonesia 5G channel model which is consist of three steps. First, we need to generate instantaneous PDP from NYU wireless simulator using real-field parameters of several cities in Indonesia. Second, we derive a representative PDP from obtained instantaneous PDP. Third, we calculate the channel capacity and draw the outage probability from the channel capacity. We need to simulate PDP with foliage and without foliage effect then compared the result to observe the foliage effect to the Indonesia 5G channel. The outage performance from this research is expected to become a benchmark for 5G system implementation in Indonesia.

##### 3.2.1 Instantaneous PDP Calculation

Instantaneous PDP for Indonesia 5G channel are generated by NYU wireless simulator using a real-field environments of several cities in Indonesia. Real-field environments parameters of several cities in Indonesia are needed to represents the environment in Indonesia.

Table 2. Environments of several cities in Indonesia.

City	Temperature (°C)	Rain Rate (mm/hr)	Barometric Pressure (mbar)	Humidity (%)	Green Space Percentage (%)
Jakarta	32.76	105.30	1009.76	59.15	3.13 – 11.26
Manado	28.69	339.36	1009.08	78.46	80.08
Bandar Lampung	29.07	332.40	1009.78	81.00	56.00
Bandung	31.15	104.19	1009.90	68.53	11.43
Denpasar	28.92	65.64	1009.99	77.76	38.03
Makassar	30.38	190.78	1009.27	70.69	6.71
Jayapura	27.46	560.10	1008.92	83.92	11.31
Palu	28.76	589.86	1009.88	85.38	29.48
Semarang	31.69	186.04	1009.82	68.38	15.69
Average	29.88	274.85	1009.60	74.81	

Source : ( www.worldweatheronline.com, 2017-2018)

Table 2 shows the real-field parameters of several cities in Indonesia which is used in this research. The data are obtained and averaged from May 2017 until May 2018. We consider ITU-R foliage attenuation calculation as a foliage attenuation model for simulation since it is applicable to a variety of vegetation types for various path geometries and suitable for calculating the attenuation of signals passing through vegetation. ITU-R foliage model covering frequency between 200 MHz to 95 GHz and distance  $d$  smaller than 400 m. The ITU-R foliage model is expressed as (ITU-R, 2016)

$$L_{ITU-R} \text{ (dB)} = 0.2 \cdot F_c^{0.3} \cdot d^{0.6}, \dots\dots\dots 8)$$

where  $F_c$  is the frequency in MHz and  $d$  is the tree depth in meter.

### 3.2.2. Representative PDP Calculation

Instantaneous PDP are then used to calculate the representative PDP based on the following steps:

- a) Instantaneous PDP ( $PDP_i$ ) are converted from dB to numeric, where  $i$  is an index number of PDP.  $i = \{1, 2, \dots, K\}$ , with total trial number of PDP are represented by  $K$ .
- b)  $PDP_i$  are then combined for every grouping index  $\alpha$  in timeslot  $\tau$  and placed into timeslot  $l$  without changing/scaling the delay. Grouping index  $\alpha = 1/B_o$  are considered, where  $B_o$  represent the operating bandwidth and  $l = \{1, 2, \dots, L\}$ , with  $L$  is a number of timeslot  $\tau$  on  $PDP_i$  divided by  $\alpha$ .

$$\tau_{(l-1)\alpha+1}^{PDP_i} = \frac{1}{\alpha} \sum_{n=(l-1)\alpha+1}^{l\alpha} \tau_n^{PDP_i} \dots\dots\dots 9)$$

- c) Each  $\tau_{(l-1)\alpha+1}$  are then combined from all  $PDP_i$  to get the CDF results.
- d) From the CDF results, 90<sup>th</sup> CDF percentile of each  $\tau_{(l-1)\alpha+1}$  are taken from all  $PDP_i$  and consider it as a representative PDP.
- e) Put the -150 dB threshold to the  $\tau_{(l-1)\alpha+1}$  from all representative PDP. The value of -150 dB is assumed to the received signal strength of 5G networks.

### 3.2.3. Capacity and Outage Performance Calculation

The capacity of the channel  $C$  is a maximum mutual information of the transmitted and received messages where the probability of error close to zero if the channel coding rate  $R$  is below  $C$ . The basic equation of channel capacity theorem is Shannon-Hartley theorem, expressed as (Shannon, C. E., 1948)

$$C = B \log_2(1 + \gamma) \text{ bits/s}, \dots\dots\dots 10)$$

where  $C$  is a channel capacity on the Additive White Gaussian Noise (AWGN),  $B$  is the channel bandwidth in Hertz, and signal to noise ratio is denoted by  $\gamma$ . The ... is also referred as a capacity for single-path or narrowband channel. Otherwise, for multi-path or broadband channel, the expected capacity is expressed as

$$C \approx \frac{B}{N} \cdot \sum_{n=1}^N \log_2(1 + (|\psi_n|^2 \cdot \gamma)), \dots\dots\dots 11)$$



where  $N$  is a block-length. The symbol  $\psi_n$  denotes the Eigen-value of parallel channel obtained from PDP and described as

$$\psi = \text{diag} |\mathbf{F} \cdot \mathbf{H}_c \cdot \mathbf{F}^H|, \dots\dots\dots 12)$$

where  $\mathbf{F}$  is a fast Fourier Transform (FFT) matrix,  $\mathbf{H}_c$  is an equivalent matrix representing the channel matrix at the receiver after the CP removal, and  $\mathbf{F}^H$  is an inverse fast Fourier transform (IFFT). SNR  $\gamma$  can be calculated as

$$\gamma = \frac{E_b}{N_0} \cdot m \cdot R \cdot \frac{N}{N+Q}, \dots\dots\dots 13)$$

where  $m$  is a modulation index,  $R$  is a channel coding rate, and the symbol  $Q$  denotes the cyclic prefix length. By considering OFDM numerology number zero (Vihril, J. et al., 2016), CP length  $Q$  can be calculated as

$$Q = \frac{4.69 \mu s}{66.77 \mu s} \cdot N_{FFT}, \dots\dots\dots 14)$$

where  $N_{FFT}$  is an FFT size.

This research tend to use  $\frac{E_b}{N_0}$  rather than  $\gamma$  in channel capacity calculation, and expressed as

$$C \approx \frac{B}{N} \cdot \sum_{n=1}^N \log_2 \left( 1 + \left( m \cdot R \cdot |\psi_n|^2 \cdot \frac{E_b}{N_0} \cdot m \cdot R \cdot \frac{N}{N+Q} \right) \right) \dots\dots\dots 15)$$

We conduct a 500.000 trial to calculate the channel capacity in  $R = 1$  and  $R = 1/2$ . The outage probability  $P_{out}$  is a probability when channel capacity  $C$  is dropped under channel coding  $R$ , expressed as

$$P_{out} = P_r(R > C) \dots\dots\dots 16)$$

### 3.3. Indonesia 5G Channel Model Validation

Since OFDM system will be used in 5G NR systems, the outage performance results will be tested and validated using cyclic-prefix orthogonal frequency division multiplexing (CP-OFDM) systems. Figure 1 shows the CP-OFDM structure with numerology zero, 5G NR complex BPSK, and Polar codes used in this research to validate the outage performance of Indonesia 5G channel. Polar codes used in this paper are sub-optimal and can be optimized further.

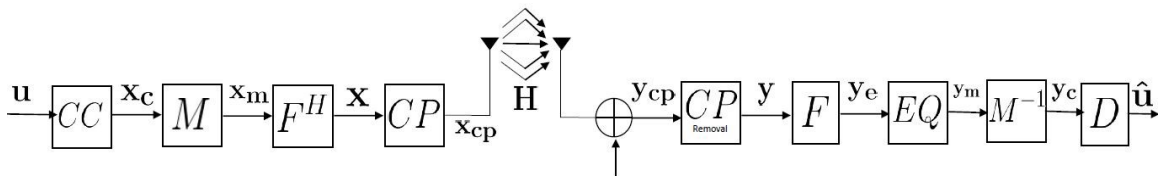


Figure 1. CP-OFDM structure to validate the outage performance of Indonesia 5G channel model.

Bit stream  $u$  are inserted to the channel coding (we consider Polar codes with rate  $R = \frac{1}{2}$  and Convolutional codes to compare the performance of polar codes) to generate codewords  $x_c$ .  $M$  is a modulation

block (we utilize 5G NR complex BPSK), where codewords  $x_c$  is mapped into symbol  $x_m$ . Modulated symbol is then transformed using inverse fast Fourier transform (IFFT)  $F^H$  with block length of 128 into  $x$ . The function of cyclic prefix  $CP$  module is to inserting some last symbols in a block of  $x$  to the early part of the symbol and become  $x_{cp}$ . The symbol is then transmitted through the obtained Indonesia 5G channel. At the receiver side, noise is added and become  $y_{cp}$ . Cyclic prefix in  $y_{cp}$  are than deleted in  $CP_{Removal}$  module and become  $y$ . Transformation of  $y$  using fast Fourier transform (FFT) are conducted in  $F$  module to generate  $y_e$  and equalized in module  $EQ$  to generate  $y_m$ . The equalized symbol  $y_m$  is then demodulated in module  $M^{-1}$  and become codewords  $y_c$ . Decoding process are conducted in module  $D$  to obtain  $\hat{u}$ . We consider soft decoding and soft demapper using LLR to increase the performance of the systems.

### 3.3.1. Block Error Rate (BLER) Calculation

BLER analysis from CP-OFDM systems is used in this research to validate the obtained outage performance of Indonesia 5G channel model. The BLER can be calculated as

$$BLER = \frac{\text{Block}_{\text{error}}}{\text{Block}_{\text{transmitted}}}, \dots\dots\dots 17)$$

where  $\text{Block}_{\text{error}}$  is a number of error block. A block can be considered as a error block if there is more than zero number of error bit on that block and  $\text{Block}_{\text{transmitted}}$  is a total number of transmitted block. The outage performance of Indonesia 5G channel model will be valid if outage curve has a same or sharper gradient with BLER curve.

### 3.3.2. Bit Error Rate (BER) Calculation

BER analysis is used in this paper with CP-OFDM systems. The BER can be calculated as

$$BLER = \frac{\text{Bit}_{\text{error}}}{\text{Bit}_{\text{transmitted}}}, \dots\dots\dots 18)$$

where  $\text{Bit}_{\text{error}}$  is a total number of error bit, and  $\text{Bit}_{\text{transmitted}}$  is a total transmitted bit.

## 4. Results and Discussion

### 4.1. Foliage Attenuation Results

The ITU-R foliage attenuation model with the tree depths are 20%, 40%, 60%, and 80% of transmitter and receiver distance are utilized in this research. The distance is varying from 50, 100, 150, and 200 m follows the maximum coverage distance of 5G systems in urban macro area.

Table 3. Foliage attenuation of Indonesia 5G channel model.

Foliage Percentage	Average Foliage Attenuation (dB)	Minimum Foliage Attenuation (dB)	Maximum Foliage Attenuation (dB)
20% foliage	17.151	9.048	20.788
40% foliage	27.005	13.715	31.509
60% foliage	35.235	17.492	40.187
80% foliage	42.532	20.788	47.759

Table 3 shows the results of foliage attenuation of several cities in Indonesia. As the foliage percentage increases by 20%, the average foliage attenuation increases about 7 until 8 dB.

#### 4.2. Indonesia 5G Channel Model

We simulate 4000 instantaneous PDP for each PDP without foliage, 20% foliage, 40% foliage, 60% foliage, and 80% foliage attenuation to observe representative Indonesia 5G channel model. Each simulation is presented in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6, respectively.

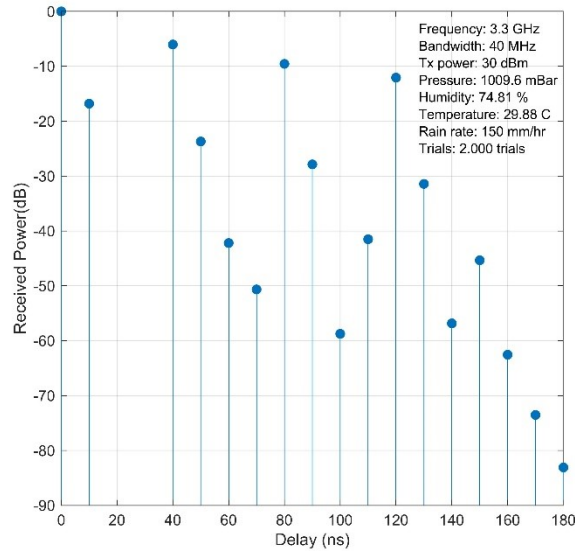


Figure 2. Obtained representative PDP of Indonesia 5G channel model without foliage.

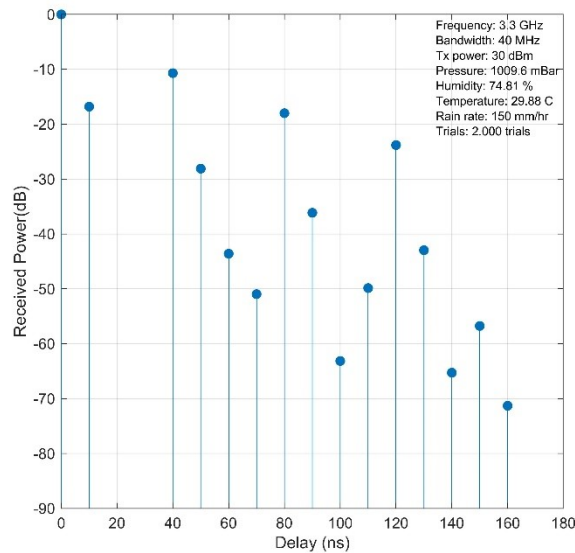


Figure 3. Obtained representative PDP of Indonesia 5G channel model with 20% foliage.

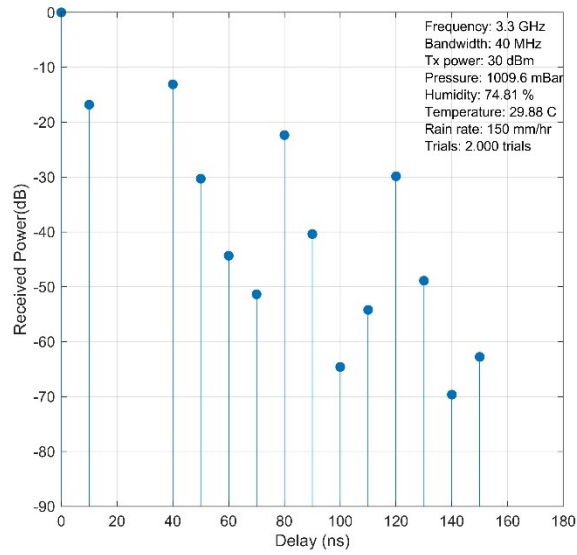


Figure 4. Obtained representative PDP of Indonesia 5G channel model with 40% foliage.

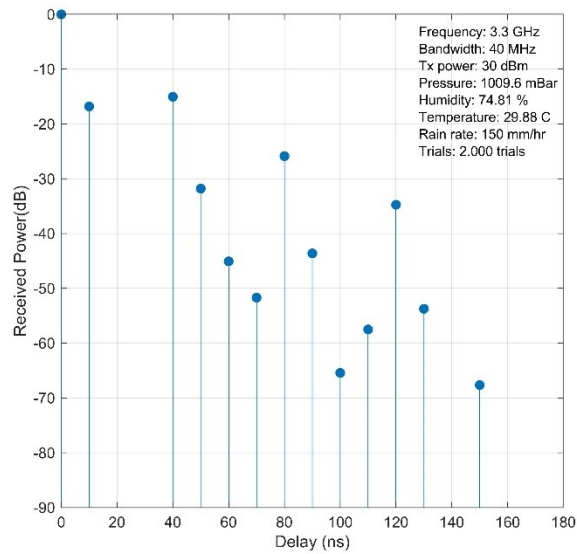


Figure 5. Obtained representative PDP of Indonesia 5G channel model with 60% foliage.

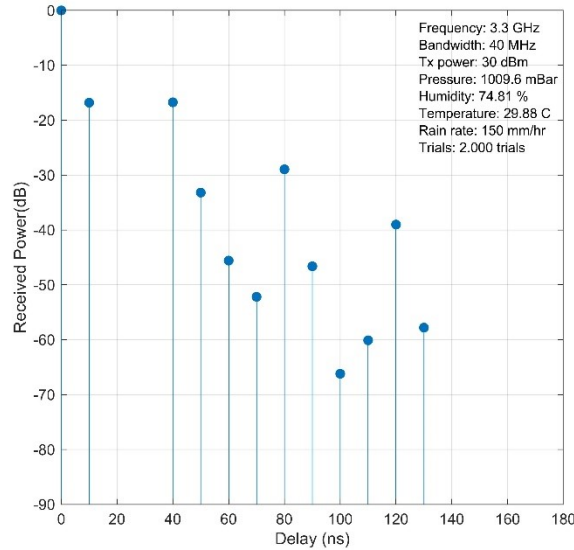


Figure 6. Obtained representative PDP of Indonesia 5G channel model with 80% foliage.

The PDP with 20% foliage represents the 5G channel in Jakarta, Bandung, Makassar, Jayapura, and Semarang which have a green space percentage to the city area below 20%. A PDP with 40% foliage represents the 5G channel in Denpasar and Palu, which have a green space percentage to the city area below 40% and above 20%. A PDP with 60% foliage represents the 5G channel in Bandar Lampung which has a green space percentage to the city area below 60% and above 40%. Furthermore, a PDP with 80% foliage represents the 5G channel in Manado which has a green space percentage to the city area below 80% and above 60%.

Table 4. Obtained PDP of Indonesia 5G channel model.

Power Delay Profile	Number of Path	Mean Excess Delay (ns)	RMS Delay Spread (ns)
No foliage	17	18.61	32.60
20 % foliage	15	4.87	15.76
40 % foliage	14	2.61	10.92
60 % foliage	13	1.65	8.30
80 % foliage	12	1.15	6.64

The coherence bandwidth of 5G Indonesia channel model without foliage, with 20%, 40%, 60%, and 80% foliage in Table 4 are 6.135 MHz, 12.69 MHz, 18.31 MHz, 24.09 MHz, and 30.12 MHz, respectively. 5G Indonesia channel is classified into a frequency selective fading channel, because transmission bandwidth  $B$  is larger than coherence bandwidth  $B_c$ , thus we need equalizer or OFDM to process the received signal. Furthermore, foliage attenuation affects the number of the path as a percentage of foliage attenuation increases, the number of path and received power decreases.

### 4.3. Outage Performance Analysis

The outage performance can be drawn when the capacity  $C$  is dropped under the coding rate  $R$ . This research considers outage probability with rate  $R = 1/2$  and validated using CP-OFDM with 5G complex BPSK and Polar codes with  $R = 1/2$ .

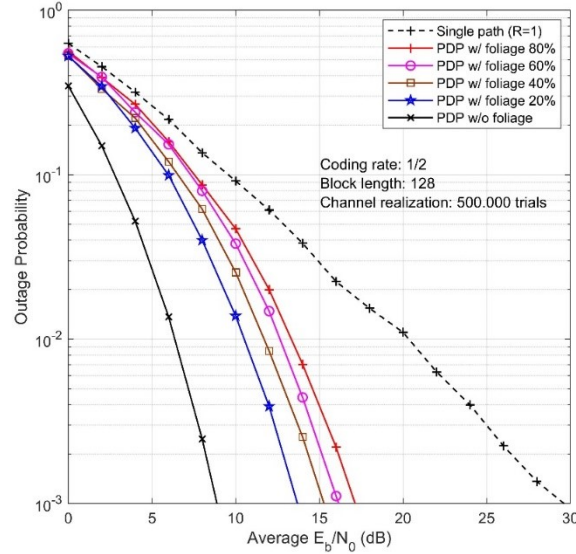


Figure 7. Outage performance of Indonesia 5G channel model under Rayleigh fading channel.

The outage probability results are expected to be a theoretical reference for 5G system implementation in Indonesia. The outage performance of 5G Indonesia channel model is shown in Figure 7. The outage performance curve from representative PDP of 5G Indonesia channel have the same or similar gradient and tendency indicating that they have same diversity order. As the foliage attenuation increases, the performance of the channel decreases. Figure 7 also shows that the outage probability of  $10^{-3}$  is achieved by the 5G systems with  $R = 1/2$  and without foliage effect at  $E_b/N_0$  of 9.1 dB. Furthermore, the outage probability of  $10^{-3}$  in representative PDP with 20%, 40%, 60%, and 80% foliage attenuation is achieved by the 5G systems at  $E_b/N_0$  of 13.8 dB, 15.1 dB, 16 dB, and 17.2 dB, respectively. These outage performances and  $E_b/N_0$  values are expected to be a theoretical reference for 5G system implementation in Indonesia.

### 4.4. Results Validation

To evaluate the validity of theoretical outage performance 5G Indonesia channel model in Figure 7 which is obtained from representative PDP and Shannon channel capacity we present the BLER and BER analysis using CP-OFDM numerology zero with 5G complex BPSK and channel coding with rate  $R = 1/2$ . Since Polar codes become a candidate of 5G NR channel coding, we consider to use Polar codes and compare it with the convolutional codes.

#### 4.4.1. BLER Performance

As described in Section 3, we use BLER and BER performance of CP-OFDM numerology zero system with 5G complex BPSK modulation to validate the outage performance at  $R = 1/2$  in Indonesia environments without foliage, 20% foliage, 40% foliage, 60% foliage, and 80% foliage. We present the BLER performance of 5G Indonesia channel model without foliage effect in Figure 8. The BLER performance curve of 5G

Indonesia channel model without foliage effect are compared to theoretical outage performance in Figure 7. These curves are then used as the baseline for practical comparison BLER performance in 5G Indonesia channel model.

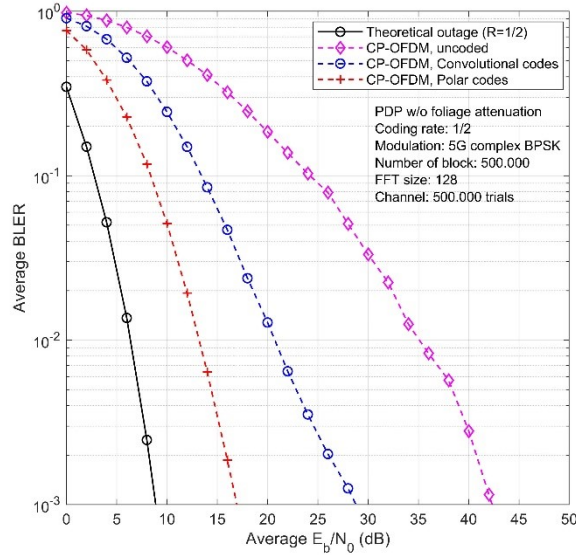


Figure 8. BLER performance of Indonesia 5G channel model without foliage.

The BLER of  $10^{-3}$  from 5G Indonesia channel model without foliage attenuation in Figure 8 can be achieved in  $E_b/N_0$  of 16.5 dB with Polar codes,  $E_b/N_0$  of 28.8 dB with convolutional codes, and  $E_b/N_0$  of 42.3 dB with no channel coding used. We present the BLER performance of 5G Indonesia channel model with foliage effect in Figure 9, 10, 11, and Figure 12. The BLER performance curve of 5G Indonesia channel model with foliage effect are compared to theoretical outage performance in Figure 7.

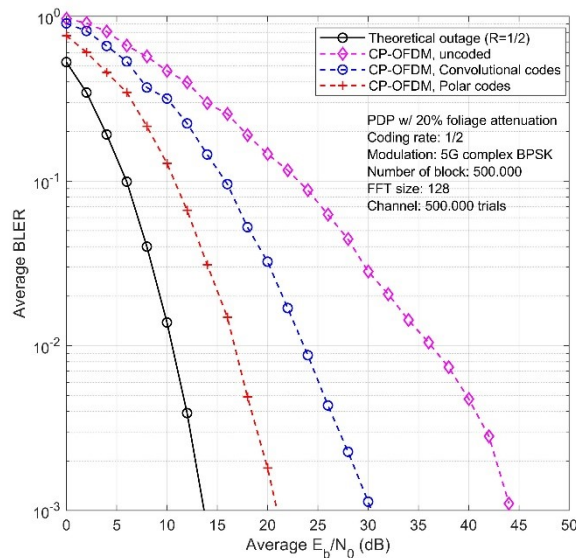


Figure 9. BLER performance of Indonesia 5G channel model with 20% foliage.

The BLER of  $10^{-3}$  from 5G Indonesia channel model with 20% foliage attenuation in Figure 9 can be achieved in  $E_b/N_0$  of 21 dB with Polar codes,  $E_b/N_0$  of 30 dB with convolutional codes, and  $E_b/N_0$  of 44.2 dB with no channel coding used.

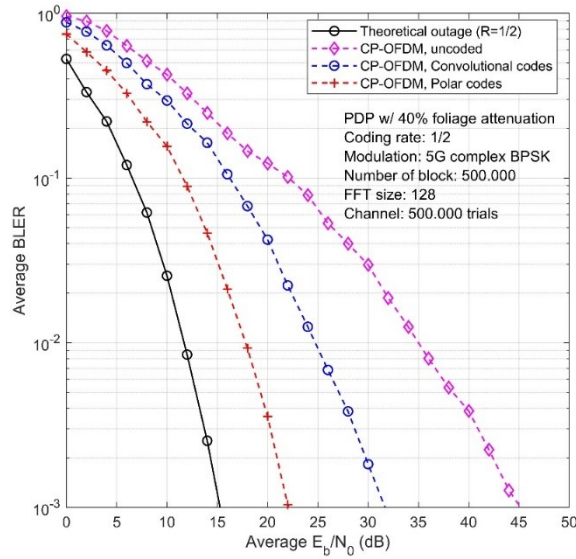


Figure 10. BLER performance of Indonesia 5G channel model with 40% foliage.

The BLER of  $10^{-3}$  from 5G Indonesia channel model with 40% foliage attenuation in Figure 10 can be achieved in  $E_b/N_0$  of 22 dB with Polar codes,  $E_b/N_0$  of 31.3 dB with convolutional codes, and  $E_b/N_0$  of 45 dB with no channel coding.

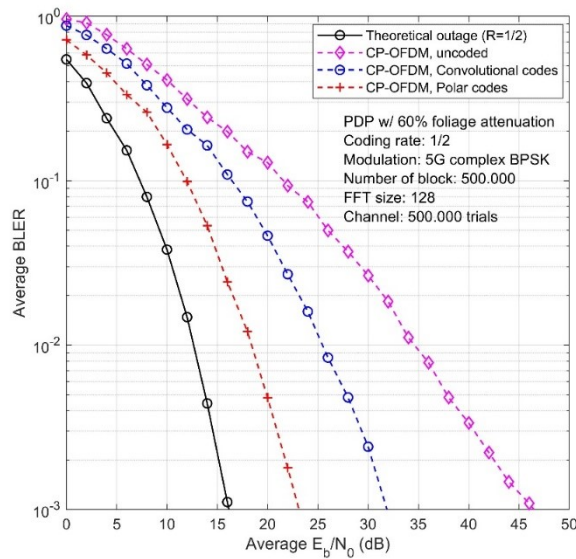


Figure 11. BLER performance of Indonesia 5G channel model with 60% foliage.



The BLER of  $10^{-3}$  from 5G Indonesia channel model with 60% foliage attenuation in Figure 11 can be achieved in  $E_b/N_0$  of 23.6 dB with Polar codes,  $E_b/N_0$  of 32 dB with convolutional codes, and  $E_b/N_0$  of 46 dB with no channel coding.

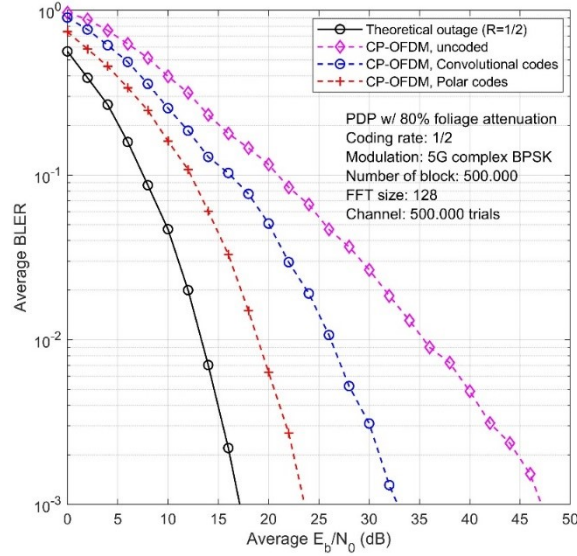


Figure 12. BLER performance of Indonesia 5G channel model with 80% foliage.

The BLER of  $10^{-3}$  from 5G Indonesia channel model with 80% foliage attenuation in Figure 12 can be achieved at  $E_b/N_0$  of 24.2 dB with Polar codes,  $E_b/N_0$  of 33.5 dB with convolutional codes, and  $E_b/N_0$  of 47 dB with no channel coding used. The utilization of channel coding can capture the diversity effect indicated by the slope differences between BLER performance curve of CP-OFDM with channel coding and without channel coding. The gap between BLER performance curve and obtained theoretical outage performance can be reduced by using a strong capacity-achieving codes, e.g., Polar codes or low-density parity check (LDPC) codes. On the contrary, CP-OFDM system without channel coding cannot capture diversity effect resulting a gradient having the same gradient of BLER in frequency-flat Rayleigh fading.

#### 4.4.2. BER Performance

We evaluate the BER performance of 5G Indonesia channel model which is expected to be used as a reference for 5G system implementations in Indonesia. We compare the result to the theoretical BER performance over single path Rayleigh fading channel, which is expressed as

$$BER_{\text{BPSK-Fading}} = \frac{1}{2} \left[ 1 - \frac{1}{\sqrt{1 + \frac{1}{E_b/N_0}}} \right] \dots\dots\dots 19)$$

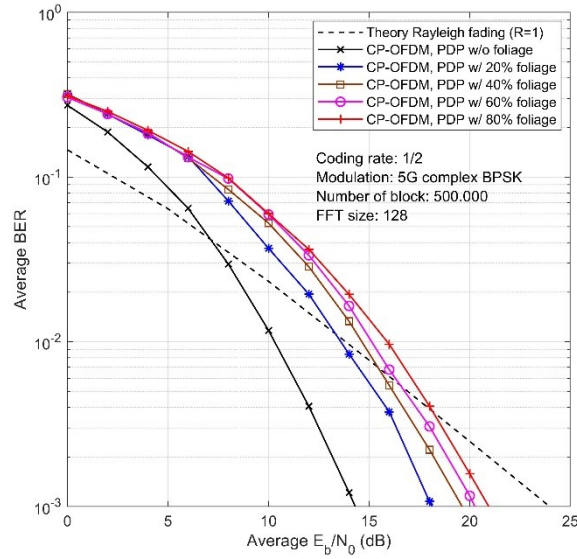


Figure 13. BER performances of Indonesia 5G channel model under Rayleigh fading channel.

BER performance of CP-OFDM with 5G complex BPSK and Polar codes are shown in Figure 13. In low  $E_b/N_0$ , BER of CP-OFDM with Polar codes are worse than the theoretical BER of uncoded system under single path channel. This is because, in this paper, we still use sub-optimal Polar codes, where the Bhattacharyya parameter is not updated based on the channel variation. However, we can still see the diversity that improve the BER performance in middle until high  $E_b/N_0$  as predicted by the outage performance curve. The BER of  $10^{-3}$  of 5G Indonesia channel model without foliage attenuation can be achieved at  $E_b/N_0$  of 14 dB with Polar codes. While BER of  $10^{-3}$  from 5G Indonesia channel model with 20%, 40%, 60%, and 80% foliage attenuation can be achieved at  $E_b/N_0$  of 17.7 dB, 19.3 dB, 20.1 dB, and 21 dB, respectively.

### 5. Conclusions

This paper has proposed (i) a framework to derive 5G channel model using real-field parameters for any locations in Indonesia and (ii) Indonesia 5G channel model under foliage effects (20%, 40%, 60%, 80%). A representative PDP are produced by considering the foliage effect for 5G networks by computer simulations, where the parameters are taken from real-field conditions of several cities in Indonesia to increase the results accuracy. We found that in 3.3 GHz frequency with 40 MHz bandwidth and numerology 0, foliage attenuation reducing the number of paths and the received power. It will cause the performance degradations confirmed by the outage, BLER, and BER performances while using sub-optimal Polar codes as a channel coding. With the development of Polar codes, the better results are expected in the future. When foliage effect does not exist, the Indonesia 5G channel model has 17 paths. However, the number of paths decreases to a value of 15, 14, 13, 12 for each 20%, 40%, 60%, and 80% of foliage attenuation, respectively. From the model, many performances were estimated including the outage performances. We expect that the outage performances can be used as a theoretical outage performance of 5G system implementation in Indonesia. Similarly, the proposed framework can be applied to create 5G channel model in any locations in Indonesia to make the 5G implementation optimal.

## 6. Future Work

To improve the accuracy, optimal Polar codes are needed. Furthermore, further investigations by combining foliage effect with humidity, rain rate, and temperature effect are also required.

## 7. Acknowledgement

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