Performance of 5G-NR under Semarang Channel Model

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Abstract. To support Twenty-Twenty Society and industrial revolution 4.0, 5G-NR becomes the solution for reliable communication. 5G-NR uses High Frequency which is sensitive towards nature and thereby need to understand its performance under real-field environment in Semarang, Indonesia. The aim of the research is to proof whether 5G can work in Semarang seen from outage probability and Bit Error Rate under three conditions for very heavy rainfall, moderate and without rainfall. This research method used channel model experiment using NYUSIM and MATLAB with CP-OFDM without channel coding with Rate in 1. Four environment parameters used as the data collection, namely temperature, humidity, rainfall rate and air pressure from Indonesia official department of Meteorological, Climatological and Geophysical Station (BMKG) of Semarang City and through sensors. The results obtain the information that the channel can work under the three conditions. It was also performed additional information about water vapour as the atmospheric attenuation due to absorption as the consideration of planning reliable communication in 22 GHz and 60 GHz. Besides, 5G-Complex BPSK generated better performance than BPSK One-path Rayleigh Fading.

1. Introduction
Internet network serving more than 50 billion devices is the main leading cause of elevating cellular network communication. It is among the most widely used by society in 2020 and beyond\([1][2]\). A technology that can support large volume of traffic is needed. This large volume of traffic requires high bandwidth and low latency. The technology with those characteristics is 5G-NR. 5G-NR (5G-New Radio) has a high bandwidth of up to 100 MHz and very low latency which is excellent, up to 1 millisecond. Therefore it can support high traffic volumes and become a support technology for the Twenty-Twenty Society and industrial revolution 4.0 framework such as Internet of Things. Specifically, 5G will become a technology standardized for people and things, massive machine connectivity, a new spectrum band, excels in mobility and security, integration through the internet, processing and storage at network scales and virtualization functional network for supporting living things\([2-7]\). 5G technology will have become the technology with high frequencies between 1 GHz - 100 GHz. The communication design which uses frequency 20 – 30 GHz must consider environment parameter \([8][9]\). A major issue of 5G-NR is the channel model. Channel modelling is very important in wireless communication system because the capacity (per-link) produced depends on the channel \([10-12]\).
There are considerable amount of literature on channel modelling. Experiments on channel modelling were carried out in 2016-2019 by a group of researchers. The system model of channel modelling performed by considering bandwidth of 200 MHz for the frequency of 28 GHz with NLOS environment in one average condition based on each air pressure, humidity and average temperature has obtained 18 paths with delay interval of 10 ns[13] [15-17] paths in specific discussion of foliage effect[14][15] and two area in one condition[16]. Two conditions of specific area has provided information of in maximum temperature, the path is 18, 6.28 ns and 15.48 ns while in minimum, the path is 18 with 6.56 ns and 16.22 ns[17]. Meanwhile Geometry based Stochastic Chanel Model (GSCM) was used to overview the map-based model. It provides consistency in frequency, time and space domain to support 5G as a conclusion. Yet, no weather condition provided and no specific calculation within the article[18]. They seem to be well-grounded and draw our attention focus on the parameter in weather conditions with specific number.

Few studies have been published on channel modelling in complete weather conditions i.e. very heavy rainfall, moderate and no rainfall. Whereas parameter finding is important to determine the optimized parameters that govern the model[19]. The present paper aims to get the performance of 5G channel modelling considering Semarang City in different topography and real-field parameters using the proposed framework to prove whether it can work in three conditions of very heavy, moderate and no rainfall. This next chapter looks at the method, numerical result and discussion as well as conclusion respectively.

2. Method

In attempt to do channel modelling experiments, we used NYUSIM and MATLAB to obtain 5G channel modelling performance. NYUSIM is a channel simulator developed by NYU Wireless and is using numerology of 5G[20-23]. To enable us do the validation, we used Frame Error Rate and Bit Error Rate. The simulation is based on weather parameter data obtained from BMKG Station in Semarang City and measurements through sensors. This method was chosen because it is one of the most practical ways to provide statistical results.

In this modelling, it was taken three conditions which is a very heavy rainfall, moderate rainfall and no rainfall based on the standard of Meteorological, Climatological and Geophysical Station (BMKG) Indonesia [24]. Reliable communication is more crucial in tropical regions because of high intensity rainfall[25] because the higher the frequency, the higher attenuation will be generated. Thus, the condition is using rainfall conditions. The data were got from BMKG in period of 2018 and the sensor for 30 days measurement. The condition of very heavy rainfall means the value of temperature was taken the lowest, the humidity was taken the highest, the air pressure was taken the lowest and the rainfall was the highest. The moderate rainfall means the average value of the temperature, humidity and air pressure was taken but as a concern, the rainfall rate was taken from the standard of BMKG Indonesia which is ranging from 5 – 10 mm/hr due to rainfall rate cannot be averaged as the temperature, humidity and air pressure. While no rainfall is when the rainfall rate value is 0 mm/hr, the temperature was taken the highest, the humidity was the lowest and the air pressure was the highest. The reason behind that data collection is because these parameters affect attenuation at high frequencies. Rainfall rate, temperature, air pressure and humidity are interdependent [26][27]. We modelled the channel using numerology 3 with the frequency 28 GHz and 100 MHz bandwidth and the scenario was UMi (Urban Micro) with environment NLOS as well as the lower and upper bound 200 m also Tx Power of 30 dBm and number of RX Locations was 1000. We also used Rayleigh fading channel with rate in 1. The appropriate delay profile parameter to provide statistical description of multipath delay time is done through one of them is Instantaneous Power Delay Profile (PDP) [28]. Propagation of multipath channel causes transmission signal dispersion and disperse level which is expected to be determined through the calculation of Power Delay Profile on a channel [29][30]. The input value in NYUSIM based on BMKG and measurement through sensor are shown in table 1.
Table 1. Input parameter value based on data from BMKG.

| Parameter          | Rainfall rate (mm/hr) | Humidity (%) | Temperature (°C) | Air Pressure (mbar) |
|--------------------|-----------------------|--------------|------------------|---------------------|
| Condition          | BMKG Sensor BMKG Sensor BMKG Sensor BMKG Sensor BMKG Sensor BMKG Sensor |
| Very heavy rainfall| 42 72                 | 93 99.9      | 24.8 18.9        | 1005.6 899          |
| Moderate rainfall  | 8.5 8.8              | 77 85       | 28 26            | 1009.9 994.2       |
| No rainfall        | 0 0                  | 53 39       | 30.5 35.5        | 1014.2 1061.6      |

Instantaneous PDP is one of the way to give a statistical description of time delay on multipath [28]. Instantaneous PDP is then performed spatially averaging to obtain short-term PDP. The purpose of doing averaging is to immerse the variation of rapid fading. Furthermore, the averaging process is carried out spatially so that it produces Representative PDP which is also called Long-term PDP that is a signal receive power over a multipath channel [15]. The steps above are shown in figure 1.

![Figure 1. Flowchart of 5G channel modelling.](image)

Representative PDP value in the 5G channel modelling were converted from dB to numeric or normalized as Eb/N0 value. To quantify the spread of incoming signals, the time dispersion parameter was used. The calculations are Mean Excess delay and RMS (Root Mean Square) delay spread [30][31]. These two parameters are important in a channel because they are used to describe the temporal dispersive nature of multipath channels. This is useful for estimating the performance and potential of ISI (Intersymbol Interference) and for measuring Coherence Bandwidth [32][33].

3. Results and Discussion
The results of running process in NYUSIM and MATLAB obtained the Representative PDP for the condition of very heavy rainfall, moderate rainfall and no rainfall based on data from BMKG and sensor are shown in figure 2 to figure 4.
Figure 2 shows the representative PDP with BMKG data that obtain 9 paths and mean excess delay in 8.76 ns and RMS in 24.6 ns with very heavy rain condition. Against the BMKG data, the result of path obtain with sensor data get 8 paths with calculations of mean excess delay in 9.7 ns and RMS in 26.4 ns.

Figure 3 shows the representative PDP in moderate rain condition with BMKG data that obtain 9 paths with mean excess delay of 7.0006 ns and RMS in 38.5 ns while with sensor data, the path obtained is as many as 9 with mean excess delay of 8.75 ns and RMS in 24.6 ns.
Changes happen in representative PDP of no rain that in BMKG data, the path obtained is 7 with mean excess delay in 8.5 ns and RMS in 23.2 ns while in sensor data, the path is increasing into 9 with mean excess delay of 8.5 ns and RMS in 23.2 ns.

Representative PDP is created from averaging short-term PDP. The length is based on the calculation of CP which is constructed according to the $T_{cp}$ and $T_{ofdm}$ that is 0.57 and 8.33 resulted 9 paths [34][35]. Bandwidth Coherence was calculated afterwards, showing the result around 8 MHz. The results of coherence bandwidth shows the value below the transmission bandwidth i.e. 100 MHz, meaning that all the results are categorized as frequency selective fading channel and needs equalizer in the receiver.

Outage performance can be made using the Shannon theorem namely Shannon capacity to get the Shannon limit. Outage probability is the probability when capacity $C$ is below the coding rate $R$. In this modelling, we used $E_b/N_0$. $E_b/N_0$ is as the normalized SNR and used in analyzing the performance [36]. The result of outage probability and its validation as well as Bit Error Rate curve in each condition are shown in figure 5 to figure 8 with 500,000 iteration.
Figure 5 shows the results with BMKG data in very heavy, moderate and no rain condition. Data in (a) shows the results of outage probability validated by Frame Error Rate. Theoretically, the value of outage probability in very heavy rain is $10^{-5}$ with power in 18.3 dB and its validation using Frame Error Rate obtain $10^{-1}$ with power in 22.2 dB. Quite same results are shown in moderate rain condition in which the outage probability of moderate rain is $10^{-5}$ with power in 18.2 dB and its validation using Frame Error Rate gets $10^{-1}$ with power in 22.2 dB. While in no rain condition, the theoretical outage probability is in $10^{-5}$ with power in 18.27 dB and validation using Frame Error Rate shows $10^{-1}$ with power in 22.1 dB.

Data in (b) shows the value of Bit Error Rate (BER). BER of CP-OFDM was performed using 5G Complex BPSK (5G CPBPSK). The Bit Error Rate in very heavy rain condition shows the value of $10^{-3}$ with power in 24 dB, against it, the value of 5G-CPBPSK obtain $10^{-3}$ with power in 22.65 dB. While in moderate rain, the Bit Error Rate shows the value of $10^{-3}$ with power in 24 dB and in 5G-CPBPSK, it shows lower power, namely 22.6 dB. Subsequently, Bit Error Rate in no rain condition shows the value of $10^{-3}$ with power in 24 dB while in 5G-CPBPSK it obtains 0.5 lower, i.e. 23.5 dB.

The power value is expected to be a theoretical reference of $E_b/N_0$ for Indonesia’s 5G system with Semarang City natural parameters. The difference between FER performance and theoretical outage can be reduced by using strong capacity-achieving coding such as Polar Codes or LDPC [15]. The difference between theoretical outage and FER is acceptable because the channel model is done uncoded namely with rate in 1. Because the difference in value will be taken into account when it uses strong capacity-achieving code[13]. Based on figure 5, it appears that the BER value of uncoded 5G CP-OFDM tends to be the same as BER performance theory but is slightly better due to the multipath fading effect of 5G channel modelling. The results of all condition indicate that the BER value practically or CP-OFDM BER is below theoretical BER. The BER value theoretically reaches $10^{-3}$ with a power value of 24 dB. This is because the BPSK modulation used 5G-complex BPSK. The results show that the BER simulation curve coincides with the BER theory so that the 5G NR modulation simulation performed is correct. The difference with regular BPSK is that BPSK usually maps bits into symbols 1 and -1 while 5G-NR maps bits into complex symbols. The value generated at 5G-Complex BPSK under BPSK theory indicates that the performance of 5G-Complex BPSK is better than the usual BPSK. This performance improvement is shown by the presence of soft demapper on BPSK 5G coding. In soft demapper, all available symbol probabilities are taken into account so that the accuracy of the demapping process on soft demapper is higher.
Figure 6 shows the results with sensor data. Data in (a) shows the outage probability, that, in very heavy rain condition, the value of outage probability is $10^{-3}$ with power in 13.283 dB. After validated using Frame Error Rate, the value changed into $10^{-1}$ with 22.1 dB. Comparing to that of BMKG data, the outage probability of sensor data has lower value. In moderate rain condition, the outage probability value obtains $10^{-3}$ with power in 29.67 dB. After validated using Frame Error Rate, the value changed into $10^{-1}$ with 22.5 dB. No rain category indicates the outage probability value in $10^{-3}$ with power in 19.88 dB. After validated using Frame Error Rate, the value changed into $10^{-1}$ with 22.1 dB. Hence, the line of very heavy rain coincides with the line of no rain condition.

Data in (b) shows the results of Bit Error Rate (BER). Using 5G-CBPSK, the very heavy rain gained $10^{-3}$ with 23.48 dB. While in moderate rain condition, it obtain $10^{-3}$ with 23.3 dB and no rain condition managed to achieve 23.5 dB. Those values are lower comparing to the theoretical using BPSK which get $10^{-3}$ with 24 dB.

According to the Information Theory basis, channels are characterized by channel capacity $C$ or in other words, each channel has capacity. $C$ value functions as the effective speed limit on a channel. According to Shannon's theorem, the use of the theorem is to calculate channel capacity based on the channel statistic description, to get $R < C$, coding techniques are needed to allow the receiver's probability of error to be smaller. This means that in theory, it is possible to send information almost without error to the C bit / second limit. But if $R > C$, the probability of error in the receiver increases when the rate is higher. So that no information is sent through the channel. The value of capacity ($C$) produced in the very heavy rain condition is 10.2864, for moderate rain is 10.6517 and no rain is 11.2823 and the coding rate for all these criteria is $R = 1$ so the equation becomes $R < C$, meaning that the channel is working in sending information but an error still occurs. The highest RMS (Root Mean Square) is 26.4 ns in very heavy rain, that according to [4], the delay is in excellent category. In conclusion, if the channel in very heavy rain, meaning that it is in extreme condition can work, so in the moderate and no rain condition the channel can work better.

The same results occur to the sensor data, in which the capacity value in very heavy rain is 10.2066, in moderate rain is 10.6516 and no rain in 10.1372. Those values are more than $R$ so that it can be concluded that the channel can work though there is likely error in transmission. The condition of water vapor (water vapor) occurs when there is a humidity value above 40% and is considered dry air when the humidity is below 40%. Humidity by definition is the amount of water vapor in the air [37]. The
inputs are variable frequency, distance, temperature, and water vapor density. The results of attenuation caused by water vapor is shown in figure 7.

![Figure 7. Water vapor attenuation](image)

The attenuation results in figure 7 shows that the highest attenuation occurs when there is no rainfall or is called a non-rainfall atmosphere. However, based on the attenuation graph, an increase in attenuation at a frequency of around 22 GHz. According to research [38] this occurs because at frequencies above 20 GHz, namely in non-precipitation conditions or conditions that tend to be dry, atmospheric components that are relevant to radio wave propagation are oxygen, water vapor and cloud water droplets. If the absorption of clouds increases with frequency, the gases absorb up to a maximum of 22 GHz for water vapor and 60 GHz for oxygen. As a result, the frequency of 20 GHz is more sensitive to water vapor. The attenuation occurs along with water vapor with relatively low rainfall. That is why attenuation that occurs without rainfall becomes one of the most important design parameters. It was also explained that the absorption that occurs in non-rainfall conditions depends on the season. Absorption by oxygen and water vapor becomes significant as a determination of transmission power and antenna gain in broadband communication services. Oxygen has a series of absorption lines at 60 GHz and water vapor has absorption lines at a frequency of 22.3 GHz. In the troposphere, radio wave propagation experiences signal attenuation or attenuation due to interactions with gas components in the transmission path. Attenuation is influenced by temperature, air pressure, humidity, frequency and water vapor. Water vapor is also a consideration for making a design in the tropics[39][40].

4. Conclusion
We have studied a channel model using scenario UMi with R = 1 or un-coded, based on real-field parameter of Semarang City we found that the total number of paths generated in the channel mostly is 9 in the highest RMS of 26.4 ns in very heavy rain which means it is in excellent criteria. It can be inferred that the channel can work in either very heavy rain, moderate or no rain condition though error is still possibly there. The overall channel condition obtained is frequency selective fading requires an equalizer on the receiver. The highest attenuation peak value was at 22 GHz and 60 GHz due to water vapor and oxygen absorption.

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