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Rain Effect to a 60 GHz Broadband Wireless System's Performance: Study Case in Purwakarta

Endah Setyowati*, Galura Muhammad Suranegara, Ichwan Nul Ichsan
[1,2,3] Program Studi S1 Sistem Telekomunikasi, Universitas Pendidikan Indonesia
[1,2,3] 229 Dr. Setiabudi Street, Isola, Sukasari, Bandung, West Java 40154, Indonesia
*Corresponding email: endahsetyowati@upi.edu

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Abstract —Nowadays, worldwide telecommunication researchers are developing 5G technology. One of the most important key technology in 5G is Millimeter-Wave (mmWave). This study measure 60 GHz broadband wireless system performance because of its promising potentials. However, these frequencies are quite sensitive to rain, resulting in attenuation in the channel. Therefore, this study proposes two schemes to address the problem. The first scheme is the use of QAM modulation (Quadrature Amplitude Modulation), and the second scheme is an addition of LDPC (Low-Density Parity Check) code techniques. From the results of this study, by using 4-QAM modulation and LDPC code code rate 1/2, the broadband wireless system's performance on the second scheme is better compared to the first scheme with an 8.33 dB Signal to Noise Ratio (SNR) value to provides BER (Bit Error Rate) 10^{-4}.

Keywords – Broadband Wireless System, millimeter-Wave, 5G, QAM, LDPC, rain

I. INTRODUCTION

In general, the target of 5G technology is to have a high data rate (1-10 Gbps), has latency below 1 ms, extensive coverage using a heterogeneous network, and stable connectivity [1]. One of the advantages of the 5G technology is that it provides data rate several times faster than previous technologies to require broader bandwidth [1],[2]. However, the current frequency spectrum band's limitations are driving the use of high frequencies for 5G ranging from 3 GHz - 300 GHz [1], [3]. The frequency in that range produces small wavelengths (on a millimeter-scale), called Millimeter-Waves (mmWave).

Telecommunication service providers are facing a reliability challenge. Their reliability is tested with some typical Indonesian challenges, contours, and weather, especially in the rain. Technically, rain can disrupt wave propagation and leads to quality degradation of communication services. Because every city in Indonesia has a different rain rate, the telecommunication service provider should anticipate this by providing appropriate treatment on each network channel.

The use of high frequencies is sensitive to rain [4]. Therefore, there are some needs to add some schemes to reduce attenuation or fading due to rain. In previous research [5], there has been a calculation of channel availability and channel capacity for BWFA (Broadband Wireless Fixed Access) system at 30 GHz with some consideration to the presence of rain in Surabaya, Indonesia. The paper shows that at a distance of 2 km, ACM (Adaptive Coded Modulation) with the encoding of Reed Solomon and Convolutional Code and Combining can produce 99.99% link availability and a maximum channel capacity of 5.98 bps/Hz.

In addition, study [3] has shown that for indoor office environments case with antennas in each room, it is more effective to use 60 GHz frequency than other frequencies (38 GHz, 28 GHz, 5GHz, and 2.4GHz) that has wider coverage causing get easier to be interference. Based on that study, this study analyzes the system performance at 60 GHz frequency with consideration of rain in Purwakarta.

Therefore, this study proposes two schemes to address the problem. The first scheme is the use of QAM (Quadrature Amplitude Modulation), and the second scheme is an addition of LDPC (Low-Density

Parity Check) code techniques. The schemes aim to reduce the rain fading effect to get better performance marked with a target BER (Bit Error Rate) 10^{-4} achieved with a relatively low SNR (Signal to Noise ratio) value.

II. RESEARCH METHODS

A. System Parameters

The system parameters used in this study can be seen in Table 1. Study [3] uses 60 GHz frequency, and the distance between the transmitter and receiver is 30 meters far in LOS (Line of Sight) condition. Therefore, this study uses the same system parameters as follows:

Table 1. System Parameters

Parameters	Value
Frequency (GHz)	60
Distance between Tx and Rx (m)	30
Coding	LDPC

LDPC code is one of the coding techniques from linear block code that has a low density with its parity check characteristics containing fewer bits "1" than the number of bits "0". The advantage of LDPC code is it has the performance that very close to the maximum capacity (Shannon Limit) of various channels and has a linear decoding process. With a high bit rate, it is expected to help produce a low probability of bit error [6].

The lower triangular-shaped based encoding method introduced by Thomas J. Richarson and Rudiger L. Urbanke in 2001 is an efficient encoding method for LDPC code. The purpose of this encoding method is to form a matrix of parity check P in the form of a lower triangular shape as the following figure:

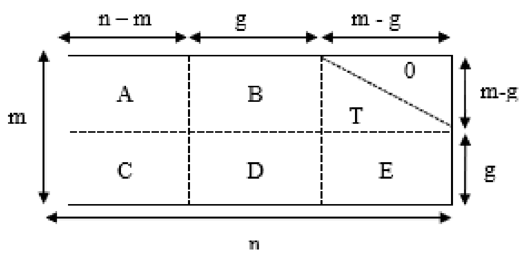

Fig. 1. Parity check matrix model [7]

The decoding method used in this paper is bit flipping which is based on marking hard decision (0 or 1) for each bit received. An important part of bit flipping is the internode message passing on Tanner charts. The hard decision decoding algorithm is bit flipping by [8] as follows:

1. Initialization: Each variable node marks the bit value the channel receives and sends a message to the check node connected to the Tanner graph indicating its value.
2. Parity update: Using a message from the variable node, each check node checks whether the parity check equation is met. If the entire parity check is met, the algorithm stops. Otherwise, each check node sends a message to the variable node that is connected, indicating whether the parity check equation is met or not.
3. Variable update: If the majority of messages received by each message node do not meet, the variable node changes (flip) the current value. Then go back to step 2. If the maximum number of iterations reached and the codeword is not yet valid, then the algorithm stops, and the failure to converge message is reported.

OFDM (Orthogonal Frequency Division Multiplexing) is a multicarrier modulation technique. All of sub-carriers are orthogonal to each other. In OFDM techniques, each sub-carrier is not spread based on existing bandwidth, but the sub-carriers are arranged to overlap with each other. It caused OFDM will not provide Inter-Carrier Interference (ICI) and greatly saving frequency spectrum [9]. The distance or space between sub-carriers are arranged in such a way so in between sub-carriers are separated by a symbol and each symbol is mutually orthogonal or does not affect each other. A symbol is orthogonal with another if the correlation factor is 0 [10].

The OFDM's working principle is to divide the high-speed data rate into several low-speed data rates that are transmitted simultaneously using multiple subcarriers that are mutually orthogonal. The low data rate on each sub-carrier leads to longer symbol periods and narrower sub-carrier bandwidth, saving bandwidth usage. OFDM is also able to reduce the Inter-Symbol Interference (ISI) arising from multipath. The OFDM parameters used in this study are shown as follows:

Table 2. OFDM Parameters

Parameter	Value
Cyclic Prefix (CP)	1/8
Subcarrier	128
Modulation	QAM

B. Block Diagram System

Block diagram system that used in this study can be shown in Fig. 2.

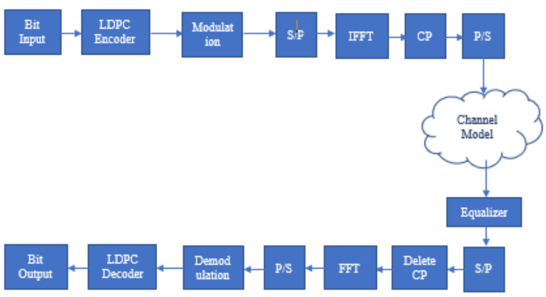

Fig. 2. Diagram system block

Based on Fig. 2, Equalizer has a function to detect signals through the multipath channel in the frequency domain. S/P (Serial to Parallel) divides the serial data stream to be parallel data stream with lower speed.

Meanwhile, P/S (Parallel to Serial) does the opposite of S/P. CP (Cyclic Prefix) in OFDM is used to eliminate ISI [11]. In this study, we used CP 1/8 means that one part of the data was copied and inserted before the data.

C. Channel Model

1. AWGN Channel Model

This study using the AWGN channel model and Rayleigh fading channels with frequency-flat fading. AWGN is a stochastic process that occurs in channels with a spectral density of noise evenly along with the frequency range with pdf (probability density function) as follows [12]:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-m)^2}{2\sigma^2}\right] \quad (1)$$

with:

$p(x)$: probability of noise appearing
σ : standard deviation
m : flattening (mean)
x : variable (voltage or signal power)

2. Rayleigh Fading

Rayleigh fading is a channel condition caused by multipath. The type of Rayleigh channel used in this study is frequency-flat fading. It means that the decreasing power occurs uniformly along the path.

3. Rain rate

This study used 90 mm/h rain rate values for Purwakarta at longitude 107.449944 and latitude -6.538681 based on ITU-R P.837-7 [13] recommendations (Fig. 3).

The higher the frequency, the more sensitive it will be to the presence of rain. It means the channel will facing greater attenuation value in rainy conditions [14].

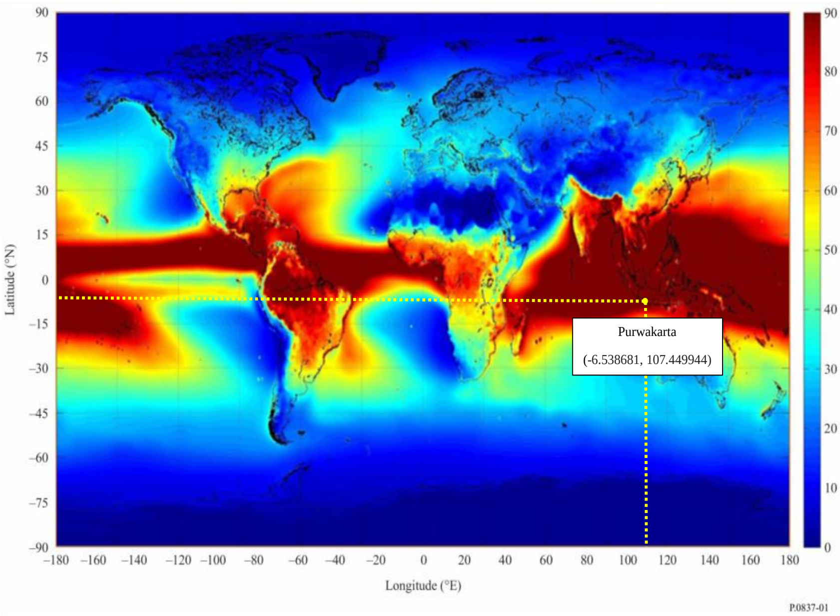

Fig. 3. Rainfall Rate Exceeded for 0.01% of an Average Year [13].

Based on ITU-R P. 838-3 the rain attenuation value (dB/km) is calculated from rainfall or γ_R rain rate R (mm/h) with the following equation [15]:

$$\gamma_R = kR^{\alpha} \quad (2)$$

The value for the coefficient k and α are determined as a function of frequency, f (GHz), in the range from 1 to 1000 GHz, calculated by the following equations, which have been developed from curve-fitting to power-law coefficients derived from scattering calculations [15]:

$$\log_{10} k = \sum_{j=1}^{4}\left(a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right]\right) + m_k log_{10} f + c_k \quad (3)$$

$$\alpha = \sum_{j=1}^{5}\left(a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right]\right) + m_a log_{10} f + c_a \quad (4)$$

with

f : Frequency (GHz)
k : either k_H or k_v
α : either α_H or α_v

k_H is the coefficient for horizontal polarization and k_v for vertical polarization which given in [15].

III. RESULTS

This section discusses the simulation performed in this study. The target of BER in this study is 10^{-4}. The simulation scenarios used in this study can be seen as follows:

A. Scheme 1

Scheme 1 is performed by using 4-QAM modulation and adding consideration of rain attenuation. This scheme aims to find out how much rain affects the system without any additional coding techniques.

Table 3. Scheme 1 Testing Parameters

Modulation	Coding	Rain rate
4-QAM	None	None 90 mm/h

B. *Scheme 2*

In scheme 2, an additional LDPC code is performed with code rate (R)= 1/2 on the system. This scheme aims to determine the effect of the LDPC code in rainy conditions at Purwakarta.

Table 4. Scheme 2 Testing Parameters

Modulation	Coding	Rain rate
4-QAM	None LDPC R= 1/2	90 mm/h

C. *Scheme 1 Simulation*

From scheme 1, the following results are obtained:

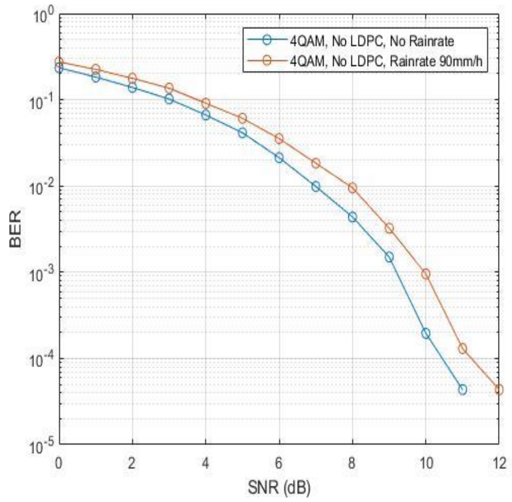

Fig. 3. Scenario 1 Simulation Result Graph.

Fig. 3 shows that the attenuation coming from the presence of rain causes bad system performance compared to no rainy day. High frequencies were more sensitive to the rain, and it can be seen in this figure. When using high frequency (60 GHz) in the rain conditions, it produced higher attenuation that needs SNR more than no rain conditions.

Based on Fig. 3, it can be known the value of SNR to reach BER 10^{-4} is,

Table 5. Scenario 1 SNR Value

Modulation	Coding	Rain rate	SNR (dB)
4-QAM	None	None	10.44
		90 mm/h	11.24

To get BER 10^{-4}, the system with 4-QAM and without LDPC code required SNR 11.24 dB for rain case, higher than without rain case, i.e., 10.44 dB.

The SNR value result from scheme 1 (Table 5) indicates that rain is strongly influenced system performance.

D. *Scheme 2 Simulation*

From the scheme 2 simulation, the following results are obtained,

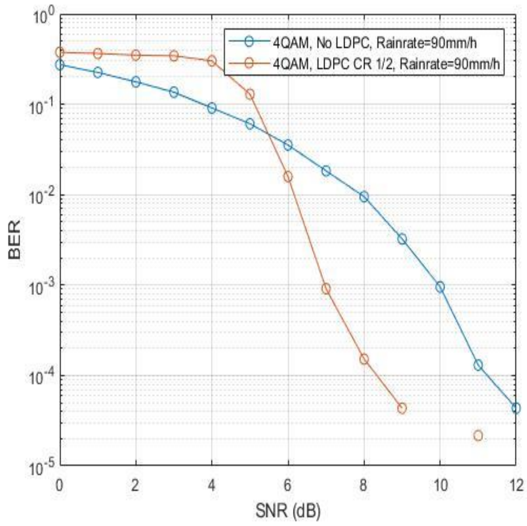

Fig. 4. Scheme 2 Simulation Results Graph.

Fig. 4 indicates that to achieve BER 10^{-4}, the SNR required for a 4-QAM modulation scheme with LDPC code code rate 1/2 is smaller than without LDPC code. The detailed result as follows,

Table 6. Scheme 2 SNR Value

Modulation	Coding	Rain rate	SNR (dB)	Coding Gain (dB)
4-QAM	None	90 mm/h	11.24	Reference
	LDPC R= 1/2		8.33	2.91

From Table 6, to achieve BER 10^{-4} by using LDPC code (R=1/2) can be obtained with a smaller SNR than scheme 1. With 4-QAM and LDPC code R=1/2 in the rainy condition, the SNR was needed only 8.33 dB to get BER 10^{-4}. It was smaller than without the LDPC code scheme, which was given the coding gain of 2.91 dB.

IV. DISCUSSION

Based on the result above, it can describe that rain affects the system. The effect of rain causes the value of SNR has to be greater than no rainy day. This is because the rainfall produces attenuation, which increases the probability of more bits of error; thereby, a greater SNR value is needed, which means it needs more power. A higher frequency will produce higher attenuation than was given by rain conditions.

In the presence of rain, the system's performance with LDPC code is better than without LDPC code. It happens because, as an ECC (Error Correcting Coding), LDPC code detects and corrects errors from redundancy bits added to the encoding process. It gives better performance of system than without LDPC code.

V. CONCLUSSION

From the simulation that has been done, it can be concluded that a 5G network communication system at 60 GHz frequency can be implemented in Purwakarta, Indonesia. For better system performance, we need to implement LDPC code. This study shows that to get BER 10^{-4}, required SNR 8.33 dB with 4-QAM modulation scheme and LDPC code code rate 1/2.

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