BER Analysis Over a Rayleigh Fading Channel: An Investigation using the NOMA Scheme

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Abstract. Researches has carried out in the academia and the industry to examine the error performance of the Non-Orthogonal Several Access (NOMA) schemes since NOMA can serve multiple users concurrently while using the same time and frequency resources. Because its access is not orthogonal, interference between users is a fundamental disadvantage of the NOMA technology. An interference cancellation approach, such as successive interference cancellation (SIC) at the receiver, is typically used to resolve this. Contrarily, inter-user interference in the SIC process cannot be eliminated and is usually due to wrong decisions at the receiver caused by the channel. The performance of the downlink NOMA for the BPSK transmission system in a Rayleigh fading was assessed in this paper using MATLAB. The findings demonstrate that NOMA offers users reasonable fairness while minimizing interference at a reasonable BER.

Keywords: NOMA, SIC, BER, BPSK.

1 Introduction

The fundamental idea of NOMA is to utilize the power domain for multiple access in contrast to previous generations of mobile networks, which depend on the time/frequency/code domain [1]. The fundamental drawback of orthogonal multiple access (OMA) approaches is that they have a low spectral efficiency when some bandwidth resources, like subcarrier channels, are given to users with low channel state information (CSI). However, while employing NOMA, every user has access to every subcarrier channel. Thus, the bandwidth resources allotted to users with low CSI can still be accessed by users with high CSI, thus increasing spectral efficiency [2].

Superposition coding at the transmitter and Successive Interference Cancellation (SIC) at the receivers are the key components of NOMA, which is anticipated to outperform Orthogonal Multiple Access (OMA) in terms of spectral efficiency [3].

For optimal performance, signal transmission attenuation, distortion, and noise must be minimized. The transmitting and receiving signals must therefore be accurately measured. Factors, coding, features, and various digital modulation techniques can impact the reliability of the received signal and the transmission quality. In contrast to its wired counterpart, wireless technology has several advantages, such as enhanced mobility, higher productivity, reduced costs, simpler installation, and scalability [4]. As a result of reflection, diffraction, and scattering effects, transmitted signals arrive at the receiver with varying power and delay, which is one of the limitations and drawbacks of different transmission channels in the wireless medium between the transmitter and receiver.

When data is transmitted over a wireless channel, there is a risk of errors in the system. The system's integrity can be compromised if errors are introduced into the data [5]. Therefore, evaluating the system's performance is necessary, and the bit error rate BER provides an ideal method to achieve this goal. Unlike many other types of evaluation, BER evaluates the end-to-end performance of a system, including the transmitter, receiver, and mediation between the two. In this way, the BER can test the system's actual performance rather than testing the components and hoping they perform satisfactorily once they are in place [6]. The BER value for the wireless medium is relatively high. The efficiency of wireless data transfer may suffer from these problems. Error management is therefore required for many applications.

Using discrete signals, a carrier wave is modified using the digital modulation approach. High carrier frequencies are employed in digital modulation to facilitate signal transmission over long distances using existing long-distance communication methods, such as radio channels [7]. The received demodulated signal is not adversely affected by channel noise. Conversely, the demodulated signal is distorted if the analogue signal contains noise. Applications that run on the fifth generation (5G) radio access networks have extremely high speeds, low latency, mass connectivity, and good mobility. [8], [9]. NOMA enables high-density networks and great spectral efficiency by allowing users to access the same radio resources **[10]**. Multiple users are served by conventional Orthogonal Multiple Access (OMA) schemes by assigning them to various radio resources, such as frequency and time. Unlike OMA, which splits users into power domains, NOMA services large numbers of User Equipment (UE) concurrently on the same resource blocks. Superposition coding at the transmitter and successive interference cancellation at the receiver are the fundamentals of a NOMA technique [11], [12]. Figure 1 details the operation of a digital-communication networks.

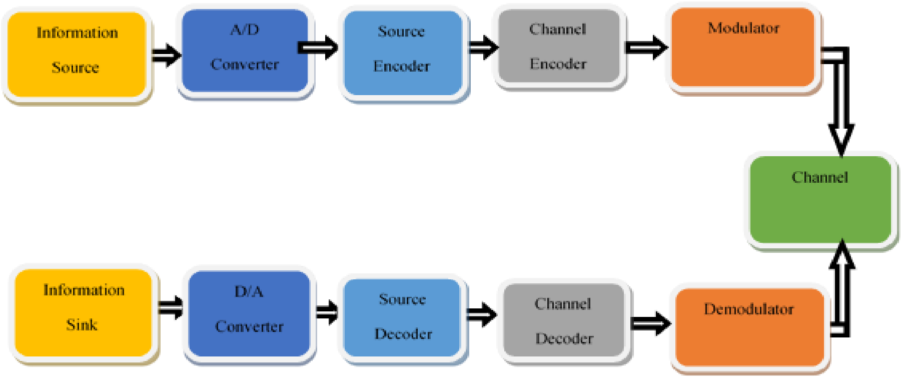

Figure 1. A digital communication system's block diagram

2 System Model

A wireless channel is vulnerable to fading and multipath propagation. Numerous channel models can be used to capture the effects of fading. Every model aims at a specific circumstance. The Rayleigh fading model is one example. The Rayleigh fading model can be used when there is no line of sight (LOS) path between the transmitter and the receiver. As a result of reflection, scattering, diffraction, and shadowing, all multipath components undergo small-scale fading. In an extreme form of Rayleigh fading, caused by multipath transmission, every bit transmitted experience a different attenuation and phase shift. In other words, the channel changes for every bit. The Rayleigh fading model is used to statistically analyze radio signal propagation. It works best without a dominant signal, which often happens with cell phones used in dense urban environments.

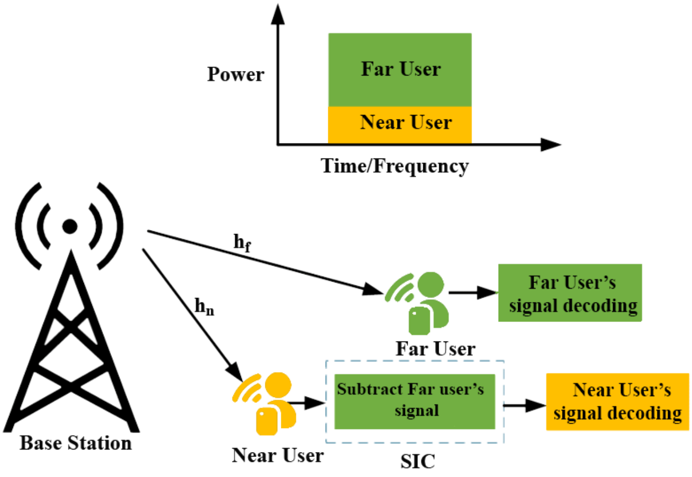

Figure 2. Network Model

The weak user in NOMA is given additional transmission power. By interpreting the messages of other users as noise, the weak user can decode its message [2]. On the other hand, the strong user will first identify its message partner under the stronger channel state, subtract the message from the weak user, and last decode its own message. This method explains the successive interference cancellation.

The Base Station has two discrete messages x_f to the far user, and x_n to the near user. The power allocation factors are α_f and α_n respectively, for the far and the near user (where $\alpha_f + \alpha_n = 1$). In a NOMA system, more power is allocated to the far user and less to the near user to promote user fairness ($\alpha_f > \alpha_n$).

2.1 NOMA Encoding and Transmission

The Base Station transmits a superposition-coded NOMA signal that is:

$$x = \sqrt{P}\,\left(\sqrt{a_f x_f} + \sqrt{a_n x_n}\,\right) \tag{1}$$

Where P is the transmit Power.

After propagating through the channel h_f, the copy of x that the near user receives is given as:

$$y_f = h_f w + w_f \tag{2}$$

Where *w* is noise.

Similarly, the copy of x that was propagated through h_n and received by the far user is given as:

$$y_n = h_n w + w_n \tag{3}$$

2.2 NOMA decoding at the Far User

Expanding the signal received by the far user:

$$y_f = h_f x + w_f \tag{4}$$

$$= h_f\,\sqrt{P}\,\left(\sqrt{\alpha_f\,x_f} + \sqrt{\alpha_n\,x_n}\,\right) + w_f \tag{5}$$

$$= h_f\,\sqrt{P}\,\left(\sqrt{\alpha_f\,x_f} + h_f\,\sqrt{P}\sqrt{\alpha_n\,x_n}\,\right) + w_f \tag{6}$$

Where:

$h_f\,\sqrt{P}\sqrt{\alpha_f\,x_f}$ is the desired and dominating signal,

$h_f\,\sqrt{P}\sqrt{\alpha_n\,x_n}$ is the interference and low power signal,

w_f is noise.

Direct decoding of y_f would yield x_f since $\alpha_f > \alpha_n$. The term x_n component was considered as an interference. For far user, the signal-to-interference noise ratio is given as;

$$\gamma_f = \frac{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{f}}{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{n} + \sigma^2} \tag{7}$$

and its achievable data rate is given as:

$$\mathrm{R_f} = log_2\left(1 + \gamma_f\right) = log_2\left(1 + \frac{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{f}}{|\mathrm{h_f}|^2 \mathrm{P}\alpha_\mathrm{n} + \sigma^2}\right) \tag{8}$$

2.3 NOMA decoding at the Near User

Expanding the signal received by the near user:

$$y_n = h_{fn}x + w_n \tag{9}$$

$$= h_n \sqrt{P}\left(\sqrt{\alpha_\mathrm{f}\, x_f} + \sqrt{\alpha_\mathrm{n}\, x_n}\right) + w_n \tag{10}$$

$$= h_n \sqrt{P}\left(\sqrt{\alpha_\mathrm{f}\, x_f} + h_n \sqrt{P}\sqrt{\alpha_\mathrm{n}\, x_n}\right) + w_n \tag{11}$$

Where:

$h_n \sqrt{P}\sqrt{\alpha_\mathrm{f}\, x_f}$ is the desired and dominating signal,

$h_n \sqrt{P}\sqrt{\alpha_\mathrm{n}\, x_n}$ is the interference and low power signal,

w_n is noise.

Before decoding his own signal, the near User must first perform successive interference cancellation (SIC). The SIC procedures are as follows;

1. direct decoding of y_n obtains $\mathrm{x_f}$ or more specially, an estimate of x_f, which is $\bar{x}$
2. y'_n = $y_n - \sqrt{\alpha_f\, \bar{x}_f}$ is computed
3. y'_n is decoded to obtain an estimate of x_n

Before SIC, the signal-to-interference noise ratio at the near user for decoding the signal of the far user is given as;

$$\gamma_{f,n} = \frac{|h_n|^2 P\alpha_f}{|h_n|^2 P\alpha_n + \sigma^2} \tag{12}$$

The corresponding achievable data rate is given as follows;

$$R_{f,n} = log_2\left(1 + \gamma_{f,n}\right) = log_2\left(1 + \frac{|h_n|^2 P\alpha_f}{|h_n|^2 P\alpha_n + \sigma^2}\right) \tag{13}$$

3 BER of a NOMA System

Firstly, we declared the values of some parameters. For the distances, $D_f = 1000\, meters$, and $D_n = 500\, meters$. Then we set the power allocation factors as $\alpha_f = 70$ and $\alpha_n = 30$. For user fairness, we allocated more power to the far user. We initialized a range of 0dBm to 40dBm for the transmit power. Our system's bandwidth was then set to $B = 1MH_z$. According to the formulae, $N_0 = kTB$, where $k = 1.38 \times 10^{-23}$ (Boltzmann constant), $T = 300K$, the thermal noise power was calculated. We then generated the Rayleigh fading coefficients for h_f and h_n. We set the path loss exponent $\eta = 4$. Next, we generated noise samples for the far and near users and randomized binary data for the users. We calculated the superposition-coded signal x after using BPSK to modulate the data. We also calculated y_f and y_n and then equalized them by diving h_f and h_n respectively. From the equalized version of y_f, we performed direct BPSK demodulation to obtain $\bar{x}_f$. We used the biterrr function to estimate BER and compared x̄ with the original data from the far user. To estimate x_f, we directly decoded the equalized version of y_n. We decoded the signal to obtain, $\bar{x}_n$ by remodulating x_f and subtrahend the remodulated x_f element from the equalized version of y_n. We further compared $\bar{x}_n$ with the near user's initial data, we estimated BER using the biterrr function. Finally, we plotted the BERs in relation to transmit power using MATLAB.

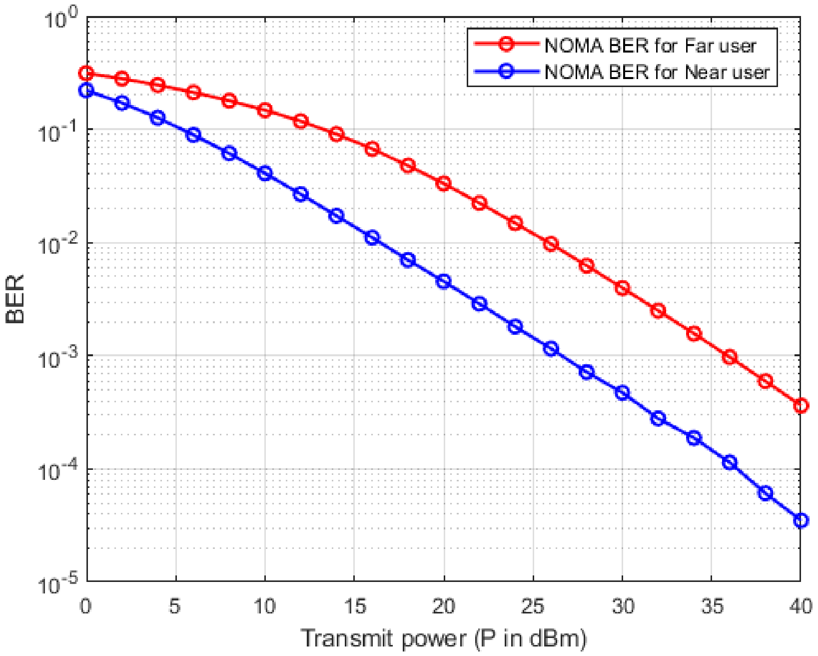

Figure 3. Theoretical and Simulated BER Performance

The BER performance for a two-user scenario is shown in Figure 3. The near and far users were allocated 0.70 and 0.30 power respectively, with a 1MHz bandwidth using the BPSK modulation technique. According to the Figure above, interference from the near user causes the far user to have a greater BER. With no interference, the near user has the lowest BER. This shows that NOMA performs as expected.

Table 1. NOMA BER Analysis.

Transmit Power (dBm)	Far User	Near User
10	0.14857	0.040852
20	0. 033698	0.00449
30	0.004079	0.000422
40	0.000447	0.000037

4 Conclusion

The integrity of the information transmitted through the downlink NOMA system can be assessed using the BER of a digital signal, which is a crucial metric. This work used MATLAB to evaluate the BER performance of a downlink NOMA with a BPSK transmission scheme over a Rayleigh fading channel. The result demonstrated that NOMA offers users a fair system that is acceptable while minimizing interference and maintaining a reasonable BER

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