

Uplink Power-Domain Non-Orthogonal Multiple Access (NOMA): Bit Error Rate Performance with Channel Estimation Errors

Faeik T. Al Rabee, University of South Florida, USA

Richard D. Gitlin, University of South Florida, USA

ABSTRACT

Non-Orthogonal Multiple Access (NOMA) has been proposed as a promising multiple access (MA) technique in order to meet the requirements for Fifth generation (5G) communications and to enhance the performance in Internet of Things (IoT) networks by enabling massive connectivity, high throughput, and low latency. This paper investigates the bit error rate (BER) performance of two-user uplink power-domain NOMA with a Successive Interference Cancellation (SIC) receiver and taking into account channel estimation errors. The analysis considers two scenarios: perfect (ideal) channel estimation and a channel with estimation errors for various modulations schemes, BPSK, QPSK, and 16-QAM. The simulation results show that, as expected, increasing of the modulation level increases the SIC receiver BER. For example, at a signal-to-noise ratio (SNR) of 5 dB for perfect channel estimation and QPSK modulation, the user that is detected first has a BER of 0.005 compared to 0.14 for the user that is detected with the aid of the SIC receiver. Similarly, the BER of QPSK, assuming 0.25 channel estimation error of user 1 is equal to 0.06 at SNR = 15 dB compared to 0.017 for perfect estimation.

Keywords: Non-orthogonal multiple access (NOMA); 5G; power domain, successive interference cancellation (SIC); BER.

INTRODUCTION

In 5G wireless communication systems, new radio access technologies are explored to satisfy the demanding requirements such as massive connectivity, low latency, and high data rate. Designing a suitable multiple access technique is an important aspect to improve system capacity (Jarray, et. al., 2015; Al-Imari, et. al., 2014).

Non-orthogonal multiple access (NOMA) is a promising multiple access technique for 5G cellular systems to improve spectral efficiency, provide low latency, high reliability, and massive connectivity (Yuan & Ding, 2016). NOMA techniques are divided into two categories, namely, power-domain and code-domain (Islam, et. al., 2016; Tao, et. al., 2015). This paper focuses on the power-domain NOMA in the uplink,

where different users share the same time, frequency, and (possibly) code, but with different power levels (Benjebbour, et. al., 2015). To detect the desired signals while minimizing the interference, a SIC technique is employed at the base station (BS) receiver (Mollanoori & Ghaderi, 2014). The signals are assigned unique power levels so that the received signals arrive at the BS with an adequate power difference to allow the SIC receiver to decode them correctly (Dai, et. al., 2018). The SIC receiver sequentially detects the signals from the superimposed received signal at the BS. Once a user signal is successfully decoded, it is subtracted from the composite signal. Various modulations schemes (levels) can be used to modulate the transmitted signals such as BPSK, QPSK, and 16-QAM (Proakis & Salehi, 2008). Here the bit error rate (BER) is investigated for the NOMA receiver with and without channel estimation errors.

Recently, NOMA has been extensively studied in the last few years. For example, a switching between orthogonal multiple access (OMA) and NOMA scheme has been proposed by Janghel & Prakriya, (2018) to improve performance of the far user (FU) while ensuring that near user (NU) does not lose performance due to cooperative NOMA (Ding, et. al., 2015). In addition, a NOMA developed system has been proposed by Liu, et. al., (2017) and the system performance has been analyzed by proposing a power allocation scheme to guarantee the data rate by minimizing the outage probability.

In this paper, the BER performance of a two-user uplink NOMA system using successive interference cancellation (SIC), has been analyzed via simulation. Also, the BER for a given channel estimation error is investigated for BPSK, QPSK, and 16-QAM modulation schemes. The performance in the presence of different estimation errors is analyzed.

The main contributions of this paper can be summarized as follows:

- A simulation study of the BER performance of a two-user uplink NOMA using BPSK, QPSK and 16-QAM with a SIC receiver is introduced.
- For the above study, two scenarios are studied:
 - Perfect channel estimation.
 - Performance with a channel estimation error as a function of the modulation level.

The rest of this paper is comprised of four sections, and it is organized as follows. Describing the system model of a two-user uplink NOMA system with SIC reception is presented in the following section. The third section focuses on the simulation results of the BER performance for different modulation schemes with and without channel estimation errors. The conclusion of this research is contained in the final section.

SYSTEM MODEL

This paper considers the uplink NOMA system which consists of two users and a BS receiver. The corresponding system diagram is illustrated in Figure 1. The first user transmits its signal, X_1 scaled by a power coefficient P_1 , to the BS over a channel with (scalar) coefficient h_1 . The second user sends its signal, X_2 with its power coefficient P_2 , to the BS with channel coefficient h_2 . The received signal, y , at the BS is represented as:

$$y = h_1x_1 + h_2x_2 + n, \quad (1)$$

where n is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2 . The transmitted signals x_1

and x_2 in (1) represent the transmitted signals X_i for each user with its power coefficient P_i .

The optimum received uplink power levels using a SIC detector were determined by Al Rabee, et. al. (2017) for any number of transmitters. The analysis in this paper assumed that there is a constant channel during the estimation and communication process. In this paper, constant channel estimation error, e , is

assumed. Furthermore, the power coefficients are set to the optimum levels as determined by Al Rabee, et. al. (2017). As in Figure 1, the SIC receiver detects user 2 signal first from the superimposed signals and noise, then the detector subtracts this signal from the superimposed signal in order to perform the detection of user 1 signal. This is illustrated in Figure 2.

Figure 1. Uplink NOMA system with two users

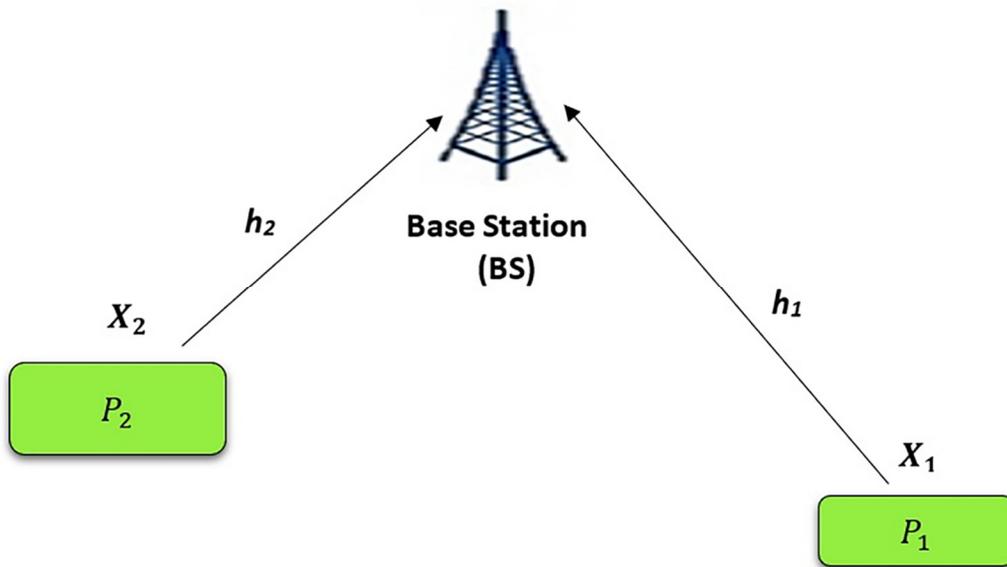
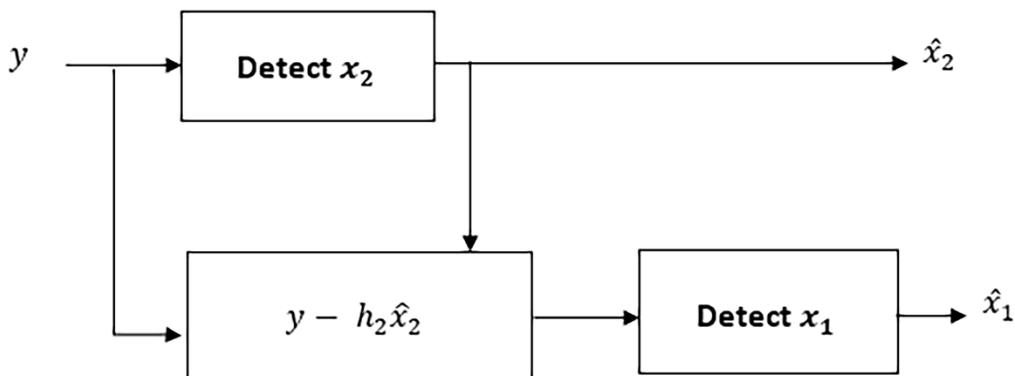


Figure 2. Illustration of SIC signal detection for a two-user uplink NOMA



This paper focuses on studying the BER performance of a two-user uplink NOMA using a SIC detector for different modulation schemes. First, the BER performance, with various modulations schemes, is studied assuming no channel estimation error (perfect channel estimation). Second, the effect of a channel estimation error on each modulation scheme is investigated.

For the perfect scenario, the methodology assumes that the two users signals have been generated each 10^6 bits in duration to create the BPSK, PSK and 16-QAM signals. In addition, AWGN noise has been generated and then it is added to the two transmitted signals at the receiver side as shown in (1).

Taking into account the channel attenuation, the power coefficients P_1 and P_2 have been selected so that the received signals are the optimum values as determined by Al Rabee, et. al. (2017) and are communicated using the Slotted Aloha-NOMA (SAN) protocol as introduced by (Balevi, et. al., 2018; Elkourdi, et. al., 2018). In the present analysis, user 2 is assumed to be detected first by the SIC detector. The simulation results of this scenario are discussed in details in the following section.

For the case with channel estimation errors, the BER performance is investigated for the different modulation schemes. In addition to the same assumptions in the perfect estimation case, there are some additional assumptions. With channel estimation errors, the received signal powers are selected to be the values that would be optimal when there are no channel estimation errors. The estimation error (e) is defined as the absolute value of the difference between the channel coefficient and its estimated value normalized to the magnitude of the channel coefficient. So that, the error value is considered as a percentage value

(normalized to the channel coefficient). The results have been simulated for different values of channel estimation error. For simplicity, the results are shown for 0.15 and 0.25 estimation errors.

SIMULATION RESULTS AND ANALYSIS

Based on the assumptions in the second section, the two scenarios are simulated for the three modulation schemes and the results are analyzed. The simulation results for perfect channel estimation of BPSK uplink NOMA system with two users is shown in Figure 3. As expected, the figure shows that user 2 has better BER performance than user 1. In this case, the parameter that affects the performance of SIC detection is the ratio of user 2's power to the combination of user one's power plus the noise power.

As assumed, the SIC detector will detect user 2 signal first from the superimposed received signal plus noise. The noise power will have a significant effect on the detection of user 1 since the receiver first performs subtraction of the detected user 2's signal in addition to processing the noise. After detecting user 2's signal with the SIC receiver, the remaining signal, assuming correct detection of user 2, is user 1's signal in addition to the noise. So that, the subtraction of user 2's signal makes the detection of user's 1 signal more vulnerable to noise than user 2 and this leads to a larger BER for this user as compared to user 2. As shown in Figure 3, the BER for user 2 at SNR = 0 dB is equal to 0.01 compared to 0.15 for user 1 at the same SNR of 0 dB. Furthermore, for SNR = 5 dB, user 2 has a BER of 0.001 and user 1 has a BER of 0.10. On the other hand, the simulation results for the same modulation of BPSK but with channel estimation errors are shown in Figure 4.

Figure 3. BER vs. SNR for two BPSK uplink NOMA users with perfect channel estimation

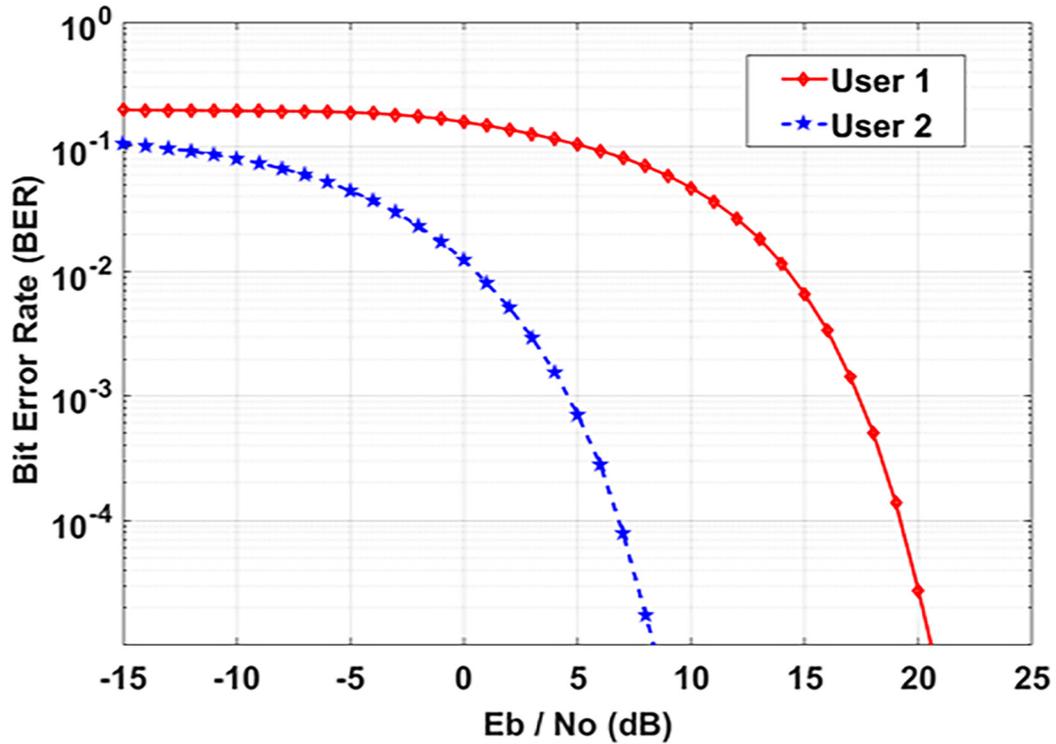
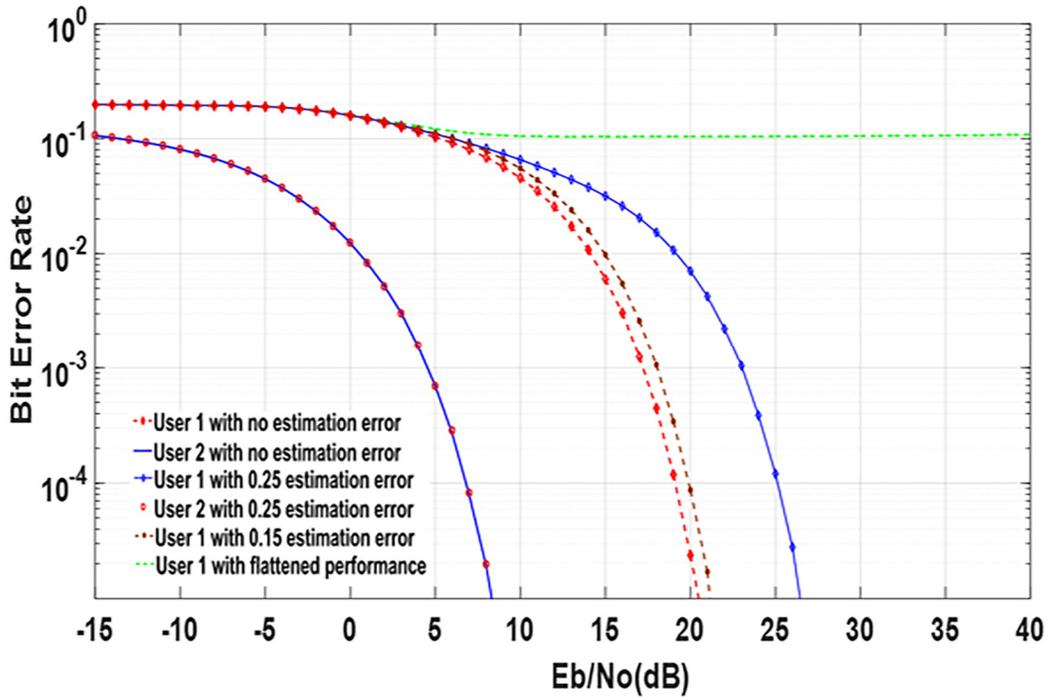


Figure 4. BER vs. SNR for two BPSK uplink NOMA users with different channel estimation errors



In this figure, two channel estimation errors, 0.15 and 0.25, are assumed. In addition to the affecting parameters of the perfect case, adding an estimation error degrades the SIC detection process and the BER performance. Assuming detection of user 2's signal first by the SIC detector, the remaining signal after detection user 2's signal is user 1's signal with an added estimation error in addition to the noise. This degrades signal reception and, as expected, leads to a degraded BER compared to the perfect case. For example, at SNR = 15 dB, the BER for user 1 is equal to 0.01 for 0.15 channel estimation error compared to a BER of 0.007 for perfect

estimation at the same SNR value. As the estimation error value increases, the BER is increased. In the same way, as shown in Figure 4, at SNR = 15 dB, the BER for user 1 is equal to 0.32 for 0.25 channel estimation error which is higher than the BER of 0.007 for perfect estimation and 0.01 for 0.15 channel estimation error at the same SNR value.

Approximately, the same analysis for the two scenarios can be followed for higher modulation schemes, QPSK and 16-QAM, as shown in Figure 5 and Figure 6, respectively.

Figure 5. BER vs. SNR for two QPSK uplink NOMA users with different channel estimation errors

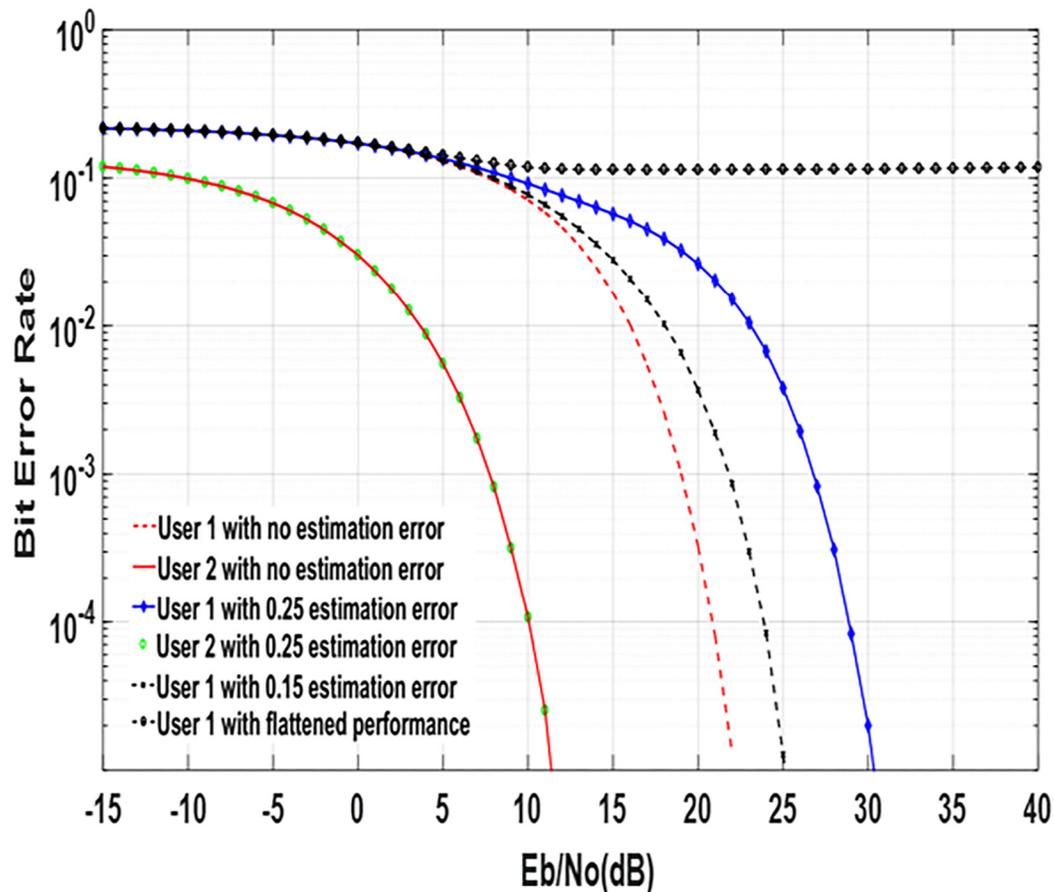
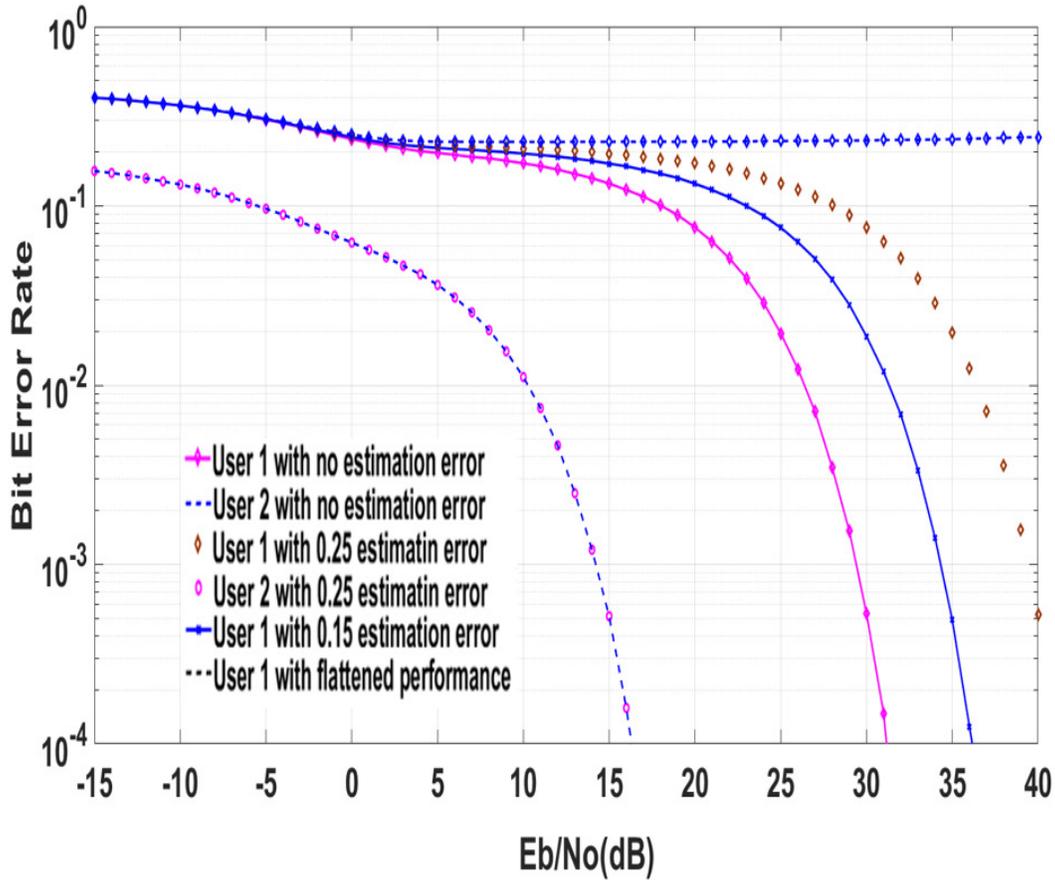


Figure 6. BER vs. SNR for two 16-QAM uplink NOMA users with different channel estimation errors



In these figures, the results for various channel estimation errors are demonstrated. For the perfect channel estimation, at SNR = 5 dB, the BER of user 2 for QPSK modulation is equal to 0.005 compared to 0.14 for user 1 at the same SNR. On the other hand, for 16-QAM, the BER for user 2 at SNR = 5 dB is equal to 0.04 compared to 0.20 for user 1 at the same SNR. As a result, the BER performance of user 1 becomes worse for the same reason discussed in the perfect estimation of BPSK and at the same time increasing the modulation level increases the degradation of the BER.

For the channel estimation error scenario, 16-QAM has a higher BER than

QPSK BER which is expected as discussed above. For example, at SNR = 15 dB and 0.15 channel estimation error, Figure 5 shows that the QPSK BER of user 1 is equal to 0.028 compared to 0.017 for the perfect channel estimation at the same SNR value. In addition, for the same SNR value of 15 dB, Figure 6 shows that 16-QAM of user 1 has a BER of 0.17 for 0.15 channel estimation error compared to 0.07 for the perfect estimation at the same SNR value.

Furthermore, for a QPSK with 0.25 channel estimation error, the BER of user 1 is equal to 0.06 at SNR = 15 dB compared to 0.017 for perfect channel estimation and 0.028 for 0.15 channel estimation error at the same SNR. For 16-QAM, the BER at

SNR = 15 dB is 0.20 for 0.25 channel estimation error compared to 0.07 for perfect estimation and 0.17 for 0.15 channel estimation error at the same SNR.

As a result, with increased channel estimation error, the BER is also increased and further increases with increased modulation order. An interesting observation is that, at high channel estimation error, the results for the three modulation schemes indicate a very high BER and a flattened performance as compared to the perfect estimation and the given channel estimation errors results. This is due to the degradation in the SIC receiver that results in high BER.

CONCLUSION

In this paper, a simulation study for the BER performance of a two-user uplink NOMA system for BPSK, QPSK and 16-QAM, using a SIC detector, has been presented. For each modulation level, two scenarios have been considered: perfect channel estimation and a channel with estimation errors. For perfect channel estimation, as expected, the simulation results show that the BER of the SIC receiver increases as the modulation order is increased. Similarly, with channel estimation errors, the BER increases as the estimation error is increased for a given noise level. For example, for perfect channel case, at SNR = 5 dB, user 2 has a BER of 0.001 and user 1 has a BER of 0.1. In contrast, 16-QAM results in a BER of 0.04 for user 2 and a BER of 0.20 for user 1 at the same SNR of 5 dB. On the other hand, for channel estimation error, the QPSK BER, for user 1 with 0.25 channel estimation error, is 0.058 at SNR = 15 dB compared to 0.017 for perfect channel estimation and 0.028 for 0.15 channel estimation error at the same SNR. For 16-QAM, the BER at SNR = 15 dB is 0.20 for 0.25 channel estimation error compared to

0.07 for perfect estimation and 0.17 for 0.15 channel estimation error at the same SNR. As a result of the degradation in the SIC receiver, at a high estimation error value, all the modulation levels results show a very high BER and a flattened performance.

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Authors

Faeik T. Al Rabee received his B.Sc. degree in Communications and Software Engineering from Al-Balqa' Applied University/ Al-Huson University College, Irbid, Jordan in 2008, with a full scholarship from the Ministry of Higher Education, Jordan. He got 94% percentile rank over Jordan in the University Achievement Test. In 2013, he received the M.Sc. degree in Electrical Engineering majoring in Wireless Communications from Jordan University of Science and Technology (JUST), Irbid, Jordan. His M.Sc. dissertation was in the Optical Fiber Communications area. He research was directed towards using an optical filter in order to compensate for fiber dispersion. During his graduate studies, he worked as teaching assistant in the Electrical Engineering department at JUST University for three years. Currently, he is pursuing his Ph.D. degree in Electrical Engineering department at the University of South Florida with the Innovations in Wireless Information Networking (iWINLAB) group under the supervision of Prof. Richard D. Gitlin. His research interests include 5G wireless systems and networking protocols, multiple access techniques for 5G wireless network (Non-Orthogonal Multiple Access -NOMA), and the Internet of Things (IoT).

Richard D. Gitlin is a State of Florida 21st Century World Class Scholar, Distinguished University Professor, and the Agere Systems Chaired Distinguished Professor of Electrical Engineering at the University of South Florida. He has 50 years of leadership in the communications industry and in academia and he has a record of significant research contributions that have been sustained and prolific over several decades. Dr. Gitlin is an elected member of the National Academy of Engineering (NAE), a Fellow of the IEEE, a Bell Laboratories Fellow, a Charter Fellow of the National Academy of Inventors (NAI), and a member of the Florida Inventors Hall of Fame (2017). He is also a co-recipient of the 2005 Thomas Alva Edison Patent Award and the IEEE S.O. Rice prize (1995), co-authored a communications text, published more than 170 papers, including 3 prize-winning papers, and holds 65 patents. After receiving his doctorate at Columbia University in 1969, he joined Bell Laboratories, where he worked for 32-years performing and leading pioneering research and development in digital communications, broadband networking, and wireless systems including: co-invention of DSL (Digital Subscriber Line), multicode CDMA (3/4G wireless), and pioneering the use of smart antennas ("MIMO") for wireless systems. At his retirement, Dr. Gitlin was Senior VP for Communications and Networking Research at Bell Labs, a multi-national research organization with over 500 professionals. After retiring from Lucent, he was visiting professor of Electrical Engineering at Columbia University, and later he was Chief Technology Officer of Hammerhead Systems, a venture funded networking company in Silicon Valley. He joined USF in 2008 where his research is on wireless cyber-physical systems that advance minimally invasive surgery and cardiology and on addressing fundamental technical challenges in 5G/6G wireless systems.