Multi-Antenna based NOMA Systems

Devesh Yadav
2016145

***Abstract*—The aim of the project is to study NOMA system and its MATLAB based implementation. This paper emphasis on power-domain NOMA which utilizes superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. Non-orthogonal multiple access (NOMA) is one of the promising radio access techniques for performance enhancement in next-generation cellular communications. Compared to orthogonal frequency division multiple access (OFDMA), which is a well-known high-capacity orthogonal multiple access (OMA) technique, NOMA offers a set of desirable benefits, including greater spectrum efficiency and mass connectivity.**

***Index Terms*—Outage probability, capacity, efficiency, NOMA, OMA**

I. Introduction

Conventional 4G networks use orthogonal frequency division multiple access (OFDMA) where information for each user is assigned to a subset of subcarriers, whereas In NOMA, all of the subcarriers can be used by each user (as shown in figure 1.).Let us consider a carrier with 1Hz bandwidth. With NOMA, the entire 1 Hz BW is simultaneously used by two users. However, with OMA, user 1 uses x Hz and the remaining (1-x) Hz is assigned to user 2. In NOMA, user 2 first performs SIC to decode the signal for user 1. The decoded signal is then subtracted from the received signal of user 2. This resultant signal is eventually used to decode the signal for user 2. For user 1, SIC is not executed, and the signal is directly decoded [1]. Before even attempting to start with

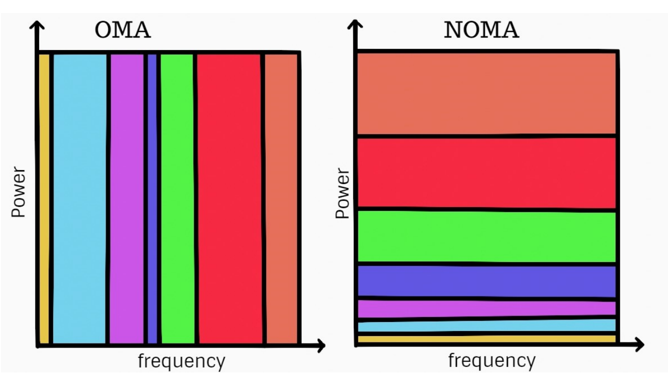

Fig. 1. A comparision NOMA vs OMA

implementation of NOMA, we first Need to know a few terms:

A. Superposition Coding (SC)

This is a technique of simultaneously communicating information to several receivers by a single source. At the transmitter site, all the individual information signals are superimposed into a single waveform [1]. X(n) = $\sqrt{P\beta_1}S_1(n)$+$\sqrt{P\beta_2}S_2(n)$ Where β_i represents a fraction of the total power P assigned to user i, subject to the constraint on $\beta_1 + \beta_2$ = 1.

B. Successive Interference Cancellation (SIC)

In SIC the user signals are successively decoded. The decoded signal is subtracted from the combined signal. When SIC is applied, the user signals are treated as interferers except for the one which is being decoded, but the former (undecoded signals) is then decoded with the benefit of the signal of the former having already been removed [1].

II. System model

We are considering two users user 1 at a distance 1000m and user 2 at a distance 500m from the base station. User 1 will have a weaker signal as he is far away from the transmitting BS. User 2 is the near/strong user. The BS has two distinct messages S1 to user 1 (far user), and S2 to user 2 (near user). β_1 and β_2 are the power allocation factors for the far and the near user respectively (β_1 + β_2 = 1). h1 and h2 denotes the channel from the BS to the near and the far user respectively.

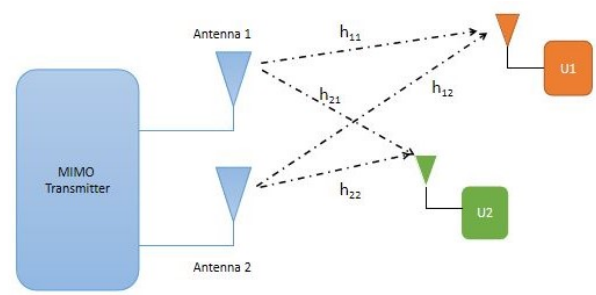

Fig. 2. NOMA system model[5]

III. Implementations

A. SC and SIC

SC

1) the superposition coded NOMA signal transmitted by the BS is: $X(n) = \sqrt{P\beta_1}S_1(n) + \sqrt{P\beta_2}S_2(n)$ where, P is the transmit power.
2) The received at the near user after propagating through channel h1 is, $y_1 = h_1x + w_1$.
3) the received at the far user after propagating through channel h2 is, $y_2 = h_2x + w_2$ [1].

SIC

1) At user 1, a single-user decoder decodes the message S1(n) by treating S2(n) as noise.
2) User 2 performs the following steps:
   a) Decode user 1's message S1(n) by using the single-user decoder.
   b) Subtract $\sqrt{P\beta_1}h_2S_1(n)$ from the received signal $Y_2'(n) = Y_2(n) - \sqrt{P\beta_1}h_2S_1(n)$, where h2 is the complex channel gain at user 2.
   c) Decode user 2's messages S2(n) by applying another single-user decoder [1].

B. Shannon-Hartley Theorem

This theorem gives us a maximum bit-rate that can be transmitted with an arbitrarily small bit-error rate (BER), with a given average signal power over a channel with bandwidth BWHz. The maximum achievable bit-rate is referred to as the channel capacity C.

1) The achievable data rate in NOMA for user 1 and user 2 are given by C_{1NOMA} and C_{2NOMA}, respectively.
   - $C_{1NOMA} = BW\log_2\left(1+\frac{|h1|^2\sqrt{P\beta_1}}{|h1|^2\sqrt{P\beta_2}+\sigma^2}\right)$
   - $C_{2NOMA} = BW\log_2\left(1+\frac{|h2|^2\sqrt{P\beta_2}}{\sigma^2}\right)$
2) The achievable data rate in OMA for user 1 and user 2 are given by C_{1OMA} and C_{2OMA}, respectively.
   - $C_{1OMA} = (\alpha)BW\log_2\left(1+\frac{|h_1|^2\sqrt{P\beta_1}}{\sigma^2}\right)$
   - $C_{2OMA} = (1-\alpha)BW\log_2\left(1+\frac{|h_2|^2\sqrt{P\beta_2}}{\sigma^2}\right)$

   where, σ^2 is the noise power and α is equal to 0.5.

C. Outage Probability

In cellular communication outage probability is defined as the probability of point at which data rate is less than the required threshold data rate. It is the probability that an outage will occur within a specified time period. Once data rate falls below threshold data rate we can say that the receiver is out of the range of BS in cellular communications [6]. If the SNR is high, the outage probability of the NOMA user in a typical disk-shaped cell with radius, R_D can be given by:

- $\mathrm{P}_{\mathrm{i}}^{\mathrm{out}} = \frac{\tau i}{i}\eta^{\mathrm{i}}\left(\psi_{\mathrm{i}}^{*}\right)^{\mathrm{i}}$
- $\tau_{\mathbf{i}} = \frac{N!}{(i-1)!(N-i)!}$
- $\eta = \frac{1}{R_D}\Sigma_{\mathrm{l=1}}^{\mathrm{L}}\beta_{\mathrm{l}}$
- $\beta_l = \frac{\pi}{l}\sqrt{1-\theta_{l.}^2}\left(\frac{R_D}{2}\theta_l+\frac{R_D}{2}\right)\left(1+\left(\frac{R_D}{2}*\theta_l+\frac{R_D}{2}\right)^{\alpha}\right)$
- $\theta_l = \cos\left(\frac{2n-1}{2L}\pi\right)$

Where the symbols L,α, and ψ^* represent the complexity-accuracy trade-off parameter, the path-loss factor, and the maximum SNR corresponding to the data rate of the ith user, respectively [1].

D. Spectral Efficiency

Spectral efficiency refers to the data rate that can be transmitted over a given bandwidth in a communication system. It is a measure of how efficiently we are utilizing a frequency spectrum [7]. The spectral efficiency of a digital communication system is measured in bit/s/Hz,

1) The Spectral Efficiency of NOMA for user 1 and user 2 are given by R_{1NOMA} and R_{2NOMA}, respectively.
   - $R_{1NOMA} = \frac{C_{1NOMA}}{BW}$
   - $R_{2NOMA} = \frac{C_{2NOMA}}{BW}$
2) The Spectral Efficiency of OMA for user 1 and user 2 are given by R_{1OMA} and R_{2OMA}, respectively.
   - $R_{1OMA} = \frac{C_{1OMA}}{BW}$
   - $R_{2OMA} = \frac{C_{2OMA}}{BW}$

IV. Results

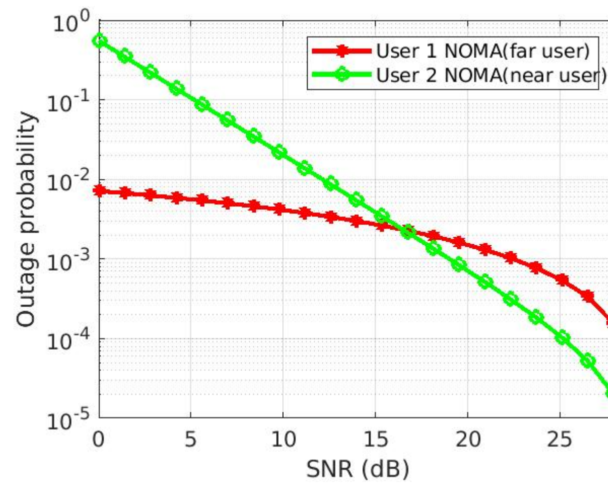

Fig. 3. Outage performance of NOMA with random users in a cell.

Figure 3. compares the outage performance of User 1 and User 2 in NOMA scheme with N=2, L =10, α= 2 and R_D = 3m. The ratio of the power assigned to a strong user to the power assigned to a weak user is 1:4. Since the assigned power to the strong user (user 2) is proportionally lower, the outage performance at a low SNR region is poor. However, as the SNR becomes high enough, User 2 shows the best performance [1].

By comparing Figure 3. and Figure 4. It is clear that NOMA achieves less outage than OMA for both the users and in high SNR regions both users (NOMA) outperform the OMA scheme (BW=10^6Hz).

In figure 5. We can notice that after a point the far/weak NOMA user (user1) suffers from a saturation in its Spectral efficiency. This is because of interference experienced by far/weak user, caused by the signals from near user.This characteristic can be observed in all NOMA networks. The

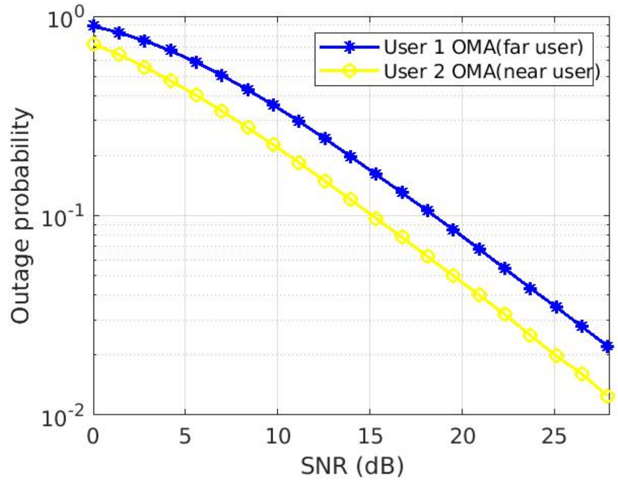

Fig. 4. Outage performance of OMA with random users in a cell.

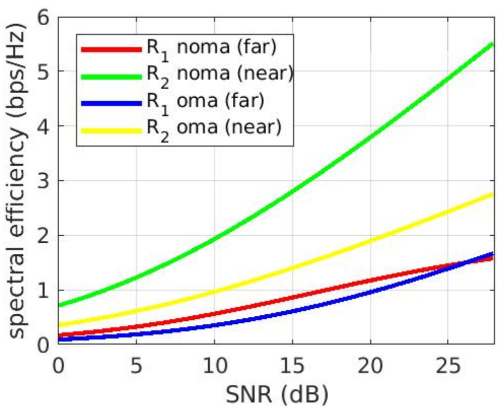

Fig. 5. Spectral eficiency of NOMA and OMA

interference experienced by far user causes its spectral efficiency to saturate after a point. This problem is not present in OMA because, the weak user does not suffer from interference due to simultaneous transmissions [5].

Figure 6. clearly shows that NOMA provides greater sum spectral efficiency than OMA, due to the fact that both users are served simultaneously with the same frequency resource.

In previous results we have assumed the SIC to be perfect but if the SIC is not perfect and has errors, then the SE graph will change. Here we can notice that as error(ϵ) is increasing the SE plot of user 2 is getting closer to user 1 and reaching saturation at a higher error and SNR(As shown in figure 7.).

V. Conclusion

This paper provides an overview and compares performance of power-domain SC-based NOMA and OMA in terms of outage probability and achievable rate with numerical results. It is clear that NOMA is a candidate multiple access technology for next-generation radio access. Many research results have been found in favor of NOMA in terms of outage probability, achievable capacity. In this paper, we saw how NOMA has

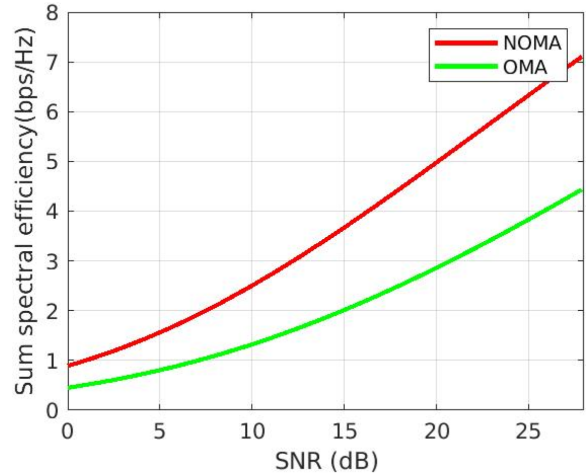

Fig. 6. sum spectral efficiency of NOMA and oma

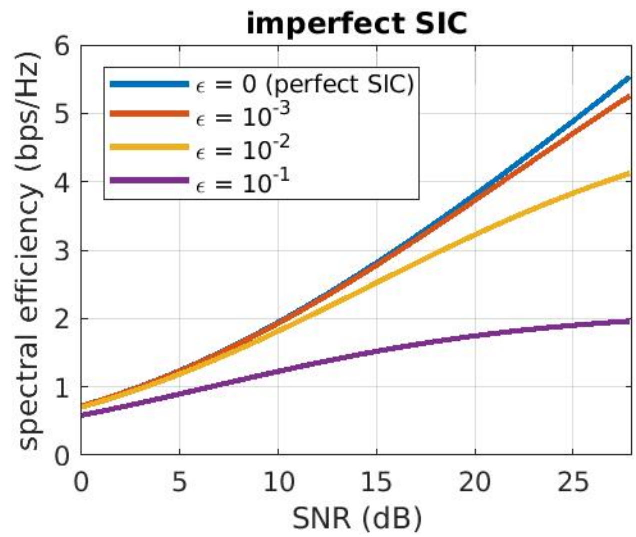

Fig. 7. sum spectral efficiency of NOMA and oma

a lesser chance of outages with a higher achievable rate and better spectral efficiency than OMA [1].

Acknowledgment

I would like to express my special thanks of gratitude to my professor Dr. Vivek Bohara as well as my project mentor Mohd. Hamza Naim Shaikh who Guided me through this course and helped me in completing this project.

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