Algorithm Analysis in NOMA

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1 Introduction

With the concern of provision of low latency, high capacity and massive connection in wireless communication, non-orthogonal multiple access (NOMA) is being considered as one of the techniques for 5G wireless networks [1]. Before NOMA came into the picture, wireless communication systems have been utilizing orthogonal multiple access (OMA) techniques. In OMA [2], allocation of resources to multiple UE's takes place orthogonally. OMA techniques include time-division multiple access (TDMA), frequency-division multiple access (FDMA), code-division multiple access (CDMA). In TDMA, multiple users undergo time-division technique by distributing the same frequency channel. In FDMA, multiple UEs follow the frequency-division multiplexing technique where communications are allowed only during their particular frequency slot. In CDMA, multiple users share the entire time and frequency, they are differentiated by the codes. As the OMA technique considers orthogonality, each UE has been allocated one resource block at a time which in turn does not give the desired high capacity and low latency [3].

Contrary to OMA, NOMA provides sharing of resources to multiple UEs which ensures high spectral efficiency, low transmission latency by allocating one frequency channel at the same time. NOMA techniques include power-domain NOMA and code-domain NOMA [4]. In code-domain NOMA, multiplexing is based on different code levels whereas in power-domain NOMA, multiplexing is done based on different power levels. This paper focuses mainly on power-domain NOMA that utilizes superposition coding (SC) and successive interference cancellation (SIC) at the transmitter and receiver side, respectively. NOMA allows multiple UEs to transmit and receive

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information simultaneously using the same frequency. This feature is only possible due to SC and SIC [5].

1.1 Benefits of NOMA

This subsection presents how NOMA is superior to OMA in several ways [6, 7], such as.

a. NOMA achieves higher spectral efficiency by utilizing the same frequency and time resource for multiple users and interference mitigation through SIC,
b. NOMA supports higher connection density by superimposing the signal of multiple UE's on the same resource block,
c. When compared to OMA, NOMA has lower latency as it does not require separate time slot for transmitting information and
d. As less power is assigned to stronger UE and more power is assigned to weaker UE. Thus, NOMA maintains user fairness.

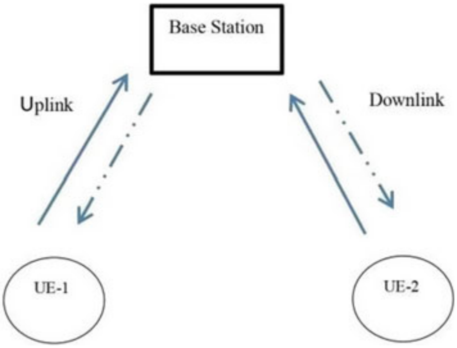
2 NOMA System Model

In this section, an overview of uplink and downlink NOMA is introduced, as shown in Fig. 1. For simplicity purpose, the system model of NOMA is analysed with a single antenna at the base station (BS) and two users (UE).

2.1 Downlink NOMA Network

In downlink NOMA, the transmitter is the BS while the receiver will be the two UEs. The BS transmits the superposed signal to both the UEs. The multiple UEs sharing the

Fig. 1 Uplink and downlink communication



same time and frequency resources are then retrieved at the receiver side. Hence, this process caused increased in spectral efficiency [8]. The superposed signal, which is the combination signals of the two UEs, is allocated with different power coefficients. Power coefficients are allocated according to their channel condition or the interval between the BS and the UE's, in inversely proportional way. The UE which is far from the BS is allocated larger power and lesser power to the other. Also, the channel gain is quasi-static, i.e. constant over the entire transmission time interval [4]. The sum of P_i is equal to P_{total} [9].

Here, assuming that UE-1 is closer to the base station, so it is allocated lower power in comparison with UE-2, which is farther from base station.

The superposed signal is represented as [10, 11].

$$x_s = \sum_{i=1}^{N} P_i x_i, \tag{1}$$

where P_i indicates the allocated power for symbol x_i of the ith UE, and N denotes the number of UE's.

At the receiver side of downlink NOMA, the decoding of UE's message from the superposed signal takes place. This process is single input multiple output (SIMO) [4]. The received signal at the ith UE's [12, 13] is

$$y_i = \sum_{i=1}^{N} h_i \sqrt{a_i x_i} + n_i, \tag{2}$$

where a_i is the power scaling factors express in terms of amplitude, and h_i is the channel gain experienced by ith UE.

2.2 Uplink NOMA Network

In uplink NOMA, the transmitter will be the UE's while the receiver is the BS. Depending upon the channel condition or the distance between the BS and the UEs, signals of the UEs are transmitted with different power levels. The user experiencing lower channel gain transmits higher power, whereas the user that experienced higher channel gain transmits low power [14]. Assuming the same for uplink case, the channel is quasi-static [4]. Now, the superposed signal from both the users is being received by the BS which will be decoded accordingly. This process is multiple input single output (MISO) [4]. In both uplink and downlink, both the user signals are weighted with different powers.

The superposed signal received by the BS [14, 15] is.

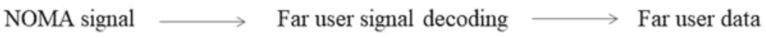


Fig. 2 Far-user processing

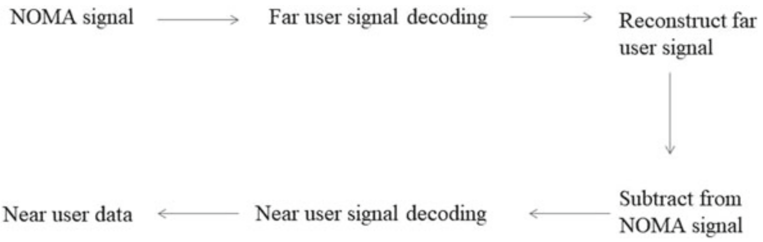


Fig. 3 Near-user processing

$$x_{Bs} = \sum_{i=1}^{N} P_i x_i + n. \tag{3}$$

The superposed signal comprises of UE-1's signal x_1 and UE-2's signal x_2 and also the noise, n. Following the power-domain NOMA principle [15], at the receiver side, i.e. at the BS, it has to perform SIC of the superposed signal which is transmitted from the UE's according to their respective power levels. A simple figure showing the processing of far-user signal in Fig. 2, and near-user processing in Fig. 3, are shown, respectively.

3 Algorithm Analysis in Power-Domain NOMA

In this section, some ideas about SC and SIC are discussed. These two main techniques play a major role in appreciating power-domain NOMA.

3.1 Superposition Coding (SC)

Superposition coding is a process of simultaneously communicating multiple users' information at the same time by a single source [1]. Simply, it is power domain multiplexing. SC process is always implemented at the transmitter side, whether it may be uplink or downlink communication.

The process of superposition coding is as follows:

a. Consider two users x_1 for UE-1 and x_2 for UE-2 which are going to communicate simultaneously,
b. The user's data x_1 and x_2 undergo digital modulation before transmission,

c. The user's data x_1 and x_2 are multiplied with the required power scaling factors, which are expressed in terms of amplitude. The power scaling factors for UE—i must follow the condition that $\sum_{i=1}^{N} a_i = 1$ [1] and
d. The user's data along with the power scaling factors are then added to form the SC signal.

3.2 Successive Interference Cancellation (SIC)

Successive interference cancellation is an algorithm where information is successively decoded according to their power levels [1], while the rest are treated as interference [16]. It is used for detecting the desired signals. SIC process is implemented at the receiver side always.

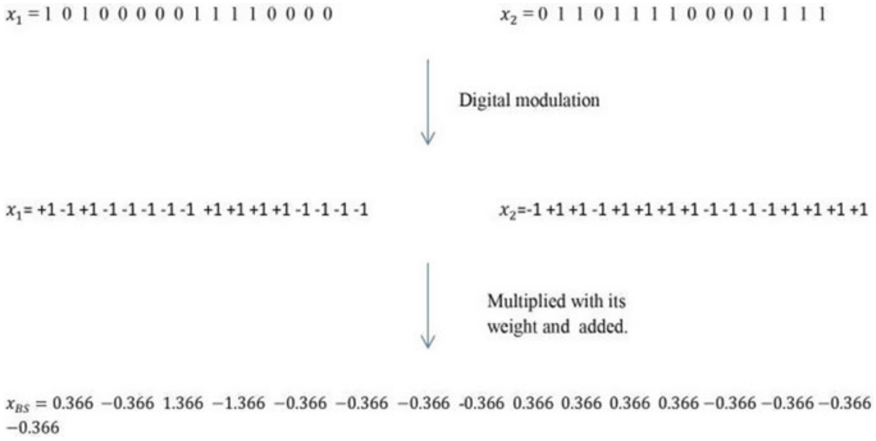
When SIC is applied, the UE signal which has the largest power is decoded first, while treating the rest as interference [9]. The required signal is then subtracted from the combined signal in order to decode the next UE's signal and so on. Before applying SIC, UEs are sequenced in accordance with their respective signal strength so that the stronger signal is decoded first by the receiver [7]. In brief [17], the process of decoding the superposed signal is expressed as follows:

a. The superposed signal x_{Bs} is received and is first decoded by demodulation technique. From this step, the user's signal which has been allocated higher power is detected and treated the rests as interference,
b. The decoded signal is then multiplied with its respective weight and then subtracted from x_{Bs} and
c. By applying the demodulation technique to the result from step (b), gives the resulting user signal which has been allocated lower power.

4 Result

The simulation analysis was carried out in MATLAB R2019a. For the simulation of the two UE signals, the value of a_1 and a_2 has been allocated 0.75 and 0.25, respectively. It is assumed that the transmission bandwidth and power for the overall system is one Hertz and one Watt, respectively.

In Fig. 4, user x_1 and x_2 are allocated 16 bits which undergoes digital modulation, multiplied with its corresponding weight and added to give the superposed signal. Figure 5 shows the graphical representation of x_1 and x_2 signals. Figure 6 shows the simulated result of the superposed signal, x_{Bs}. Figures 7 and 8 show the decoded signal of user x_1 and x_2.



x_1 = 1 0 1 0 0 0 0 0 1 1 1 1 0 0 0 0

x_2 = 0 1 1 0 1 1 1 1 0 0 0 0 1 1 1 1

x_1= +1 -1 +1 -1 -1 -1 -1 -1 +1 +1 +1 +1 -1 -1 -1 -1

x_2=-1 +1 +1 -1 +1 +1 +1 +1 -1 -1 -1 -1 +1 +1 +1 +1

x_{BS} = 0.366 −0.366 1.366 −1.366 −0.366 −0.366 −0.366 -0.366 0.366 0.366 0.366 0.366 −0.366 −0.366 −0.366 −0.366

Fig. 4 User data x_1 and x_2 and the SC signal *xBS*

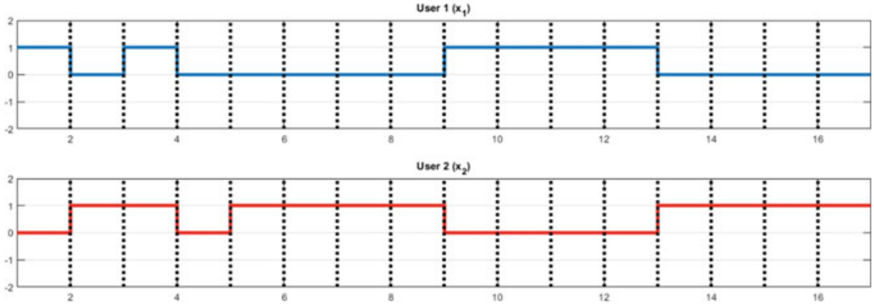


Fig. 5 Graphical representation of x_1 and x_2 signal

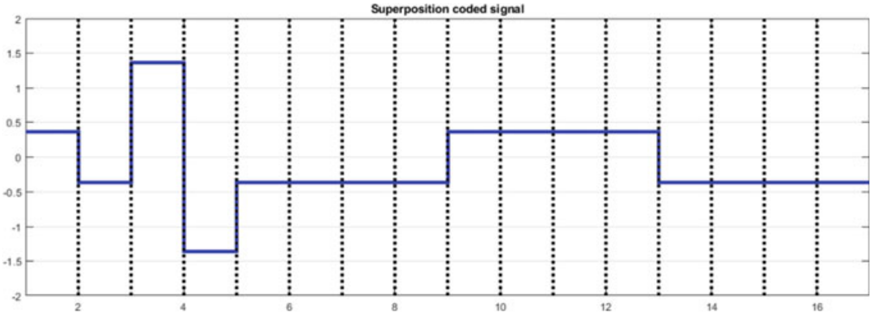


Fig. 6 Simulated result of the SC signal

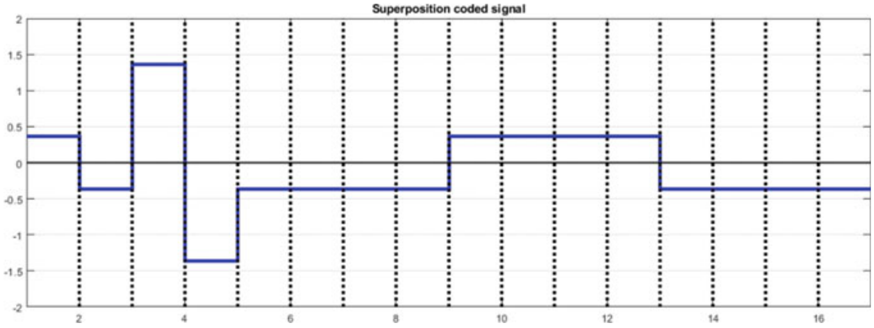


Fig. 7 Result of the far-user ($x_1\prime$) after applying SIC

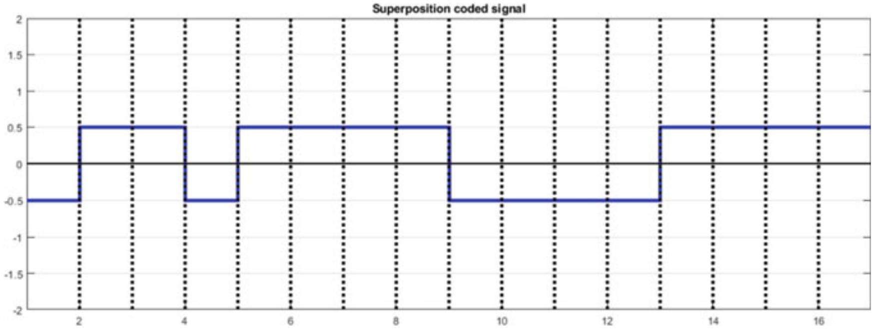


Fig. 8 Result of the near-user ($x_2\prime$) after applying SIC

5 Conclusion

In this paper, two UEs are considered for the analysis. The UEs are allocated 16 bits of data which are multiplied with its corresponding weight to give the perfect SC at the transmitter. SIC is then applied to the resultant SC signal to give error-free user signals at the receiver. Thus, it illustrates how NOMA requires SC at the transmitter side and SIC at the receiver side in order to give every individual user separate messages.

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