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Research paper

Non-orthogonal multiple access: basic interference management technique

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Abstract

Non Orthogonal Multiple Access (NOMA) is a technique that offers spectral efficiency, Quality of Service (QoS), user fairness, low latency, high data rate, and overall better performance as compared to Orthogonal Multiple Access (OMA). The main feature of NOMA is the efficient utilization of spectrum due to increasing demand of data rate. We have introduced a new technique known as MNOMA (Modulation based NOMA) which will help in reducing the interference and complexity of signals decoding, not only in uplink but downlink as well. We have achieved the target of proposed technique by working on superposition coding (SC) of the system. In NOMA interference between users is certain due to removal of orthogonality in spectrum. The problem of interference has been tackled with superposition coding and a number of SIC's (Successive Interference Cancellation) performed on the receiver's end. With MNOMA technique we have tried to reduce the complexity of system by integrating the basic orthogonality in the transmitter instead of spectrum. In this paper, we have shown the reduced expression of data rate for the proposed technique, which shows reduced complexity of the system in terms of SIC, Symbol Error Rate (SER), and better data rate of the proposed technique as compare to conventional OMA.

Keywords: *MNOMA; QPSK; Data Rate; Successive Interference Cancellation; Superposition Coding*.

1. Introduction

Orthogonal multiple access (OMA) is a very useful and already implemented technique. It has been used from 1G to onwards technologies. A continuous enhancement in the technology has been observed with the passage of time and demand of the modern age. Requirement of more data rate, higher spectral efficiency, enhanced user fairness, extremely low latency, massive connectivity, better QoS, low cost and other parameters of future technology, demands conventional OMA techniques such as TDMA, FDMA (including OFDMA), and CDMA transition to NOMA [1], [2]. Quality of service has been decreased while proceeding from 1G to 3G due to increase in the number of users which resulted in self interference. 4G communication is based on OFDMA technique. OFDM forms the basis of all latest wireless communication techniques. For LTE uplink transmission SC-FDMA has been used due to several drawbacks of OFDM including power loss in self-interference, spurious radiation and inter-modulation distortion [2]. For meeting high technological demands, Non Orthogonal Multiple access (NOMA) has been proposed as an aspirant of imminent 5G technology [1]. It can provide a number of benefits including user fairness, extremely high speed, best spectral efficiency, better latency, superior ergodic sum rate and massive connectivity etc. Along with the basic requirements it offers resource sharing, user fairness and improved system throughput by transmitting superimposed signal at the transmitter and retrieving required message via SIC at the receiver [3] and [5]. It is clarified that the outage probability of NOMA depends on the choice of suitable sum rate and power in [5]. Allocation of sub-carriers to the users of poor channel conditions significantly affects the spectral efficiency of the system in OMA. The use of NOMA in 5G can overcome this drawback due to better and efficient utilization of spectrum by all users together (with poor and good channel conditions) by using different or conventional power allocation strategies [7], [10]. In OMA only users with good/strong channel conditions were served under certain cases, whereas in NOMA all users are given equal preferences which will comparatively provide user fairness in NOMA with high connectivity and low latency [4]. For the improvement in spectral efficiency MIMO-NOMA and the link between cognitive radio and NOMA has been discussed in [8]. Benefits of NOMA over OMA including OFDMA have been shown using simulation results in [9]. Bandwidth and energy efficiency trade-off for power domain NOMA and several challenges for NOMA has been targeted in [11].

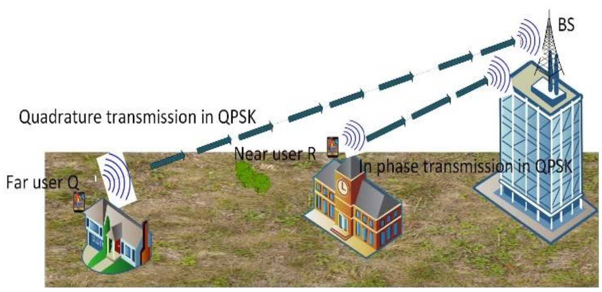

Fig. 1: Transmission of Uplink Where Q and R Are Transmitting Signals on Quadrature and in-Phase Components of QPSK Modulation.

It has been observed from the literature review, much work has not been done for interference management of NOMA technology. However, in [3] Successive bandwidth division (SBD)-NOMA algorithm has been given for UL of an OFDMA based NOMA systems which will be helpful in managing inter-set interference by

dividing spectrum into sub frequency bands. In [6], number of SICs have been reduced by using STBC Alamouti Scheme in order to reduce the overall system complexity. In the proposed technique, better data rate, reduced SER, interference and complexity of the system has been targeted. Proposed technique is based on QPSK modulation for uplink and downlink NOMA system. To the best of our knowledge, we are first who implemented this technique. No one ever has used this for any of the work.
The proposed technique is further elaborated as a system model in section II, where the description of scenario and expressions for data rate have been stated for conventional NOMA and for the proposed technique as well, with explanation. In section III discussion of simulation results, assumed parametric values, and analysis of the proposed technique have been given, and this paper has concluded in IV followed by acknowledgment and references at the end of paper.
Table 1 shows abbreviations and symbols of variables used in this paper.

Table 1: Parameters Used in the Paper

Parameters	Abbreviations/Symbols
Base Station	BS
Quality of Service	QoS
Successive Interference Cancellation	SIC
Multiple Input Multiple Output	MIMO
Orthogonal Frequency Division Multiple Access	OFDMA
Time Division Multiple Access	TDMA
Code Division Multiple Access	CDMA
Frequency Division Multiple Access	FDMA
Single Carrier FDMA	SC-FDMA
Space Time Block Coding	STBC
Superposition Coding	SC
Far user	Q
Coefficient of power allocation for user R	α_1
Coefficient of power allocation for user Q	α_2
Noise variance	σ
Channel coefficient between Q and BS	g_{BQ}
Near user	R
Channel coefficient between R and BS	g_{BR}
DL Channel coefficient between R/Q and BS	g_m
Path loss coefficient	c
Distance from BS to R	l
Uplink	UL
Downlink	DL
Total Power	P_T
Power allocated for far user	P_Q
Power allocated for near user	P_R
Signal transmitted/received to/by users R	$x_1(t)$
Signal transmitted/received to/by users Q	$x_2(t)$
Superposed signal transmitted/received to/by users R	$x_R(t)$
Superposed signal transmitted/received to/by users Q	$x_Q(t)$
Superposed signal broadcast by BS	$x_m(t)$
Received signal by BS or users in UL or DL	$y_m(t)$
Additive White Gaussian Noise	w
Symbol Error Rate	SER
Signal to Noise Ratio	SNR
Signal to Interference plus Noise Ratio	SINR
Data rate of near user	R_R
Data rate of far user	R_Q
Modulation based NOMA (Proposed technique)	MNOMA

Fig. 2. Transmission of down-link where Q and R are transmitting signals on quadrature and in phase components of QPSK modulation.

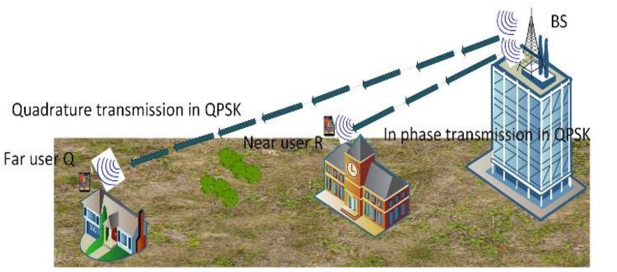

Fig. 2: Transmission of Down-Link where Q and R are Transmitting Signals on Quadrature and in Phase Components of QPSK Modulation.

2. System model

The proposed technique has been considered for both UL and DL NOMA in QPSK modulation. We have used the simplest scenario with one BS and two users.

Proposed UL transmission can be well understood with the help of Fig. 1. There are in-phase and quadrature components for the transmission of message signal, in QPSK modulation. It has been shown in figure that far user is using quadrature and near user is using in-phase component of the QPSK constellation for the transmission of their signals. The idea is to avoid interference between the simultaneous uplink of the two users. BS receives superposed signal of both users' signals.

In UL NOMA both users transmit their signals to the BS using same spectrum but with different power level. The amount of power allocation has been stated in section III. The signal transmitted from user R can be written as

$$x_R(t) = \sqrt{\alpha_1 P_T} x_1(t) = P_R x_1(t) \quad (1)$$

And the signal transmitted from user Q can be written as

$$x_Q(t) = \sqrt{\alpha_2 P_T} x_2(t) = P_Q x_2(t) \quad (2)$$

The superposed signal with the addition of noise received by the BS from both users can be written as

$$y_m(t) = \sum_{m=R}^{Q} x_m(t) g_m + w(t) \quad (3)$$

BS receives a strong signal from user R due to its better channel conditions, therefore it can directly decode its signal without SIC. For user Q, BS has to implement SIC by removing decoded signal of user R from the total received amount and then obtain the required message of user Q. Far transmitter uses more power for the transmission of signal and near user transmits with least power. Different levels of power have been considered as per channel conditions of each user. R has better channel condition than far user Q. In our technique SIC is not required because of integrated orthogonality in superposition coding. However, we have simulated with and without SIC. No changes has been observed when SIC has not been done. This is due to the fact that in proposed technique, signals for users R and Q have been transmitted on different components of QPSK modulation.
Fig. 2. explains the same scenario for proposed DL where base station broadcasts signals of both users with superposition coding using different power levels as per known channel conditions and according to the requirement of proposed scheme it can be seen from the figure that BS has used different components of QPSK modulation for user R and Q.
In DL NOMA as BS broadcasts signals, it also allocates more power to user Q and less power to user R during superposition coding of the transmitted signals. However, the total power of the transmission is constant. Similar to UL, in proposed technique, BS set different components of the modulation for each user and broadcasts the combined signals without any division of the spectrum in

frequency bands. Broadcast signal after superposition coding in DL NOMA can be written as

$$x_{\boldsymbol{M}}(t) = \sum_{m=\boldsymbol{R}}^{\boldsymbol{Q}} \sqrt{\alpha_m P_T} x_m\,(t) \tag{4}$$

Each user receives the encoded signals of both users. The total received signal by each user is given as

$$y_m(t) = x_M(t) g_m + w(t) \tag{5}$$

In DL conventional NOMA, near user has to apply SIC for subtracting more power signal of other user, then it can decode its own signal without interference. For proposed scheme, we have done the simulation with and without SIC. However, it is observed that SIC is not required in our scheme for DL as well, which is discussed well in simulation section. User Q can directly decode its signal by considering R's message as interference in all techniques.

2.1. Computation of data rate

In this section we state and explain expressions of SNR and SINR for conventional NOMA schemes and proposed technique for both UL and DL. For conventional NOMA, SINR for near UL user is given as

$$SINR_R = \frac{P_T|g_{BR}|^2}{\sigma^2 + P_T|g_{BQ}|^2} \tag{6}$$

After decoding R's signal, BS subtracts it from the total received signal for decoding Q's message. Far user's information is retrieved without interference after subtraction of R's signal then SNR of the Q can be written as

$$SNR_{\boldsymbol{Q}} = \frac{P_T|g_{BQ}|^2}{\sigma^2} \tag{7}$$

The DL SNR for user R is also given as,

$$SNR_R = \frac{P_R|g_{BR}|^2}{\sigma^2} \tag{8}$$

whereas, far user Q can decode its signal directly by considering R's information as interference due to high power of its own signal, therefore the SINR of user Q can be written as

$$\mathrm{SINR_Q} = \frac{\mathrm{P_Q}|\mathrm{g_{BQ}}|^2}{\sigma^2 + \mathrm{P_R}|\mathrm{g_{BQ}}|^2} \tag{9}$$

The data rate for user R UL NOMA is given as

$$R_R = log_2\left(1 + \frac{P_T|g_{BR}|^2}{\sigma^2 + P_T|g_{BQ}|^2}\right) \tag{10}$$

And for user Q it is given as

$$R_Q = log_2\left(1 + \frac{P_T|g_{BQ}|^2}{\sigma^2}\right). \tag{11}$$

Similarly according to SNR calculated above, data rate of DL NOMA for user R is given as

$$R_R = log_2\left(1 + \frac{P_R|g_{BR}|^2}{\sigma^2}\right) \tag{12}$$

And data rate for user Q is given as

$$R_Q = log_2\left(1 + \frac{P_Q|g_{BQ}|^2}{\sigma^2 + P_R|g_{BQ}|^2}\right) \tag{13}$$

In the proposed technique, orthogonality has been introduced during superposition coding which has removed interference between users as shown by the simulation results in the next section. SINR of user R in UL is reduced to the following equation of SNR after removal of interference factor from the expression,

$$\mathrm{SNR_R} = \frac{\mathrm{P_T}|\mathrm{g_{BR}}|^2}{\sigma^2} \tag{14}$$

Hence the data rate has been reduced to

$$R_R = log_2\left(1 + \frac{P_T|g_{BR}|^2}{\sigma^2}\right) \tag{15}$$

Similarly the SNR of user Q in DL NOMA in the proposed technique can be written as

$$\mathrm{SNR}_{\boldsymbol{Q}} = \frac{\mathrm{P_Q}|\mathrm{g_{BQ}}|^2}{\sigma^2} \tag{16}$$

And the data rate is given as

$$R_Q = log_2\left(1 + \frac{P_Q|g_{BQ}|^2}{\sigma^2}\right) \tag{17}$$

The data rate expressions are reduced to these forms due to removal of interference between users in both UL and DL. The change of expression is possible, where there is no SIC in conventional NOMA scheme. The expressions remain same for remaining cases.

3. Simulation results

In this section we discuss the simulation results of the proposed MNOMA technique that has been simulated and compared with conventional NOMA scheme. We have considered the following parametric values in our simulations, AWGN channel (h=1), c= 2, the distance between BS and Q has been taken as 1, $l = 0.2$, g_{BQ}=1, gBR=1/√l^c and users Q and R are supposed to be in a single line with BS, P_T=1, P_Q=0.8, P_R=0.2 and channel conditions are considered as known at receiver/s (BS, Q, and R). For a fair comparison same parameters have been considered for conventional NOMA and proposed scheme.

According to the proposed technique, signal transmission has taken place in QPSK modulation, with far user's signal is considered to be on the quadrature component and near user's signal has been taken on the in-phase component of the constellation. Implementation has been done with and without SIC for the required user for both UL and DL in the proposed scheme. No change has been observed when SIC has not been performed. This is due to the fact that in proposed technique, signals for users R and Q have been broadcast in DL and transmitted in UL on different components during modulation.

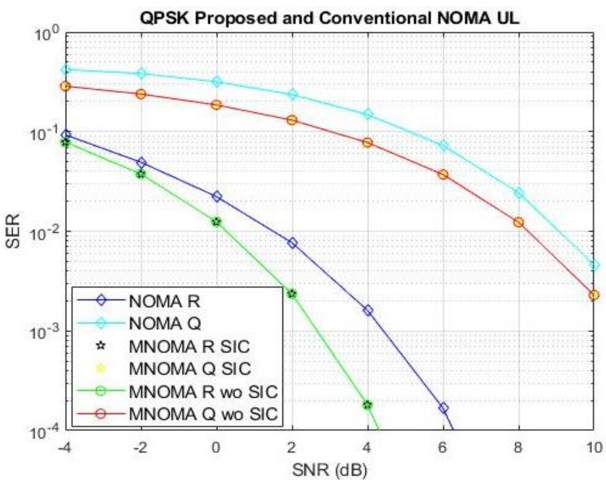

Fig. 3: Simulated SER for Conventional UL NOMA, MNOMA with and without SIC.

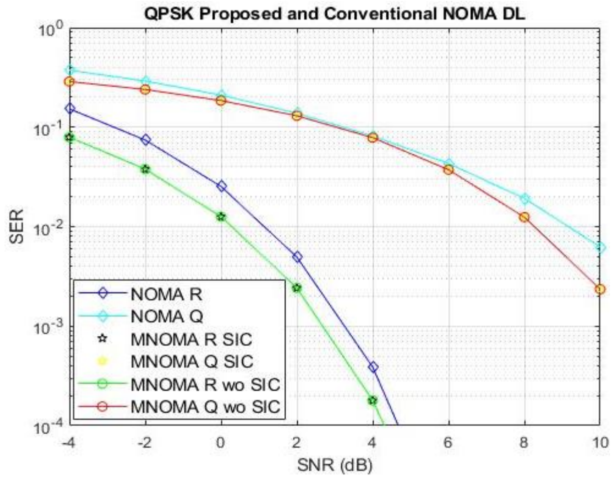

Fig. 4: Simulated SER for Conventional DL NOMA, MNOMA with and without SIC without SIC.

SER comparison for NOMA DL can be observed from Fig. 3. At low and high SNR, proposed scheme for user R shows minimum SER as compare to all other SER responses. In Fig, dark blue curve shows the SER response of user R for conventional NOMA scheme, whereas, green and black curves are representing the SER response of user R for MNOMA technique with and without SIC. User R shows low SER for MNOMA technique at low and high SNR, which is representing that it has outstripped conventional NOMA scheme. In the same figure red and yellow curves which are overlapping with each other are showing the SER of user Q for MNOMA scheme with and without SIC. Whereas, sky blue curve represents conventional NOMA scheme for far user Q. It can be observed from these three curves that for far user Q, MNOMA scheme shows better SER response as compare to conventional NOMA. It should also be noted that simulated proposed MNOMA for user R without SIC exactly overlaps the simulation with SIC. It proves that there is no need for SIC in our case, as we have used orthogonal constellation positions for both signals which avoids interference between both users. Overall, it can be observed clearly that for both near and far user, proposed UL MNOMA scheme outstrips conventional UL NOMA.

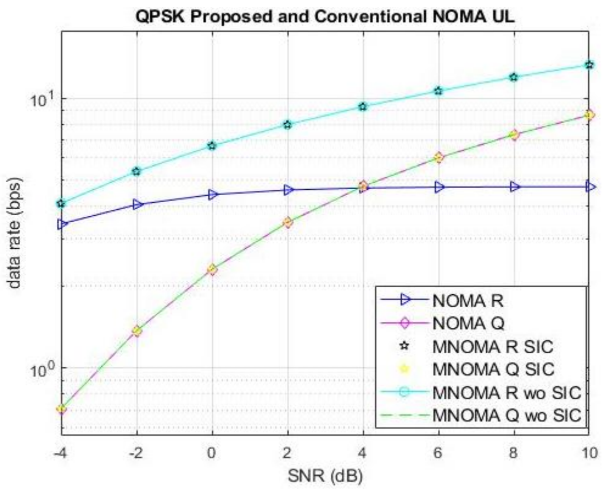

Fig. 5: Simulated Data Rate Comparison of Conventional UL NOMA, MNOMA with and without SIC without SIC.

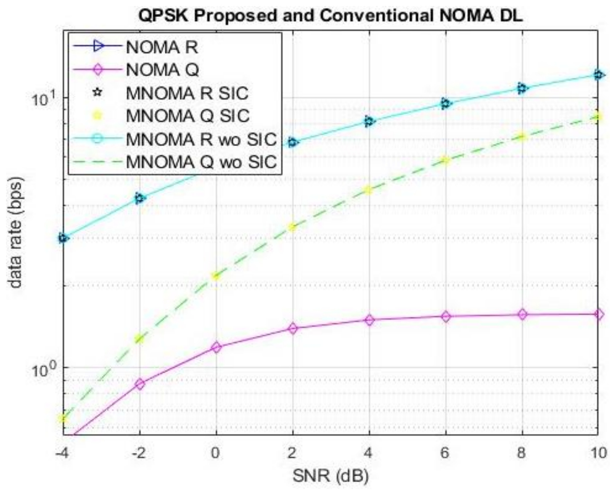

Fig. 6: Simulated Data Rate Comparison of Conventional Dl NOMA, MNOMA with and without Sic without Sic.

NOMA DL simulation of SER can be observed from Fig. 4. In the Fig. dark blue and sky-blue curves are representing near and far users R and Q for conventional DL NOMA. Whereas, black and yellow curves are representing near and far users R and Q for proposed DL MNOMA scheme with SIC. Green and red curves are showing near and far users for proposed DL MNOMA without SIC. It can be observed that user R shows a clear difference in the comparison of both schemes. However, in the case of user Q, a small difference or a little better performance is observed for the proposed DL MNOMA at low SNR and a comparative good response can be observed at high SNR, however, for the SNR between 0 to 6 dB, no clear difference is observed. Similar to UL MNOMA scheme, the response with and without SIC is same that confirms the zero interference in the proposed scheme. Overall, DL MNOMA proposed technique has outstripped conventional NOMA.

Fig. 5. shows the data rate compassion for UL NOMA, in the Fig, dark blue curve shows user R for conventional NOMA, black and sky-blue are showing the curves of user R for proposed scheme. Far user Q responses are represented by magenta colour for conventional NOMA, yellow and green colours for the proposed schemes with and without SIC. In the figure, it can be observed that for far user conventional NOMA and the proposed scheme are overlapping each other, as there is no performance gain in term of data rate. Whereas, near user R shows a clear improved performance difference in the data rate of the proposed scheme. Therefore, it can be concluded that for near user R, data rate comparison outstripped for MNOMA as compare to conventional NOMA.

Similarly, data rate difference for DL can be seen from Fig. 6. In this Fig, colour representation of curves for all schemes are same as data rate UL NOMA curve. It can be observed from this result that for near user conventional DL NOMA and proposed DL MNOMA schemes exactly overlaps. However, for far user Q proposed scheme shows a remarkable better data rate as compare to conventional NOMA.

4. Conclusion

The basic attraction toward the NOMA technology is high spectral efficiency that can be achieved by removing the orthogonality of available spectrum, which results in interference. Removal of interference is done using SICs performed on the receiver. The number of SICs increases the complexity of conventional NOMA system. In the proposed technique we have tried to remove the basic interference in UL and DL NOMA by adding orthogonality in the system during SC. It has been shown that the proposed technique is useful in reducing SER, complexity, interference, and improving data rate for the system of two users as compare to conventional NOMA.

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