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Power allocation for downlink users using SIC in NOMA for better QoS

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Abstract

Non-orthogonal multiple access (NOMA) scheme is the utmost importance for the future communication technologies to meet the requirements of high speed, low latency, massive connectivity and high efficiency. The main idea behind the NOMA scheme is to fascillitate the massive number of users in the same time slot or in the same spreading code. The maximum advantage of NOMA depends on the fact that the resources such as; time and spreading codes should be effectively allocated which includes power allocation along with proper channel assignment. The NOMA is a general framework and this system contains base station (BS) and multiple users (MUs) for uplinks and downlinks. This paper investigates an effective study on NOMA along with power allocation schemes with SIC (successive interference cancellation) which is used in downlink channels to enhance the quality of service (QoS) to the weak users. The comparison between OMA and NOMA with or without Power Allocation Coefficients (PAC) is presented and the improved performance of NOMA as a whole system has been shown by the simulation results.

Keywords: *IDMA, NOMA, Power control, QoS, downlink*

1. Introduction

For future generation communication (5G and beyond) , recently a new scheme is proposed named Non-Orthogonal Multiple Access(NOMA) to meet the need of large connectivity, high reliability ,improved fairness, low latency of about 1ms as compared to 10ms in 3G ,and support for 10 gbps throughput [1-4]. In the recent past the radio access technologies (RAT) used are FDMA, TDMA, CDMA and Orthogonal Frequency Division Multiple Access (OFDMA) [5]. In all these access schemes signals are orthogonal whether in time or in frequency domain for serving different users without multiple access interference (MAI) [6]. However that will not meet the needs of upcoming era of wireless communication such as; Internet of things (IoTs) which is also known as machine to machine communication (M2M) [6-7].

Further NOMA could be the possible solution to avoid the data traffic which is increasing day by day and will be 1000 times in 2020 in comparison to 2010 [7]. NOMA also enables multiplexing in power domain through successive interference cancellation (SIC). NOMA is not just the modification of technologies that are using in 4G communication rather it can be considered as a new technique which allows massive users to access more than the active resources i.e. non-orthogonality is introduced. The basic concept of NOMA is to serve several users using the same time, same frequency and same resources by providing different power levels to the users [7-8]. In downlink communication the signals of different users are multiplexed and obtaining the power differences of users at the receiver for proper reception. Successive interference cancellation (SIC) scheme can be used to de-multiplexed the data [9-10]

2. Categories of NOMA

Mainly, NOMA can be subdivided into two main broad categories, one is power domain NOMA and the second one is code domain NOMA [11]. Interleave division multiple access (IDMA), multi-user shared access(MUSA), pattern division multiple access (PDMA) and Sparse code multiple access(SCMA) are the popular code-domain multiplexing in which signals are modulated/multiplexed over the same time-frequency resources by assigning different codes, the important thing to notice for PDMA is it can be work in both code domain and spatial domain. Other schemes for code domain NOMA also investigated like bit-division multiplexing (BDM) which is used for scalable video broadcasting (SVB) [12-13]. In BDM, few bits for multiple symbols are added to avoid the unequal error protection levels in high-order modulation. IDMA is also suggested as NOMA scheme in which the multiple users are separated by the means of chip level interleaving and superior in terms of Bit Error Rate(BER) performance and complexity with direct sequence code division multiple access (DS-CDMA). Further MIMO-NOMA has been presented to improve the spectral efficiency and reduce the latency [12]. Other technique such as MISO-NOMA i.e., the combination of multiple input single output technique with NOMA has also been investigated to enhance the signal strengths. Furthermore, few more techniques are also suggested in literature, such as resource spread multiple access which comes under the classification of spreading code multiple access (SDMA), Group orthogonal coded access (GOCA), and repetition division multiple access (RDMA) and non-orthogonal coded access (NOCA) [14]

3. Standards for NOMA

In April, 2016 the 3GPP RAN working group 1 (WG1) officially launched six NOMA schemes. In this meeting many companies like Huawei, ZTE, CATT, NTT DoCoMo Inc. (DCM) Qualcomm etc. submitted their proposals. Many companies supplements the simulations like link level simulations (LLS) and system level simulations (SLS) for multiple access (MAs) [14]. Later on in May 2017, many specifications has been drafted by 3rd generation project partnership (3GPP) for NOMA namely mobile technology specifications [14-15]. Further, enhanced mobile broadband (eMBB) massive machine type communications (mMTC) and ultra-reliable and low latency communications (URLLC) are the three major 5G scenarios, designed for the possible implementation of NOMA. Moreover, eMBB scheme has the requirements of high capacity, high mobility, and low power consumption with the motive to provide high throughput, reliability and energy efficiency. The second scenario i.e. mMTC has the requirements of connectivity at massive scale, small packets transmission with high efficiency and long-range coverage and the aim is connectivity, density and coverage whereas URLLC has the requirements for ultra-high reliability, ultra-low latency and their design targets are to provide reliability and low latency [15]. Other than these three standards, many other scenarios and standards are in research to make NOMA better and promising technology.

In this paper, section II presents the basic concept and mathematical modelling of PD-NOMA, which is taken as the promising technology to investigate the power allocation for users in downlink. The comparison of NOMA with OMA has also been presented with the help of simulation results in section III and at the end the applications and future research directions are discussed

4. PD-NOMA

This is very clear in literature that NOMA schemes are advantageous over OMA schemes. Some of benefits of NOMA scheme can be summarized as follows

- Improved spectral efficiency
- Cell edge throughput
- Massive connections
- Low latency and cost etc.

In contrast to NOMA schemes based on code, time or frequency, the power domain is preferred for future communication networks [12]. In PD-NOMA, different signals are generated by anonymous users and after suitable modulation as well as coding the information can be sent on the channel. At the receiver, the signals can be detected by SIC which stated as the technique in which stronger signal decode first then subtracting it from combined or superposed signals to decode the weaker signal.

5. System Model

Here the downlink scenario has been considered and transmitter block contains the M base station antennas and $(N \geq M)$ N single antenna users. This is assumed that $'m'$ be the number of NOMA pairs for station serving at one time slot, where $m \leq M$. All the elements of each NOMA pair share a beamforming vector and each pair cannot have more than 2 user. Therefore, at most $'2m'$ users can be served at the same time slot in one cell. Now the user with larger channel gain referred as strong user and for smaller channel gain are referred as weak users.

Fig 1 1illustrates the performance analysis of NOMA by considering 3 different users for downlink by supposing channel gains h_1, h_2 and h_3 of UE1 ,UE2 and UE3 respectively along with w_1, w_2 and w_3 that denotes to additive white Gaussian noise (AWGN). Suppose $h_1 > h_2 > h_3$, then UE1, UE2 and UE3 get desired messages after implementation of SIC. UE1 can perform SIC to cancel messages of UE2 and UE3 as interference and UE2 perform SIC only on UE3 and UE3 left as a residue.

Let $d_\alpha \beta$ denotes the user's distance for higher channel gain(strong user) and $\hat{d}_\alpha \beta$ for the weaker one for the α-th pair respectively, where β is the time bust and α = 1,2,……………m , stands for the α-th pair in the cell. The base station transmits the signal which is written as

$$S(\beta) = \sum_{\alpha=1}^{m} \gamma_\alpha^* \left(\sqrt{\delta_\alpha |P_\alpha|} d_\alpha(\beta) + \sqrt{\hat{\delta}_\alpha} |\hat{P}_\alpha| \hat{d}_\alpha(\beta) \right) \tag{1}$$

Where $\gamma_\alpha \in B^{(M\times 1)}$ denotes α-th pair's beamforming vector, $(\bullet)^*$ is the conjugate, P_α denotes the transmitted power of the strong user and $\hat{P}_\alpha$ denote for the transmitted power of the weak users of the α-th pair, respectively. For α-th pair, the received signal of the strong user can be written as

$$r_\alpha(\beta) = \sum_{K=1}^{m} hS(\beta) + W$$

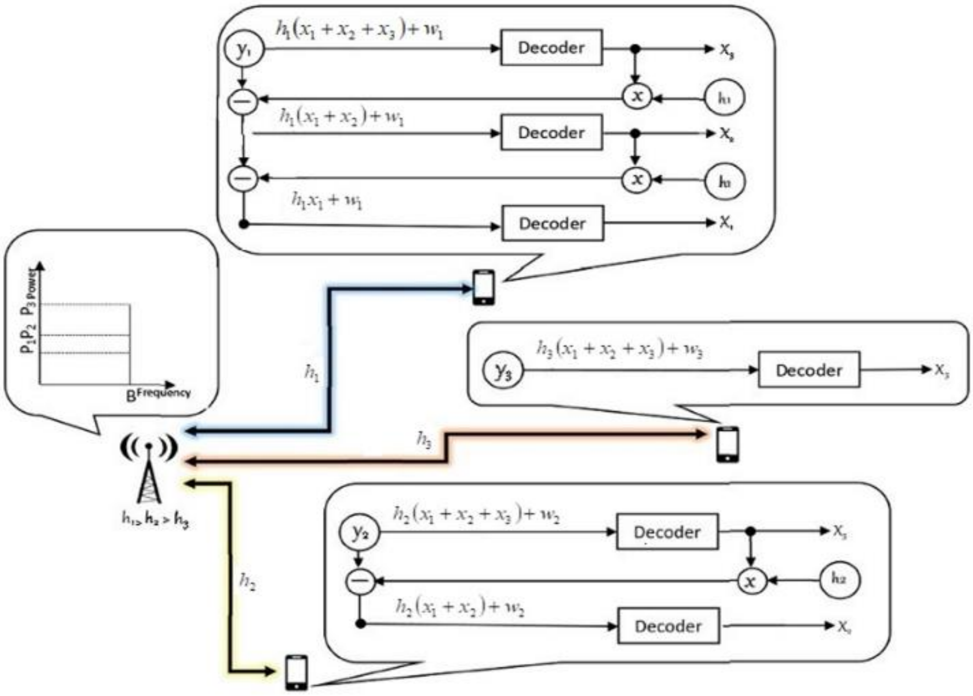

Fig 2:- Cluster of 3 user downlink at BS with the help of SIC

$h_m = [h_1 h_2 \ldots\ldots\ldots\ldots h_m]^T$ is the channel coefficients vector between the BS and the strong user of the α-th pair. Using equation (1) and (2), we can rewrite these equation as (3) :

$$r_\alpha(\beta) = \sum_{K=1}^{m} h\left(\sum_{\alpha=1}^{m} \gamma_\alpha^*\left(\sqrt{\delta_\alpha|P_\alpha|}d_\alpha(\beta) + \sqrt{\hat{\delta}_\alpha|\hat{P}_\alpha|}\hat{d}_\alpha(\beta)\right)\right) + W \tag{3}$$

Figure 2 illustrates the performance analysis of NOMA by considering 3 different users for uplink by supposing channel gains h_1, h_2 and h_3 of UE1 ,UE2 and UE3 respectively along with w_1, w_2 and w_3 that denotes to additive white Gaussian noise(AWGN). Suppose $h_1 > h_2 > h_3$, then UE1, UE2 and UE3 get desired messages after implementation of SIC. In uplink NOMA, BS decodes the first which have highest channel gain. Achievable Rates are obtained at receiver to achieve the desired signal from the received signal

$$r_\alpha(\beta) = \sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma_\alpha^*\left(\sqrt{|P_\alpha|}d_\alpha(\beta)\right) + \sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma_\alpha^*\left(\sqrt{|\hat{P}_\alpha|}\hat{d}_\alpha(\beta)\right) + W$$

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(4)

Let assume by using SIC, weak user's signal can be extracted from strong user for the same pair .So, the received signal of the strong user can be written as:

$$r_{\alpha}(\beta)=\underbrace{\sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma^{*}_{\alpha\sqrt{|P_{\alpha}|}d_{\alpha}(\beta)}}_{desired\ signal}+\underbrace{\sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma^{*}_{\alpha\sqrt{|P_{\alpha}|}\hat{d}_{\alpha}(\beta)}}_{interfernce}+\underbrace{W}_{noise} \tag{5}$$

Similarly, the received signal of the weak user in the α-th pair can be written as:

$$r_{\alpha}(\beta)=\underbrace{\sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma^{*}_{\alpha\sqrt{|P_{\alpha}|}d_{\alpha}(\beta)}}_{interference}+\underbrace{\sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma^{*}_{\alpha\sqrt{|\hat{P}_{\alpha}|}\hat{d}_{\alpha}(\beta)}}_{desired\ signal}+\underbrace{W}_{noise} \tag{7}$$

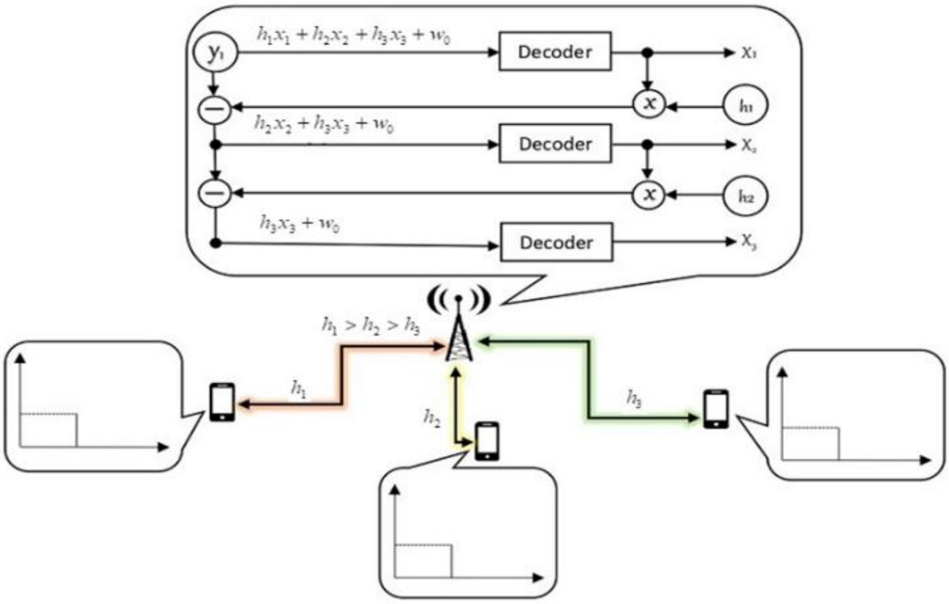

Fig 3:- Cluster of 3 user uplink at BS with the help of SIC

6. Performance parameters in PD-NOMA

In PD-NOMA, the receiver used SIC for multiuser detection (MUD). In SIC the detection is being done on the basis of the detection of strongest user to weakest user and the users can be ordered on the basis of their channel gains (i.e. (h_i^2/N_i). w.l.o.g.; this can be assumed that $h_1^2/N_1 \square\ h_2^2/N_2 ....\square\ h_i^2/N_i$. In the error free environment the achievable rate for stronger user can be written as

$$R_{\alpha}(\beta)=W\log_2\left(1+\frac{\Sigma_{K=1}^{m}|h|^2\delta_{\alpha}^2}{\Sigma_{K=1}^{m}|\hat{h}|^2\delta_{\alpha}^2+\frac{1}{\rho}}\right)$$

Where

$$\rho = \sum_{K=1}^{m} h \sum_{\alpha=1}^{m} \gamma_\alpha^T \left|\hat{P}_\alpha\right| \hat{d}_\alpha(\beta)$$

Similarly the achievable rate for the weak user can be expressed as

$$\hat{R}_\alpha(\beta) = Wlog_2\left(1 + \frac{\sum_{K=1}^{m} \left|\hat{h}\right|^2 \hat{\delta}_\alpha^2}{\sum_{K=1}^{m} |h|^2 \delta_\alpha^2 + \frac{`1}{\hat{\rho}}}\right)$$

(8)

On the other hand, the general relationship for OMA, schemes, the achievable rate can be written as:

$$R_\alpha(\beta) = Wlog_2\left(1 + \frac{\sum_{K=1}^{m} |h|^2}{\frac{1}{\rho}}\right)$$

(9)

Equation (9) shows the achievable rate for strong user and equation (10) express the weak user

$$\hat{R}_\alpha(\beta) = Wlog_2\left(1 + \frac{\sum_{K=1}^{m} \left|\hat{h}\right|^2}{\frac{1}{\hat{\rho}}}\right)$$

(10)

With the help of mathematical manipulations, the sum capacity for both OMA and NOMA can be written as in equation (11)

$$R_T = \sum_{\alpha=1}^{m} R_\alpha(\beta)$$

The other parameter which can be used for performance evaluation of NOMA scheme is known as fairness index (F.I.) which indicates that how the system is fair to provide the signal strength to the users.

$$F.I. = \frac{[\sum R_\alpha(\beta)]^2}{W \sum R_\alpha^2(\beta)}$$

(11)

Eq (12) shows the mathematical abbreviations of F.I. With this F.I. parameter the allocation of power requirement can be adjusted such that more power to far user and less power to near user from the base station. The assumptions made in power allocation are; 1) the base station should have perfect CSI (channel state information) and 2) users have fixed data rate. If instantaneous CSI is known at the BS then fairness among all users can be ensured by maximizing the minimum achievable rate. Let P_T is the available power at the base station. The motive of power allocation is to maximize the sum capacity of NOMA under the constraint of F.I. parameter,

$$\underbrace{maximize}_{\delta_\alpha} \quad R(\beta)$$

$$Subject\ to: \sum_{\alpha=1}^{m} P_\alpha < P_T$$

$$P_\alpha \geq 0, \forall \alpha$$

$$F.I. = F^{opt}$$

F^{opt} is the target fairness parameter, which utilized to get optimum power allocation coefficient. The algorithm to get optimum power allocation coefficients is as follows

Algorithm: Optimum power allocation

```
Initialization
Set fairness constraint to $F^{opt}$
    For i in power signal matrix do
            Calculate achievable rate
            Calculate fairness index
        If fairness index ≤ fairness constraint then
            Set achievable rate (i) to zero
        End if
    End for
    Set maximum achievable rate to zero
        For i in achievable rate (i)
        If achievable rate (i) ≥ maximum achievable rate then
        Set maximum achievable rate to achievable rate
        End if
End for
```

7. Simulation Result

In this section the simulations have been presented for the performance analysis of PD-NOMA. The results are compared to OMA scheme. Here two main objectives are focused, first is that in two users scenario (far user and near use), the optimum power distribution is explained for better QoS. A comparison between NOMA and OMA scheme has been presented using optimum power allocation coefficients. Same channel gain is considered between far user and near user. The other issue, which discussed in the simulations is to show the role of SIC among the users to provide better signal strength to weak user.

In all simulation experiments, no of users $N_u = 3$ are taken. User 1 is considered nearest to the BS, second user lies between the farthest and nearest user and the third user is farthest from the BS. Fig 4 shows the superposition of different signals i.e. the combined strength of different users that is transmitted from base station.

Further, in fig 5 and 6, two user scenario has been considered i.e. near user and far user. The simulation experiment shown in fig 5 has been carried without power allocation scheme and it is clear that NOMA performs better in comparison to OMA. In fig 6, the optimum power allocation scheme is considered with same channel gain. The performance gain (achievable rate) of the NOMA is superior to OMA. The fairness index =0.5 is used for the simulation experiment

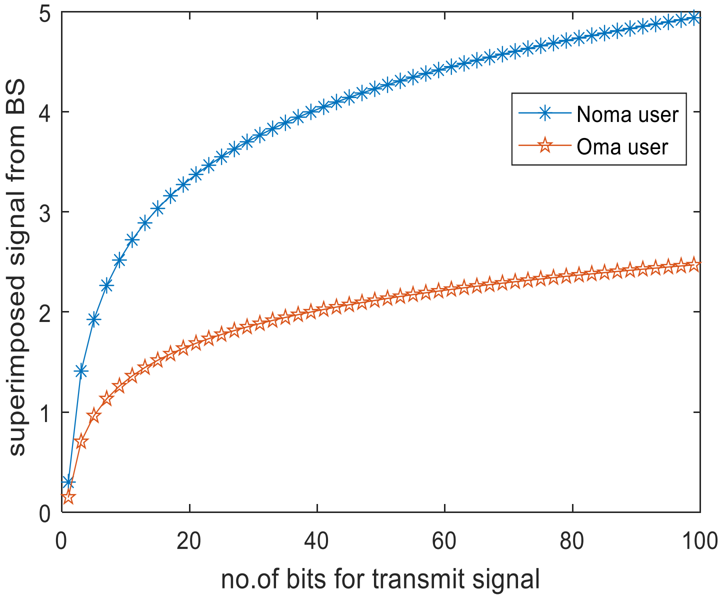

Figure 4:- Combined strength of signals from base station for both NOMA and OMA

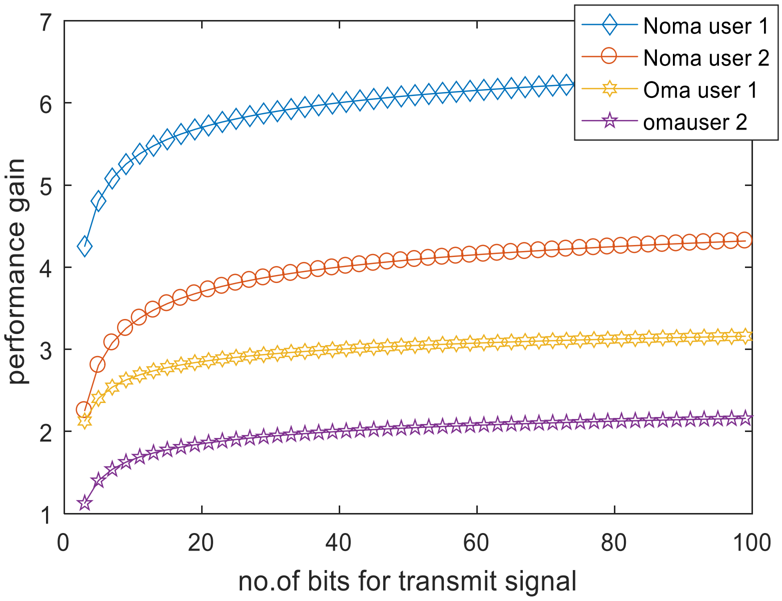

Figure 5:- Without using power allocation method for equal channel gain of different user signals for both NOMA and OMA

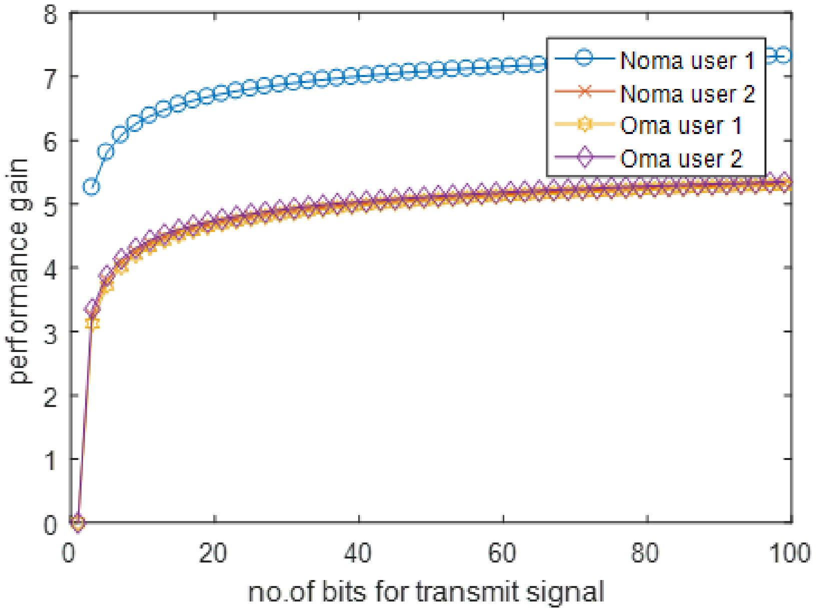

Figure 6:- Using power allocation method for equal channel gain of different user signals for both NOMA and OMA

8. Conclusion

In this paper, the performance of a NOMA is exploited with the consideration of optimum power allocation and SIC for detection. The fairness index=0.5 is taken for the simulation. The simulation results clearly depicts that PD-NOMA performs better than OMA scheme. The signal strength of transmitted combined is also calculated and this is found that NOMA provides better QoS for weak user. In conclusion PD-NOMA with SIC could be the suitable candidate for future radio access and improved spectral efficiency

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