Pak. J. Engg. Appl. Sci. Vol. 30 January, 2022 (p.34–40)

Throughput Comparison of Two User System for Orthogonal and Non-Orthogonal Multiple Access

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Abstract

Non-orthogonal multiple access (NOMA) technique has gained a significant attention as paramount multiple access technique for the future generation mobile networks. The code/time/frequency resources that are being used by conventional multiple access techniques, i.e., orthogonal multiple access (OMA) has been getting saturated gradually. The unexploited resource, i.e., power domain is utilized by NOMA to support multiple users at same time/frequency resources. In this work, an analysis and improvement of throughput are presented based on varying channel conditions of two users within a beam using NOMA over OMA.

Key words: Throughput, OMA, NOMA, M-MIMO, power domain

1. Introduction

Massive multiple input multiple output (M-MIMO) systems have turned out to be the core of upcoming wireless communications. It employs a huge number of antennas at BS (base station), resulting in huge number of beams which are capable of tackling same number of TEs (terminal equipments). Since each beam can accommodate only a single TE at given time frequency resources, so number of TEs cannot exceed than number of beams, arising a potential problem. To cater multiple TEs within a single beam, there is a need of integration of M-MIMO with multiple access techniques like OMA or NOMA [1,2]. By doing so, more than one TEs can be served by a single beam, resulting in greater number of supported TEs than number of antennas at BS.

There are various forms of multiple access techniques that are being used in conventional and ongoing wireless communications. The most employable of them are code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA) and orthogonal frequency division multiple access (OFDMA) [3,4]. The best serving multiple access out of these is OFDMA which was adopted in 4G.

But these multiple access techniques have constraints for serving a large number of TEs, due to limited code/time/frequency resources. Particularly in OMA (OFDMA), due to restriction in constructing orthogonal pilot sequences, various BSs share identical time-frequency resources and reuse the same pilot sequences. This severely effects channel estimation and degrades throughput of the system, limiting orthogonality of large number of TEs in given spectrum [3-8]. Also, these multiple access techniques allocate resources to various TEs irrespective of their channel conditions without satisfying user fairness. So, the TEs with poor channel conditions are deprived of appropriate channel resources, resulting degradation of overall system performance.

Another multiple access technique, non-orthogonal multiple access (NOMA) is a current trending technique over OMA, delivering various benefits like user fairness, low latency, high throughput as well as massive connectivity. It supports multiple TEs simultaneously by allocating different power levels to various TEs depending upon their channel conditions at same time frequency resources. The key concept of NOMA is to explore the power domain at the cost of inter-user interference, which has not been exploited by any other multiple access techniques [3,7,8-11]. NOMA performs superposition coding at transmitter for intra beam multiplexing where channel gain differences between TEs are interpreted as multiplexing gain. The signal separation is carried out by successive interference cancellation (SIC) at receiver to eliminate multi-user interferences [9-14]. In SIC, the interference of the previously detected signal component is subtracted from the present received signal vector which results in a new received vector with a relatively fewer interference. There is a proposed implementation of NOMA for 3rd generation partnership project (3GPP) for long term evolution advanced (LTE-A) networks under name ‘multi user superposition transmission’ (MUST) [10,13]. The work in [15] employed NOMA using spread spectrum structure in conjunction with a low complexity Vertical Bell Laboratories Layered Space Time (C-V-Blast) detection scheme under various channel impairments and imperfections.

The authors in [3,6-9] presented comparative study of orthogonal and non-orthogonal multiple access techniques and verified the spectrum efficiency of non-orthogonal technique is better than orthogonal one in MIMO systems. In scalable version of MIMO i.e. M-MIMO system, every TE is provided an independent or a shared beam on the basis of channel conditions of TEs. So, there could be a single TE or more than one TEs forming a cluster, assigned to a beam. In this work, a downlink system having two TEs, forming a cluster within a beam is integrated with NOMA and OMA separately. Throughput of these systems based on varying channel conditions of TEs are compared. The rest of the paper is organized as follows: section 2 presents system model for NOMA with two users in a cluster and formulates expressions of throughput for two multiple access techniques (OMA and NOMA), section 0 presents results from the derived expressions and finally conclusions are summarized in section 4.

2. System model

In downlink NOMA system, BS transmits the super-positioned signal of all symbols meant for transmission with different power levels to every serving TE. Serving TEs are classified by their channel conditions, ones having better channel conditions are said to be strong TEs and others with relatively weaker channel conditions are called weak TEs. For fairness sake, low power is assigned to strong TEs as they can withstand at low signal strength, and TEs with relatively worse channel conditions are allocated with higher power level, as there are chances of losses and these can be counterpoised by higher power level of signal. As illustrated in Fig. 1, TEs with higher power (TE 2) decode their own signals by treating others as noise and TEs with lower power (TE 1) subtract higher power signals before decoding their own signal by adopting SIC at receiver. The power allocation to TEs in NOMA and OMA is illustrated in Fig. 2 where high power is allocated to TE 2 having weak channel condition and less power is allocated to TE 1 with strong channel condition, while in OMA the same power is allocated to both TEs.

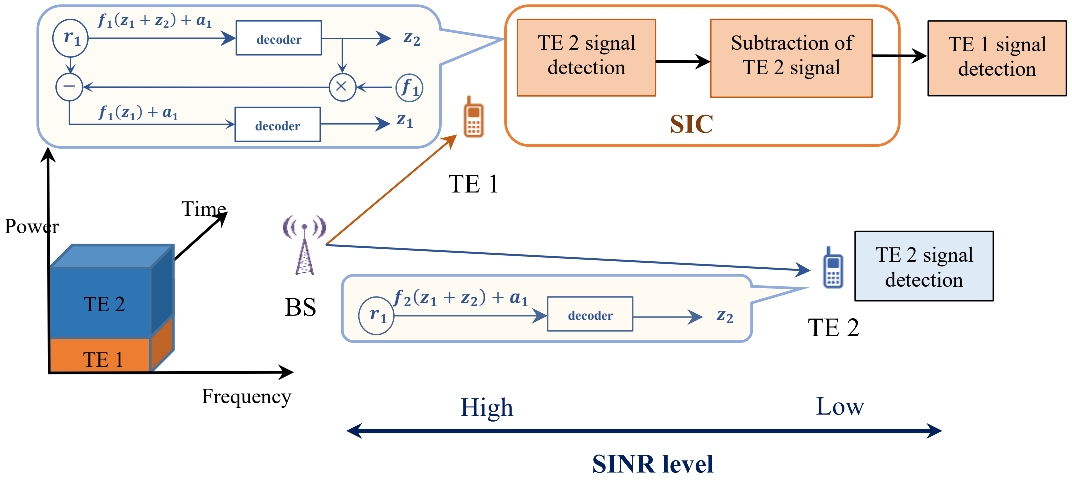
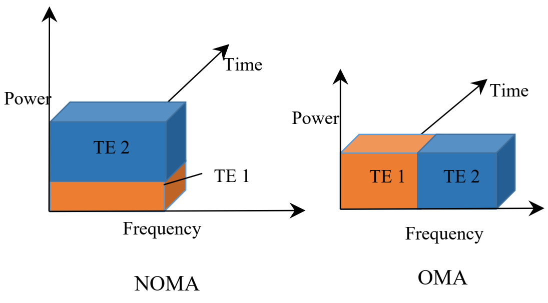


Fig. 1: System model of NOMA

Fig. 1 shows a single beam of downlink system supporting two TEs simultaneously. In NOMA system, BS transmits superposition of two signals z_1 meant for TE 1 and z_2 meant for TE 2 with transmit powers p_1 and p_2, respectively such that $p = p_1 + p_2$ and $p_2 > p_1$, where p is overall transmitted power. The broadcasted signal t to two TEs can be given as:

$$t = \sqrt{p_1}z_1 + \sqrt{p_2}z_2. \tag{1}$$



NOMA OMA

Fig. 2: Power allocation for NOMA vs OMA.

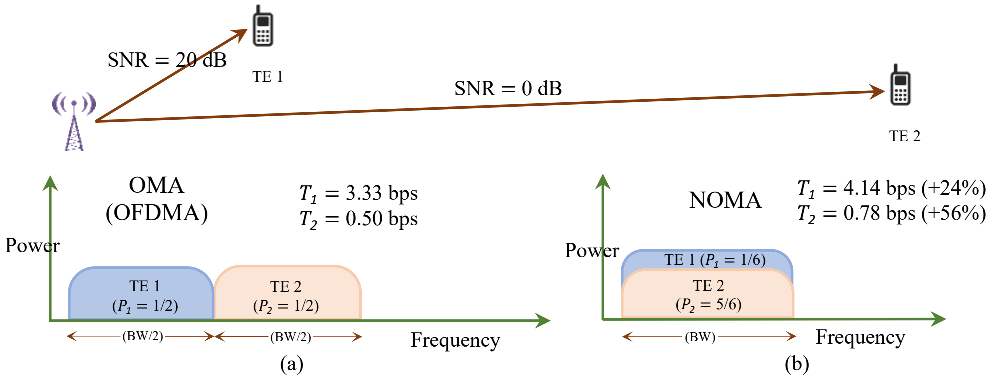


Fig. 3: Example of OMA vs NOMA

The signals u_1 and u_2 received by TE 1 and TE 2, respectively are given as

$$u_1 = f_1 t + a_1, \tag{2}$$

$$u_2 = f_2 t + a_2, \tag{3}$$

where f_1 is channel fading coefficient between TE 1 and BS, and f_2 is channel fading coefficient between TE 2 and BS antenna and these are i.i.d. complex circular Gaussian random variables, such that $|f_1|^2 > |f_2|^2$ and, a_1 and a_2 are additive white Gaussian noise (AWGN) at TE 1 and TE 2, respectively.

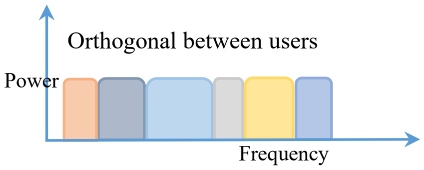
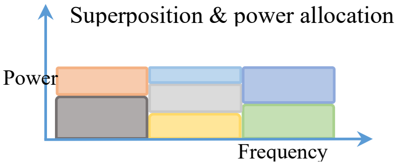
The order of decoding is determined by signal to noise ratio (SNR) of channels of respective TEs. As in this case, SNR of TE 1 is considered to be greater than SNR of TE 2, i.e., $\frac{|f_1|^2}{A_1} > \frac{|f_2|^2}{A_2}$, where A_1 is noise spectral density of a_1 and A_2 is noise spectral density of a_2 [6]. TE 1 performs SIC to get its own signal form the broadcasted signal sent by BS. TE 1 first decodes z_2 (having higher power) and then subtracts this component from u_1, after that it decodes z_1 without interference from z_2. TE 2 decodes z_2 directly by ignoring others as noise, since z_2 has higher power p_2. Thus, throughput T_1 and T_2 for TE 1 and TE 2, respectively using NOMA are given as:

$$T_1 = b \log_2 \left(1 + \frac{p_1 |f_1|^2}{A_1}\right), \tag{4}$$

$$T_2 = b \log_2 \left(1 + \frac{p_2 |f_2|^2}{p_1 |f_1|^2 + A_2}\right), \tag{5}$$

where b is total transmission bandwidth.

Table 1: Comparison of OMA versus NOMA

Technique	**OMA (OFDMA)**	**NOMA**
User multiplexing	Orthogonal	Non-orthogonal with SIC
Adopted in	4G	5G (Expected)
Illustration		
Users supported	Orthogonality limits the number of users	Massive connectivity
Bandwidth per user	Narrow transmission bandwidth per user	Wide transmission bandwidth per user
Receiver circuitry	Simple	Complex due to SIC
Throughput	Less	High
User fairness	Users with good channel conditions are allocated more power in order to achieve throughput	Power allocated to users is inversely proportional to their channel conditions so that all users can be served efficiently

By assuming $b = 1\,Hz$, $p = 1$ W, $p_1 = 1/6$ W, $p_2 = 5/6$ W, $|f_1|^2/A_1 = 20$ dB and $|f_2|^2/A_2 = 0$ dB, throughputs become $T_1 = 4.14$ bps and $T_2 = 0.78$ bps, as illustrated in Fig. 3 (b).

Whereas, in downlink OMA for two user system, bandwidth β Hz $(0 < \beta < 1)$ is assigned to TE 1 from transmission bandwidth b and $(b - \beta)$ Hz is assigned to TE 2. The received signals at u_1 and u_2, respectively are given as

$$u_1 = f_1 p_1 z_1 + a_1, \tag{6}$$

$$u_2 = f_2 p_2 z_2 + a_2. \tag{7}$$

Thus, throughput T_1 and T_2 for TE 1 and TE 2 for OMA, respectively are given as

$$T_1 = \beta \log_2\left(1 + \frac{p_1|f_1|^2}{\beta A_1}\right), \tag{8}$$

$$T_2 = (b - \beta)\log_2\left(1 + \frac{p_2|f_2|^2}{(b - \beta)A_2}\right). \tag{9}$$

By assuming $p_1 = p_2 = 1/2$ W, $|f_1|^2/A_1 = 20$ dB, $|f_2|^2/A_2 = 0$ dB, $b = 1$ Hz and $\beta = 1/2$ Hz, throughputs become $T_1 = 3.33$ bps and $T_2 = 0.50$ bps, as illustrated in Fig. 3 (a). It can be observed that 24% and 56% throughput gains are achieved at TE 1 and TE 2, respectively by using NOMA over OMA. Table 1 shows the comparison of OMA versus NOMA.

3. Simulation Results

The plots of throughputs of TE 1 w.r.t. throughputs of TE 2 based on various channel conditions of two TEs are presented in Fig. 4, Fig. 5, Fig. 6 and Fig. 7. During simulations, system bandwidth b is assumed to be 1 Hz and transmitted power p to be 1 W. The power level p_1 is varied from zero to maximum i.e. 0 → 1 for TE 1 and p_2 is varied from 1 → 0 for TE 2 in both OMA and NOMA. The bandwidth β is varied from $0 \rightarrow 1$ for OMA. The graph is plotted between throughput of TE 1 obtained in equations (4) and (8) w.r.t. throughput of TE 2 obtained in equations (5) and (9) for NOMA and OMA, respectively.

In Fig. 4, $\frac{|f_1|^2}{A_1}$ of TE 2 is fixed at -10 dB and SNR level $\frac{|f_2|^2}{A_2}$ of TE 1 is varied from -10 dB to 20 dB in steps of 10 dB. As the power levels p_1 and p_2 are varied, it is noted that in Fig. 4, at the location (0, 0.137) $p_1 = 0$ and $p_2 = 1$ are considered, resulting maximum throughput of TE 2 at -10 dB. Whereas, for TE 1 at -10 dB, 0 dB, 10 dB and 20 dB, the power levels considered $p_1 = 1$ and $p_2 = 0$ at locations (0.137, 0), (1, 0), (3.459, 0) and (6.658, 0), respectively. It is depicted from the figure that the NOMA have better results as compared to OMA for SNR values of 10 dB and 20 dB of TE 1. While for SNR values of -10 dB and 0 dB of TE 1 the results show hardly any change in throughput of NOMA over OMA. This is because SIC should be employed to a relatively strong TE for satisfying the NOMA criteria.

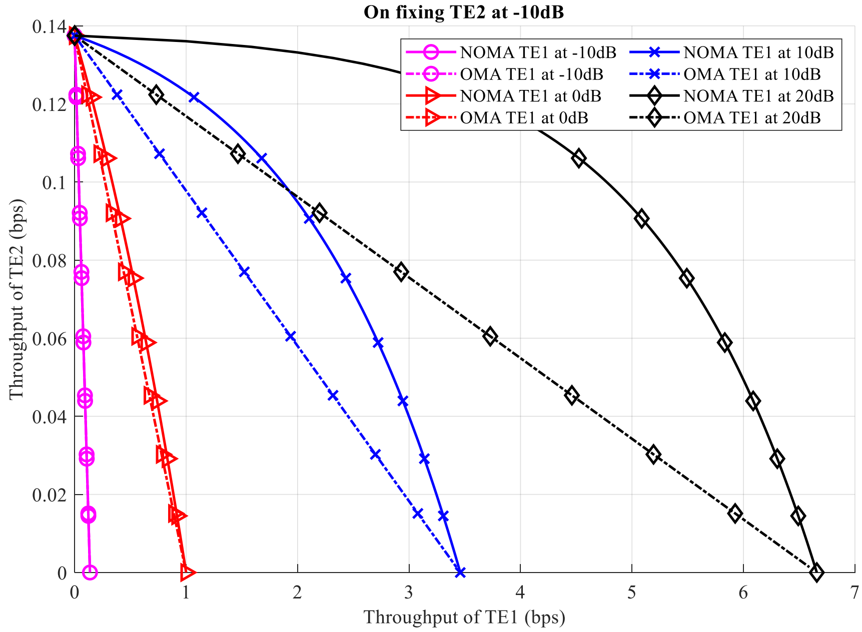


Fig. 4: Throughput of TE 1 versus TE 2 by fixing TE 2 at -10 dB and varying TE 1 from -10 dB to 20 dB

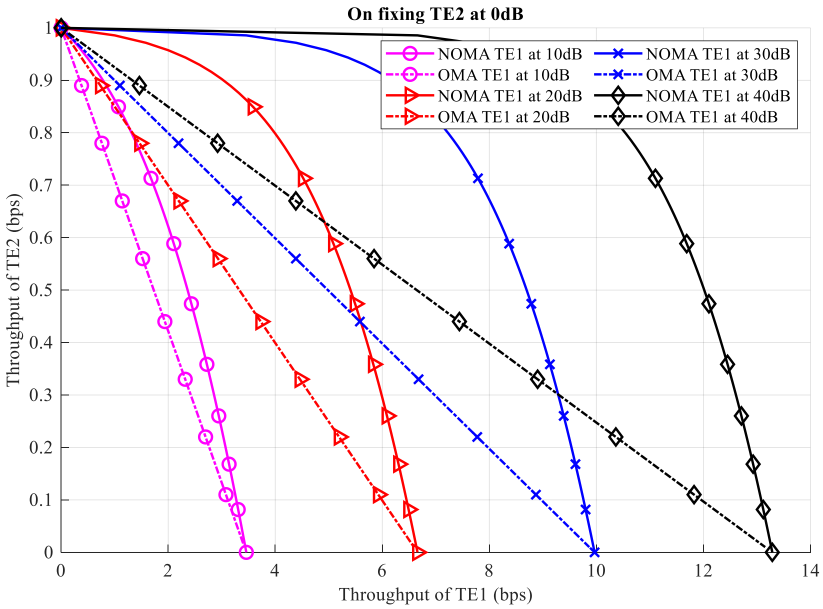


Fig. 5: Throughput of TE 1 versus TE 2 by fixing TE 2 at 0 dB and varying TE 1 from 10 dB to 40 dB

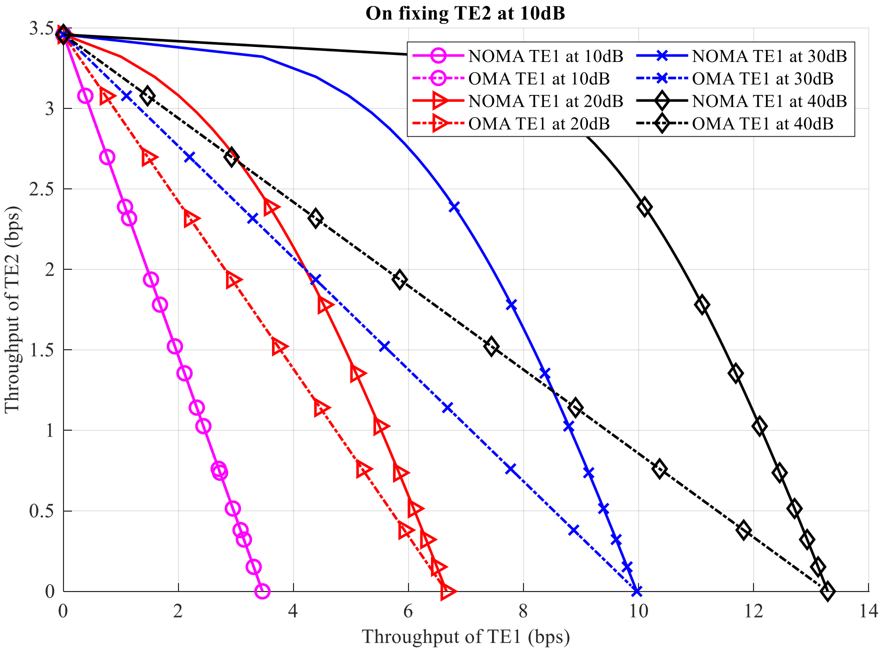


Fig. 6: Throughput of TE 1 versus TE 2 by fixing TE 2 at 10 dB and varying TE 1 from 10 dB to 40 dB

Further, in Fig. 5 and Fig. 6, SNR $\frac{|f_1|^2}{A_1}$ of TE 2 is fixed at 0 dB and 10 dB, respectively, and SNR level $\frac{|f_2|^2}{A_2}$ of TE 1 is varied from 10 dB to 40 dB in steps of 10 dB. In Fig. 7, SNR $\frac{|f_1|^2}{A_1}$ of TE 2 is fixed at 20 dB, and SNR level $\frac{|f_2|^2}{A_2}$ of TE 1 is changed from 20 dB to 40 dB in steps of 10 dB.

It is observed that at any power level (other than 0 and 1), T_1 and T_2 for NOMA always have better outcomes than OMA. There are cases where channel becomes symmetric, i.e., SNR of TE 1 equals to SNR of TE 2, like 'o' marker in Fig. 4 and Fig. 6, and '▷' marker in Fig. 7, the system performance of OMA becomes identical to NOMA. The percentage increase in throughput by NOMA over OMA by varying channel gain differences of two TEs is tabulated in Table 2. This can be deduced that as channel condition differences between TEs increase, the system performance of NOMA is getting progressively improved w.r.t. OMA. NOMA is thus effective than OMA in cases where TEs have different channel conditions, but under same channel conditions there is no improvement by use of NOMA. Greater the gap between channel conditions, greater performance improvement achieved by NOMA. But in real scenarios, TEs may have similar channel conditions. To increase the channel gain difference, precoding matrix at BS can be designed to reduce effective channel gain at TE 1 and to improve the effective channel gain at TE 2 at same time.

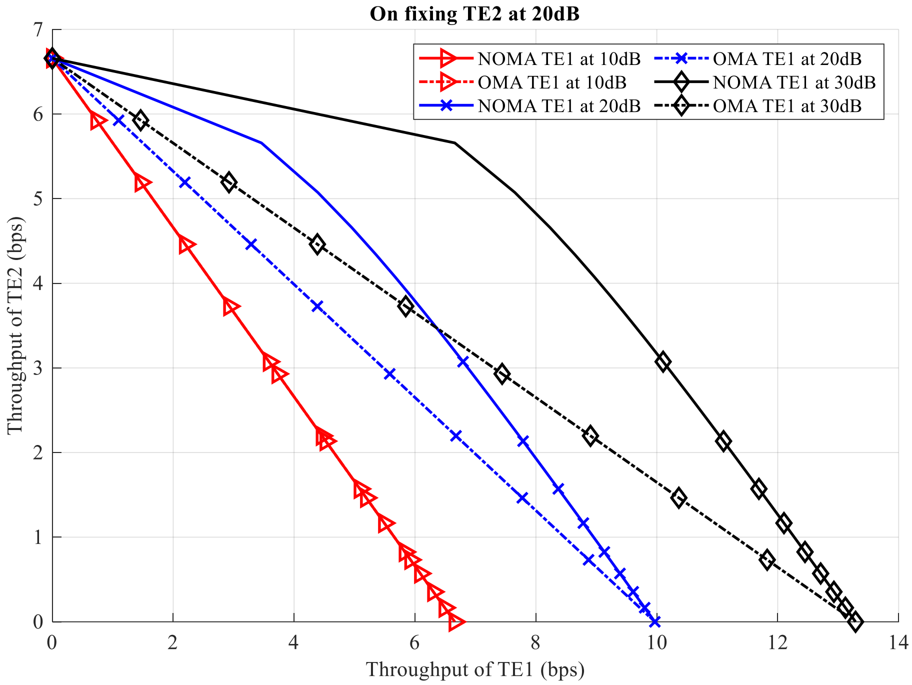


Fig. 7: Throughput of TE 1 versus TE 2 by fixing TE 2 at 20 dB and varying TE 1 from 20 dB to 40 dB

Table 2: Percentage increase in throughput of a two user system by using NOMA over OMA

SNR at TE 1	SNR at TE 2	Channel gain difference between TE 1 and TE 2	% Increase in Throughput of NOMA over OMA
-10 dB	-10 dB	0 dB	0%
0 dB		10 dB	9.78%
10 dB		20 dB	34.78%
20 dB		30 dB	56.84%
10 dB	0 dB	10 dB	25.56%
20 dB		20 dB	48.99%
30 dB		30 dB	62.95%
40 dB		40 dB	71.02%
10 dB	10 dB	0 dB	0%
20 dB		10 dB	25.81%
30 dB		20 dB	42.93%
40 dB		30 dB	53.79%
20 dB	20 dB	0 dB	0%
30 dB		10 dB	18.96%
40 dB		20 dB	32.07%

4. Conclusions

NOMA is a promising technology for upcoming 5G communication systems, as by allocating different power levels to different TEs, system throughput gets improved significantly at same time frequency resources. Whereas for OMA, different time frequency resources are required for different TEs. This can be concluded that when channel conditions are dissimilar between TEs, NOMA has an edge over OMA in terms of throughput and user fairness. This work can be extended in future to incorporate NOMA technique within a beam in M-MIMO system to cater greater number of TEs and within multiple beams of M-MIMO system.

5. References

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