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Influence of the Number of Antennas on the Outage Probability of Non-Orthogonal Multiple Access in 5G Systems

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Abstract: The 5G wireless system relies on Non-Orthogonal Multiple Access (NOMA) as a radio access scheme using extremely-dense base stations and unprecedented number of antennas to provide improved performance, high degree of integrative services, high-rate coverage and seamless user experience. The difference in the number of antennas used in the Mobile Devices (MDs) and those in the Base-Stations (BSs) in a cell plays a significant role in the overall system performance. Evaluation of the influence of such difference (**δ**) is analyzed in this study based on the outage probability, Pr_k^{out}. Computer simulation results are provided to facilitate the performance evaluation of the MIMO-NOMA and also, to demonstrate the accuracy of the developed analytical results. The achieved results reveal that a trade-off between the level of the SNR and the **δ** in the outage probability. Also, strategy of pairing users in a cluster plays an important role in the value of Pr_k^{out} when the number of users in a cluster is increased more than two users the performance is governed by allocation of the transmit power coefficient with level of SNR besides **δ**, compared with that of the conventional 0rthogonal Multiple Access (OMA).

Key words: 5G, non-orthogonal multiple access, outage probability, MIMO, antennas, next generation

INTRODUCTION

Multiple access technologies are the main features that distinguish different wireless systems from the first generation to the fourth one (4G). Frequency Division Multiple Access (FDMA) was used with 1G, Time Division Multiple Access (TDMA) was used with 2G, Code Division Multiple Access (CDMA) with 3G and Orthogonal Frequency Division Multiple Access (OFDMA) with 4G. These schemes rely on using orthogonality of the resources, either in time, frequency, code domain, respectively, to avoid or at least alleviate cross-user interference (Gupta and Jha, 2015; Basturk and Ozbek, 2016). According to the CCS-insight, it is predicted that by 2021, smartphones will account for 92% of the total mobile phone market (Anonymous, 2017). Accessing for Radio Access (RA) in 2020 and beyond requires massive system capacity; Higher peak rate up to 20 GB/sec 10 MB/sec in real-life deployments wherever and several 100 MB/sec in dense urban environment. This requires more spectrum, both licensed and unlicensed and spectral efficiency enhancements. Work on the new generation, 5G, mobile communication systems has already begun (Hoymann *et al*., 2016). The 5G works in 3GPP, according to release 14 envisions 14 service types: enhanced reality, enhance end-user Quality-of-Experience (QoE), wireless data download, lower energy consumption, etc. (3 GPP-websit). To enable realizing such demands, different schemes are introduced such as massive MIMO (Larsson *et al*., 2014; Abuibaid and Colak, 2017), nonorthogonal transmission (Saito *et al*., 2013; Yuan *et al*., 2016), sparse code multiple access (Chen *et al*., 2016a, b), high frequency communications (Wang *et al*., 2017; Yifei and Longming, 2014). Recently, the Non-Orthogonal Multiple Access (NOMA) has attracted increasing research interest from both academia and industry as a promising candidate for the 5G mobile networks due to its superior spectral efficiency (Anxin *et al*., 2015; Ding *et al*., 2017). Unlike, the conventional Orthogonal Multiple Access (OMA) used in previous generations of mobile networks, the NOMA is based on utilizing the power domain. The users in a one cell served by a BS with the same time, frequency and code, the signals are multiplexed by employing different power allocation coefficients. Also, unlike the OMA which supports power to the channels with better conditions in NOMA, the power allocation is inversely proportional to their channel conditions. The users with "Good" channel conditions use the Successive Interference Cancellation (SIC) (Benjebbour *et al*., 2015; Chinnadurai *et al*., 2017). By this method the messages to the users with poorer channel conditions is decoded first and then decode their own by removing the other user's information. Since, small cells in the 5G networks will be ultra-densely deployed which provides low power and low cost with superior quality of services as that with previous mobile generation. The number of antennas in the BS and that in the mobiles was a crucial bound in many studies such as the condition for evaluating the overall system performance (Zhang *et al*., 2016). This δ influences on many factors the mobile radio system such as the bandwidth, Quality of Services (QoS), traffic statistic, access protocol, shape and size of service area, (Tomba, 1997; Yang *et al*., 2016). Hence, the influence of such factors will be summarized into outage probability, Pr_k^{out} which is the probability of not achieving a satisfactory signal-to-noise ratio. Outage probability is a good metric for QoS in the system design (Hasna *et al*., 2001). Ding *et al*. (2014) analyzed the outage probability in terms of the data rates and allocation of transmit power for the downlink in NOMA system while Zhang *et al*. (2016) presented a theoretical analysis for the outage probability for the uplink in NOMA system in terms of the data rate and the power back-off step. Ding *et al*. (2015) analyzed MIMO-NOMA system for downlink under the assumption that all nodes are equipped with multiple antennas and the performance was analyzed using the criteria of outage probabilities and diversity orders. Available work did not take into account the influence of the difference in number of antennas used in the BS and that in the subscriber devices on the outage probability in a cell MIMO-NOMA of the 5G systems. This study analyzes such influence with different paring cases. The achieved results show that Pr_k^{out} is improved for users in worst channel conditions with pairing two users in a cluster. There is a trade-off between the δ and the SNR for evaluating the Pr_k^{out}. The value of Pr_k^{out} may get worse with δ when number of clustered users increases without taking allocation of the transmitted power into account, compared with that in the OMA.

MATERIALS AND METHODS

System model: Consider the downlink of a MIMO-NOMA network shown in Fig. 1. where the cell includes a Base Station (BS) equipped with M antennas sending data to multiple users (receivers), U_i, I = {1, ..., N_T. Assuming that the users are randomly grouped into M clusters with K users in each cluster, each user is equipped with N antennas, N = M as justified in (Ding *et al*., 2016). Assuming the wireless channels are quasi-static Independent and Identically Distributed (IID) with Rayleigh fading distribution. For the k-th user in the M-th cluster, denoted (m, k), $m \in \{1, 2, ..., M\}$ and $k \in \{1, ..., K\}$. The downlink channel from the BS to the k-th user in the m-th cluster is encountering Rayleigh fading, $H_{m,k} \in \mathbb{C}^{N\times M}$. The M×1 information bearing signal, $\tilde{s}$, to all K users in an M-th cluster is:

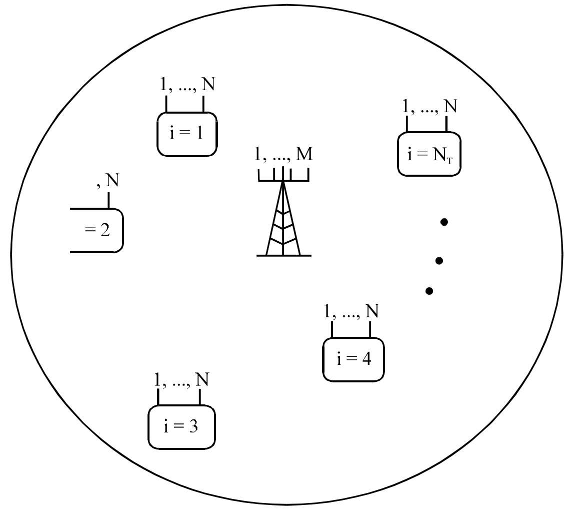

Fig. 1: Cellular system model

$$\tilde{s} = \begin{bmatrix} \gamma_1 S_1 \\ \vdots \\ \gamma_K S_K \end{bmatrix}^H = \begin{bmatrix} \tilde{s}_1 \\ \vdots \\ \tilde{s}_K \end{bmatrix}^H \quad (1)$$

where, γ_j $\{1 \le J \le K\}$ is the NOMA power allocation coefficient. The transmitted signal $X = P\tilde{s}$ with $E[\|x^2\|] = 1$ which depends on the type of the precode matrix, P, used at the Tx. he observed signal vector, $Y_{m,j}$ for an arbitrary user in any of the M-th clusters is: $Y_{m,j} = H_{m,j}\,Px + n_{m,j}$ where $n_{m,j}$ is N×1 IID. Additive White Gaussian Noise (AWGN) vector with CN (0,1) entries. If ρ is the average received Signal-to-Noise Ratio (SNR) at the user which is a function of the path loss. Assuming the path loss to user j in cluster m, at a link distance d is equal for each path and given as:

$$\omega(d) = \alpha\zeta d^{\beta}$$

Where:

α = The path loss offset constant
β = The exponent of the path loss and
$\zeta \sim N(0, \sigma^2)$ = The shadow fading with standard deviation σ

The value of the path loss offset is typically calculated analytically by the free-space path loss at a reference distance, d_o, (Erceg *et al*., 1999) as:

$$\alpha = \left(\frac{\lambda}{4\pi d_o}\right)^2$$

where, λ is the wavelength of the carrier frequency, f. Since, the same procedure may be applied at each user in all clusters, hereafter we will omit the cluster sequence from the used quantities and show the user sequence.

If R_j is the detection vector used by user j, the received signals is: $R_j^H H_j P\tilde{s} + R_j^H n_j$. In NOMA strategies, the channels are sorted as:

$$|R_1^H H_1 P_1|^2 \geq |R_2^H H_2 P_1|^2 \geq, ..., \geq |R_K^H H_K P_1|^2 \quad (2)$$

The power allocation coefficients for the K-th users are ordered as: $\gamma_1 < \gamma_2 <, ..., < \gamma_K$. The ordered variables, effective channel gains to users, z_k, $R^H{}_K H_K$ is complex Gaussian vector (Edelman and Rao, 2005) with PDF (David and Nagaraja, 2005):

$$f_{zk}(z) = \frac{K!}{(K\text{-}k)!(k\text{-}1)}\left\{\int_0^z \frac{e^{-y}}{\delta!} y^\delta dy\right\} K\text{-}k\left\{1\text{-}\int_0^z \frac{e^{-y}}{\delta!} y^\delta dy\right\}^{k\text{-}1}$$

In order to avoid consuming the system overhead assuming the BS does not need to request the users to send feedback all their Channel State Information (CSI). Thus, the BS broadcasts the messages without manipulating them. To evaluate the system performance without focusing on type of coding and modulation the outage probability will be analyzed. The criterion, Pr_k^{out} is usually considered for nonergodic fading channels and held fixed for all time (Zheng and Tse, 2003). It is declared when the SNR, ρ, falls below a predetermined protection ratio. The outage probability, Pr_k^{out}, may be expressed as:

$$P(SINR < r_k) = P\left(z_k \gamma_k^2 \rho \text{-} z_k r_k \sum_{k=1}^{K} \gamma_k{}^2 \text{-} r_k < 0\text{-}1\right)$$

Following the analyses (Ding *et al*., 2016; Chen *et al*., 2016a, b) yields:

$$Pr_k^{out}(\delta) = \begin{cases} \frac{K!}{(K\text{-}k)!(k\text{-}1)!}\sum_{j=0}^{k\text{-}1}\binom{k\text{-}1}{j}\frac{(\text{-}1)^j}{(K\text{-}k\text{+}j\text{+}1)} \\ 1 \end{cases} \left\{\frac{\gamma(\delta\text{+}1.r_k^{'})}{\delta!}\right\}^{K\text{-}k\text{+}j\text{+}1} \text{if} \gamma_j^2 > r_j r_j^{'} d$$

where, $r_k = 2^{Rk} - 1, r_j^{'} = \sum_{j=1}^{K-1}\gamma_j^2, \gamma(.)$ is the incomplete gamma function and:

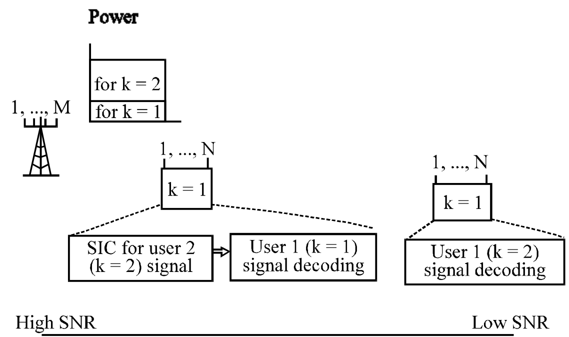

Fig. 2: Concept of the received power in MIMO-NOMA with SIC downlink system

$$r_k^{''} = \begin{cases} \max\left(\frac{r_K}{\rho(\gamma_K^2\text{-}r_K r_K^{'})}, ..., \frac{r_k}{\rho(\gamma_K^2\text{-}r_K r_K^{'})}\right) & \text{for} 2 \leq k \leq K \\ \max\left(\frac{r_K}{\rho(\gamma_K^2\text{-}r_K r_K^{'})}, ..., \frac{r_k}{\rho(\gamma_2^2\text{-}r_2 r_2^{'})}, \frac{r_1}{\rho(\gamma_1^2\text{-}r_1 r_1^{'})}\right) & \text{for} k = 1 \end{cases}$$

Following the analyses by Ding *et al*. (2016) and Biglieri *et al*. (2007) for systems using Orthogonal Multiple Access (OMA) schemes, the outage probability may be expressed as:

$$Pr_k^{out}(\delta) = \frac{K!}{(K\text{-}k)!(k\text{-}1)!}\sum_{j=0}^{K-1}\binom{k\text{-}1}{j}\frac{(\text{-}1)^j}{(K\text{-}k\text{+}j\text{+}1)}\left\{\frac{\gamma(\delta + 1, \varphi_k)}{\delta!}\right\}^{K\text{-}k\text{+}j\text{+}1}$$

where, $\varphi_k = 2_{KR}k\text{-}1/\rho$

Principle of signal detection in NOMA: The NOMA scheme can be applied for both downlink and uplink. The different signals from the users in the NOMA systems are superimposed in the power domain based on the channel gain difference. In the downlink which is considered in this study the Successive Interference Cancellation (SIC) is used with the advanced receivers for separating of user signals as depicted in Fig. 2. Consider two users with k = 1 for the user close to the BS with good channel condition and user 2, k = 2, the far user to the BS with worst channel condition. For the far user, the BS assigns higher fraction of power and low level for the near one, user 1. The sum of the two levels is always equal to the total power transmitted by the BS. Detection of the signals to user 2 is accomplished directly by regarding the signal of the near user as interference. On the other hand, the received signals by the near user, the SIC is used to decode each weaker signal. Then, the decoded signals are subtracted one after another from the received signal to get the desired user signal.

RESULTS AND DISCUSSION

In this study, a numerical analysis for the outage probability is presented. Figure 3 shows the influence of the difference in number of antennas on the outage probability for the two systems, namely, MIMO-NOMA and MIMO-OMA with different level of SNR (10, 20, 30) dB and fixed allocation for the transmitted power. Figure 3 considers two users at cluster j with power coefficients $\gamma^2_1 = 0.25$ and $\gamma^2_2 = 0.75$ the Bit Per Channel Used (BPCU) is 3 for the first user, k = 1 which has relatively, best channel condition. It is obvious that the outage probability is a strong function of δ and the SNR plays a strong role. There is no improvement with adapting NOMA system compared with that employing the OMA system with low level of SNR as shown in Fig.3a. For instance, to achieve $Pr_k^{out} \approx 10^{-4}$, δ should be about 7, 2 and 0 when the SNR is 10, 20 and 30 dB, respectively when NOMA system is used while δ should be about 3, 2 and 0 when SNR is 10, 20 and 30 dB, respectively when OMA system is employed. On the other side, Fig. 3b depicts variation of the outage probability with δ for user 2 which is assumed with relatively worst channel condition and 1.3 BPCU. The performance is almost equal to achieve a specific level of Pr_k^{out}. For instance to get $Pr_k^{out} \approx 10^{-4}$, δ should be about 4, 2 and 1 which correspond to SNR equal to, 10, 20 and 30 dB, respectively with both systems.

Figure 4a-c illustrate variation of the outage probability versus the difference number of antennas when three users are pairing at a cluster with different levels of SNR and different amount of power coefficients: $\gamma^2_1 = 1/6$, $\gamma^2_2 = 1/3$ and $\gamma^2_3 = ½$ rates: and $R_1 = 2$ BPCU, $a_2 = 1.2$ BPCU and $R_3 = 0.9$ BPCU . Figure 4 shows that Pr_k^{out} as well as level of SNR are strong function of δ. Fig. 4a depicts Pr_k^{out} for the near user with best channel condition. To get a specific level of Pr_k^{out}, say 10^{-4} for example, the δ should be about 4, 1 and 0 corresponding to SNR of 10-30 dB, respectively with

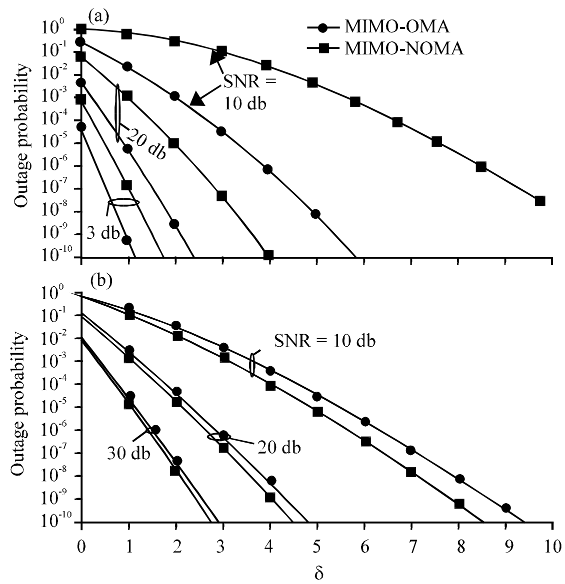

Fig. 3: Outage probability as a function of difference number of antennas for MIMO-NOMA and MIMO-OMA when number of considered users in each cluster is two; a) For the near user, k = 1 and b) For the far user, k = 2

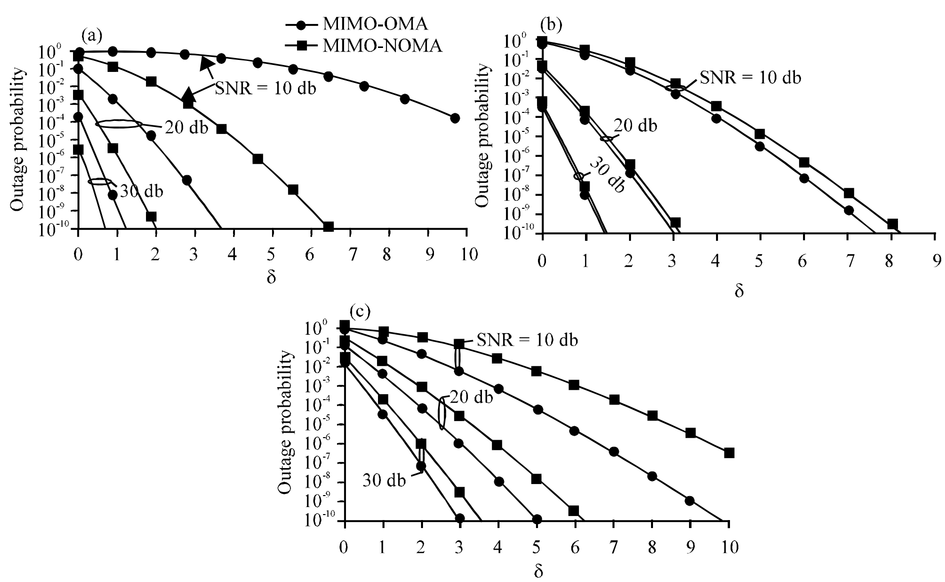

Fig. 4: Different number of antennas versus the outage probability for MIMO-NOMA and MIMO-OMA with K = 3; a) For the nearst user, k = 1; b) for the second user, k = 2 and c) for the far user, k = 3

NOMA system. However, δ should be about 4, 2 and 0 corresponding to SNR 10, 20 and 30 dB with using OMA system. On the other hand, Fig. 4b shows that the performance is almost the same for the second user, k = 2 when NOMA and OMA system are employed. On the other hand, Pr_k^{out} the requires δ less when using OMA against NOMA system for the far user which has worst channel condition as shown in Fig. 4c.

In all considered cases the level of SNR plays a crucial role in the probability of outage and the different number of antennas used in the mobile sets and in the BS. Hence, we conclude that the 5G systems with dense cells and smart devises do have no significant point with the bounds claimed by some studies to get the overall performance with evaluating the probability of outage without taking level of SNR into consideration.

CONCLUSION

In this study, the influence of the number of antennas used in the mobile sets and in the BS is analyzed according to the outage probability. Results show that the outage probability is a strong function to δ and the pairing strategy for the users play a crucial role in the performance. Also, there is a trade-off between δ and SNR. Considering two users in a cluster the outage probability improves with assigning a sufficient of transmitted power for the far users while clusters with more users, the outage probability for far users will not get a significant improvement using NOMA systems compared with that with OMA systems. Further, level of SNR plays a significant role in the outage probability of the system.

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