Research Paper Presentation

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Title and Authors

Title

On the Performance of Non-Orthogonal Multiple Access in 5G Systems with Randomly Deployed Users

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Abstract

- The fourth generation of mobile networks,such as long term evolution are being deployed world wide and defining the next generation mobile network is receiving a lot of attention.
- Non Orthogonal Multiple Access has been recognized as a promising multiple access techniques for fifth generation (5G) networks.
- This paper describes the performance of NOMA over other access techniques in a downlink network with randomly deployed mobile users.

Prerequisites

- NOMA
- SIC
- Outage Probability
- Ergodic Rate
- Rayleigh Distribution

Prerequisites

Non Orthogonal Multiple Access(NOMA)

- NOMA was proposed as a candidate radio access technology for 5G cellular systems.
- NOMA exploits superposition coding at the transmitter and successive interference cancellation (SIC) at the receiver to seperate the user data, thus multiplexing users in the power domain.
- NOMA has evolved as a spectral efficient,multiple access scheme so that it can cater to a large number of devices.

Prerequisites

Successive Interference Cancellation(SIC)

- SIC is a technique used by receiver in wireless communication that allows decoding of two or more packets that arrived simultaneously.
- SIC is achieved by the receiver decoding the stronger signal first, subtracting it from the combined signal and then decoding the difference as the weaker signal.
- SIC enhances user security by using MAC address and IMEI ,Which are dedicated to a smartphone as a private keys

Prerequisites

Outage Probability(OP)

Outage Probability is defined as the probability that a given information rate is not supported i.e the probability that information rate is less than the required threshold information rate(where the value relates to the minimum signal to noise ratio (SNR) with in a cellular network), One can say that the receiver is out of range of Base Station (BS) in cellular communication.

Ergodic Rate

Ergodic rate is defined as maximum achievable rate averaged over all the fading channels.

Prerequisites

Rayleigh Distribution

- Rayleigh distribution is a continuous probability distribution for non negative valued random variables.
- The channels whose magnitude of the signal through a transmission medium varies according to Rayleigh distribution are called Rayleigh fading models.
- The probability density function of the Rayleigh distribution is :

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-x^2/(2\sigma^2)} \tag{1}$$

- The cumulative distribution function of the Rayleigh distribution is :

$$F(x;\sigma) = 1 - e^{-x^2/2\sigma^2} \tag{2}$$

Abbreviations

Abbreviation	Meaning
h_m	Channel between m th user and base station
g_m	Rayleigh fading channel gain
α	Path loss factor
d_m	Distance between user and base station
s_m	Message for m th user
P	Transmission power
a_m	Power allocation coefficient
n_m	Additive noise for m th user
ρ	transmit SNR
R_m	Achievable data rate for m th user
$\bar{R}_m$	Targeted data rate for m th user
$R_{j \to m}$	Data rate of m th user to detect the j th user message.

Table: Abbreviations used in the experiment

Formulae

Abbreviation	Formula
ϕ_j	$2^{\bar{R}_j} - 1$
ψ_j	$\frac{\phi_j}{\rho(a_j - \phi_j \sum_{i=j+1}^{M} a_i)}$ for $j < M$
ψ_M	$\frac{\phi_M}{\rho a_M}$
ψ_m^*	$\max \psi_1, ...\psi_m$
$E_{M,M}^c$	$\rho \lvert h_m \rvert^2 a_M > \psi_M$

Table: Formulae used in the experiment

NOMA Transmission Protocol

- Let us consider a cellular downlink in which base station is at the centre of disk 'D' with radius R_D and 'M' users are uniformly distributed within the disk. Then the channel h_m is given by

$$h_m = \frac{g_m}{\sqrt{1 + d_m^{\alpha}}} \tag{3}$$

- The channels are sorted as:

$$|h_1|^2 \leq |h_2|^2 ...... \leq |h_M|^2 \tag{4}$$

- The power allocation coefficients are sorted as:

$$a_1 \geq a_2 .... \geq a_M \tag{5}$$

NOMA Transmission Protocol

- According to NOMA protocol, Observation for the m th user is given by

$$y_m = h_m \sum_{i=1}^{M} \sqrt{a_i P} s_i + n_m \tag{6}$$

- As Successive Interference Cancellation (SIC) is carried out at all the users, m th user will detect i th user message for $i < m$ and for $i > m$ it will be treated as a noise.
- So,The data rate achievable for mth user, $1 \leq m \leq M-1$ is given by:

$$R_m = \log\left(1 + \frac{\rho |h_m|^2 a_m}{\rho |h_m|^2 \sum_{i=m+1}^{M} a_i + 1}\right) \tag{7}$$

NOMA Transmission Protocol

- Also, The data rate of m th user to detect the j th ($j \leq m$) user message is:

$$R_{j \to m} = \log\left(1 + \frac{\rho |h_m|^2 a_j}{\rho |h_m|^2 \sum_{i=j+1}^{M} a_i + 1}\right) \quad (8)$$

- The two equations (7) and (8) are obtained if and only if the condition $R_{j \to m} \geq \bar{R}_j$ is true.
- Rate of M th user is given by:

$$R_M = log(1 + \rho |h_M|^2 a_M) \quad (9)$$

- Consequently sum rate achieved by NOMA is

$$R_{sum} = \sum_{m=1}^{M-1} \log\left(1 + \frac{\rho |h_m|^2 a_m}{\rho |h_m|^2 \bar{a}_m + 1}\right) + log(1 + \rho |h_M|^2 a_M) \quad (10)$$

Density Functions of Channel gains

- The channel gain h contributes its part in evaluation of outage probability and ergodic sum rate.
- As the users are uniformly distributed over the disk and small scale fading is Rayleigh distributed,The CDF of the channel gain $|h|^2$ is given by:

$$F_{h^2}(y) = \frac{2}{R_D^2} \int_0^{R_D} \left(1 - e^{-(1+z^{\alpha})y}\right) zdz \tag{11}$$

- By Gaussian-Chebyshev quadrature we can approximate the integral as

$$F_{h^2}(y) \approx \frac{1}{R_D} \sum_{n=1}^{N} \omega_n \times g(\theta_n) \tag{12}$$

Density Functions of Channel gains

- The PDF of the channel gain can be approximated as

$$f_{h^2}(y) \approx \frac{1}{R_D} \sum_{n=1}^{N} \beta_n e^{-c_n y} \tag{13}$$

Where,

- $g(x) = \sqrt{1 - x^2}(1 - e^{-c_n y})(\frac{R_D}{2} x + \frac{R_D}{2})$
- $c_n = 1 + \left(\frac{R_D}{2}\theta_n + \frac{R_D}{2}\right)^{\alpha}$
- $\omega_n = \frac{\pi}{N}$
- $\theta_n = cos(\frac{2n-1}{2N}\pi)$
- $\beta_n = \omega_n \sqrt{1 - \theta_n^2} \times (\frac{R_D}{2}\theta_n + \frac{R_D}{2})c_n$

Outage Performance of NOMA

- The outage events of m th user is defined as the event that m th user cannot detect the j th user's message.So the event $E_{m,j}$ is

$$E_{m,j} \cong \left(R_{j\to m} < \bar{R}_j\right) \tag{14}$$

- The outage probability of m th user can be expressed as :

$$P_m^{out} = 1 - P(E_{m,1}^c \cap .... \cap E_{m,m}^c) \tag{15}$$

- The events $E_{m,j}^c$ can be expressed as :

$$E_{m,j}^c = \left\{ \frac{\rho|h_m|^2 a_j}{\rho|h_m|^2 \sum_{i=j+1}^{M} a_i + 1} > \phi_j \right\} \tag{16}$$

$$= \left\{ \rho|h_m|^2 \left(a_j - \phi_j \sum_{i=j+1}^{M} a_i \right) > \phi_j \right\} \tag{17}$$

Outage Performance of NOMA

- The equation (17) is derived if and only if the below condition is true

$$a_j > \phi_j \sum_{i=j+1}^{M} a_i \tag{18}$$

- When $\rho \to \infty$,$\psi_m^* \to 0$ the outage probability is given as i.e high SNR approximation of OP is :

$$P_m^{out} \to \frac{1}{\rho^m} \tag{19}$$

- From (19) we can say that m th user will experience a diversity order of 'm'.This is better than conventional orthogonal MA scheme whose diversity order is one.
- So, NOMA will achieve better spectral efficiency and user fairness as all the users are served at same time,frequency.

Outage Performance of NOMA

Drawback

- The superior outage performance of NOMA is worthy pointing out,But it is conditioned to the constraint of (18).
- When such a condition is not satisfied ,e.g $a_j \leq \phi_j \sum_{i=j+1}^{M} a_i$ then the user's outage probability is always one,
  i.e $P_m^{out} = 1$
- We can consider this as a drawback of NOMA.

Graphs of Outage Performance vs SNR

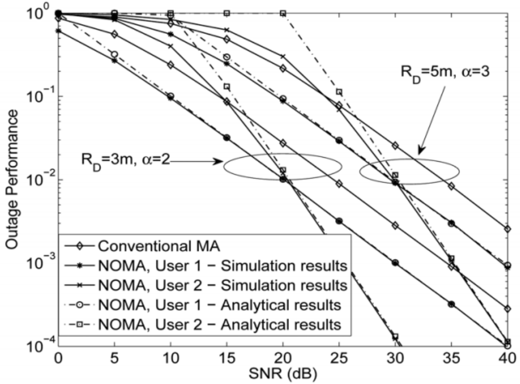

Figure: OP of MA techniques with $\bar{R}_1 = 0.1$ BPCU,$\bar{R}_2 = 0.5$ BPCU

Graphs of Outage Performance vs SNR

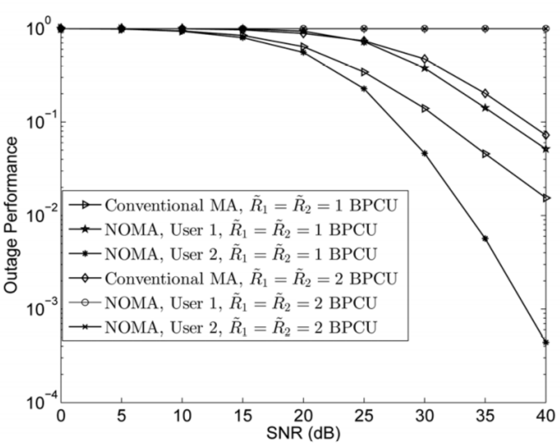

Figure: OP of MA techniques with $R_D = 5$ m ,$\alpha = 3$

Ergodic Sum Rate of NOMA

- The ergodic sum rate when $R_j = \bar{R}_j$ is given by

$$R_{avg} = \sum_{m=1}^{M} \int_0^{\infty} log\left(1 + \frac{x\rho a_m}{x\rho \bar{a_m} + 1}\right) f_{|h_m|^2}(x)dx + \int_0^{\infty} log(1 + \rho x a_M) f_{|h_M|^2}(x)dx \quad (20)$$

- The exact expression of above integral is difficult to obtain.So we do approximation with $M \rightarrow \infty$

$$R_{avg} \rightarrow log(\rho log(log(M))) \quad (21)$$

- NOMA will achieve the same asymptotic performance as the opportunistic scheme,but NOMA can offer better fairness since all the users are served simultaneously.

Graphs of Ergodic Sum Rate vs SNR

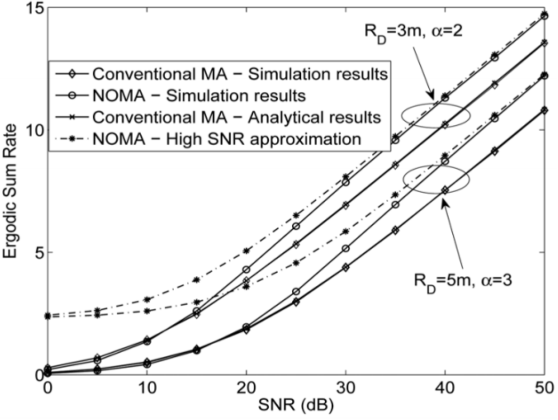

Figure: Ergodic Sum Rate achieved by MA techniques with M=2

Graphs of Ergodic Sum Rate vs SNR

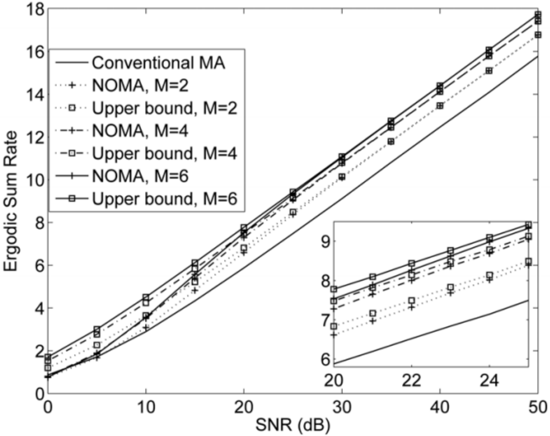

Figure: Ergodic Sum Rate achieved by MA techniques with R=5 m and $\alpha = 2$

Conclusions

- In this paper we have demonstrated that NOMA can achieve better outage performance than the orthogonal MA techniques, under the condition that the users rates and power coefficients are carefully chosen.
- Also,NOMA can achieve a superior ergodic sum rate, and is asymptotically equivalent to the opportunistic MA technique

Potential Drawbacks

- NOMA introduces additional complexity due to the use of SIC.
- The performance gain of NOMA at low SNR is insignificant.

THANK YOU

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