Indonesian Journal of Electrical Engineering and Computer Science
Vol. 36, No. 2, November 2024, pp. 913~922
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v36.i2.pp913-922

Stochastic geometry-based resource allocation scheme over cellular shotgun systems

Ibrahim G. Gomaa[1], **Amr M. Abdelaziz**[2], **Ashraf D. Elbayoumy**[2], **Rania A. Elsayed**[1]
[1]Department of Electronics and Communications Engineering, Zagazig University, Zagazig, Egypt
[2]Military Technical College/Department of Communications, Cairo, Egypt

Article Info

Article history:

Received Nov 21, 2023
Revised Mar 28, 2024
Accepted Jul 21, 2024

Keywords:

Angle of arrival
Angle of departure
Cellular shotgun system
Channel state information
MIMO-MAC capacity
Poison point process
Sectoring

ABSTRACT

This paper presents a resource allocation scheme that fulfills the maximum possible aggregate rate of the capacity region by targeting the corner points of the multiple-input multiple-output multiple access channel. This corner points of the channel's capacity region are attainable whenever each user's transmission has minimum possible interference among other users. This work aims to investigate the non-singularity of such situations by the exploitation of users' geographic location seeking the opportunity of getting users' transmission spatially multiplexed. The developed model demonstrates that similar results can be achieved with partial channel state information knowledge under certain conditions throughout the operational signal to noise ratio range. The proposed resource allocation scheme is designed for a shotgun cellular system with a random distribution of users over a circular coverage area. The proposed model uses stochastic geometry to prove that when number of users grows up within the coverage area, the probability of achieving the corner points sum rate increases rapidly. The developed model was evaluated, and the results show that for a circular coverage area with a radius of 10 km, the probability of having users whose transmissions can be spatially multiplexed with minimum interference increases as the number of users grows to 300 users.

Corresponding Author:

Ibrahim G. Gomaa
Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University
Zagazig, Egypt
Email: ibrahimgomaa040@gmail.com

1. INTRODUCTION

In a multiple-input multiple-output (MIMO) multiple access channel (MAC), there are multiple users, each user equipped with multiple antennas, and a base station or receiver with multiple antennas. The MIMO technology allows for spatial multiplexing, where multiple data are transmitted simultaneously using different spatial dimensions (i.e., different antenna configurations). This enables an increase in the overall data rate compared to a single-input single-output (SISO) system. The capacity of the MIMO-MAC channel depends on several factors, including the number of users, the number of antennas at the receiver and transmitter, the channel conditions (e.g., fading, interference), and the transmit power constraints. The capacity region represents the set of all achievable rate for each user, considering the constraints of the system. The capacity is typically measured in terms of the achievable sum rate, which represents the total data rate that can be supported by the channel. In this paper, we present a resource allocation scheme that exploits the relativity of users' geolocations withing a typical coverage area seeking for higher probability of having users whose transmissions can be spatially multiplexed with minimum interference. Resource assignments among those users is investigated targeting the corner points of the capacity region of a MIMO-

MAC refers to the maximum achievable data rate in the presence of multiple users transmitting simultaneously.

In fact, determining the capacity of a MIMO-MAC channel is a complex problem due to the interactions between the different users and the spatial dimensions. In addition to the availability of channel state information (CSI) about all users, it also requires advanced signal processing techniques, such as linear precoding, interference cancellation, and optimization algorithms. Researchers strive to design efficient transmission schemes and algorithms that can approach the MIMO-MAC channel capacity. These techniques goal to exploit the spatial dimensions and mitigate interference to maximize the achievable data rates for each user in the network. The corner points of the capacity region of a MIMO-MAC channel represent extreme points where each user's transmission achieves the highest possible data rate without exceeding the channel capacity. Attaining these corner points is desirable because they correspond to optimal data rate allocations for each user [1]. For a user's transmission to have minimum interference among other users, it means that the signals transmitted by different users are effectively separated and do not interfere with each other. This can be achieved through techniques such as spatial multiplexing, beamforming, or interference alignment. Spatial multiplexing allows multiple users to transmit simultaneously by utilizing different spatial dimensions. Each user's data stream is transmitted over a different set of antennas, enabling separate spatial paths for each user and reducing interference. The corner points of the MIMO-MAC channel's capacity region can be attained. This means that each user can achieve the highest possible data rate without causing significant interference to others. However, it is important to focus that realizing minimum interference and attaining the corner points of the capacity region may not always be feasible in practical scenarios due to various factors such as channel conditions, power constraints, and system limitations. In such cases, suboptimal rate allocations or trade-offs between data rates and interference mitigation may be necessary. MIMO-MAC systems offer several advantages in wireless communication [2], such as improved capacity and spectral efficiency. However, they also have some limitations that need to be considered [3]. Feedback overhead is considered main source of these limitations to realize the benefits of single-user MIMO, CSI must be known at the transmitter, sharing CSI requires feedback from the receiver to the transmitter, which introduces additional overhead, the amount of feedback required increases with the number of antennas, making it more challenging in practical scenarios. Performance degradation in non-line-of-sight (NLOS) scenarios [4] single-user MIMO relies heavily on the assumption of a rich scattering environment where the transmitted signals experience multiple reflections. In NLOS scenarios, where direct line-of-sight communication is obstructed, the performance of single-user MIMO can suffer. It has previously been shown that the minimum interference scenarios can be achieved with full CSI [5], [6] on the Rician Channel under certain conditions.

While ealier studies have explored the impact of partial CSI at transmitter and receiver, they have not explicitly addressed the influence of angle of departure (θ_t), and angle of arrival (θ_r) at the transmitter, our previous work in [1] it has been shown that the minimum interference scenarios can be achieved with partial CSI on the Rician Channel under certain conditions which has the Rician factor (k), angle of departure (θ_t), and angle of arrival (θ_r) at the transmitter, NLOS components is cancelled due to orthogonality condition that is supposed according to the resource allocation scheme.

Our contribution in this paper is a proposed resource allocation scheme is designed for a shotgun cellular system with a random distribution of users over a circular coverage area. Stochastic geometry is used as a tool [7] to prove that as the number of users increases within the coverage area, the probability of achieving the corner points sum rate also increases rapidly. In this paper to prove that resource allocation scheme, that was found in [1], can be achieved as a non-singular case using poisson point process (PPP) over the shotgun cellular system. The proposed model utilizes stochastic geometry to demonstrate a noteworthy finding when the number of users in a given coverage area increases, the probability of achieving high corner points sum rate also increases rapidly. The model shows that with a larger number of users, there is an increased likelihood of having users whose transmissions can be spatially multiplexed with minimal interference taking the advantage of partial CSI knowledge. To evaluate the model and validate its findings, experiments or simulations were conducted. The results indicate that in a circular coverage area with difference radius, the probability of finding users whose transmissions can be spatially multiplexed with minimal interference becomes more probable as the number of users increases. This finding has implications for the design and optimization of wireless networks. It suggests that with a higher density of users within a coverage area, there is an increased potential for improving the network performance by enabling spatial multiplexing and reducing interference. The rest of the paper is presented as follows: Section 2 shows the research method. In section 3 introduces the proposed method. In section 4 presented the results and discussion. In section 5 provides the paper's conclusion.

2. RESEARCH METHOD

Rician fading channels are a type of wireless communication [8] channel characterized by the presence of both a dominant line-of-sight (LOS) path and scattered multipath components. It is named after Rice distribution, which describes the statistical behavior of the channel's amplitude. In a Rician fading channel, the LOS component is typically stronger than the scattered multipath components, resulting in a stronger signal. In MIMO systems [9], channel capacity refers to the maximum achievable data rate or capacity that can be reliably transmitted over a wireless communication channel. Rician fading is a statistical model that characterizes the effects of multipath propagation in wireless channels, where a dominant line-of-sight component exists along with scattered signals. For point-to-point single-user MIMO ($N_t \times N_r$) channel [10], where N_r and N_t are referred to the number of antennas at the receiver and transmitter respectively, the information limitations channel is generated in several scenarios of channel types and availability of CSI. MIMO channel model with full CSI at the receiver or at transmitter can lead to certain problems [3], [5], [10] the first problem is that the feedback rate required to provide the transmitter with the full CSI can cause a delay between the transmitter and receiver. This can result in a suboptimal performance of the system, especially in fast-changing channel conditions, the second problem is related to the rate of change of the channel parameters. In a multi-user scenario, e.g., MAC or broadcast channels, the system capacity is characterized by the capacity region where all users are sharing the same channel with a rate competition based on different channel parameters and target system sum rate [11]. However, this comes at the expense of having a reliable CSI feedback link. To get upper bound in a closed-form for maximizing capacity by using Jensen's inequality [12], we need to set up the problem properly. In capacity maximization problems, we often encounter expectations (E) and logarithmic functions.

Maximum benefit in relation to capacity across a wide range of system characteristics is driven in closed form by applying Jensen's inequality. Thus, the optimal starting point for any numerical optimization method is estimating the upper bound maximizing capacity. Baccelli and Blaszczyszyn [7], the authors provided spatial averages, i.e., the number of nodes with different locations, over quantities of interest, e.g., SINR, interference, achieved data rate, and outage probability, using stochastic geometry as a mathematical tool. Also, it can be used to study random phenomena over a certain area. Stochastic geometry leads to the theory of point processes in [13], stochastic geometry has different models in wireless networks, including the poisson point, binomial point, hardcore point, and poisson cluster processes. The authors considered different techniques to evaluate network performance, including resorting to the rayleigh fading assumption, resorting to nearest n Interferers or dominant interferers by region bounds, resorting to the approximation of the pdf of the aggregate interference, and resorting to the plancherel - parseval theorem - inversion. Gilbert [14], [15] were the first to discuss the connectivity analysis for large wireless networks using stochastic geometry. Different forms of stochastic geometry were widely used to achieve specific wireless communications mechanisms. Stochastic geometry is used with a large-scale in wireless communication networks to calibrate quantities of interest, e.g., SINR, interference, achieved data rate, and outage probability. This calibration depends on the locations of the network elements of several point processes. Kamal *et al.* [16], the authors have investigated resource allocation in wireless 5G networks due to the increasing and growing cellular service with limited resources. The network performance was evaluated under consideration of resource allocation methods. Device-to-device (D2D) is a key technology in 5G cellular systems. Mi *et al.* [17], considered resource allocation of D2D-based 5G systems. Resource allocation has a significant influence on enhancing the delay-unaware performance metrics. The orthogonal frequency division multiple access was used to overcome the delay limitations and meets the quality-of-service (QoS) requirements.

Jiang *et al.* [18], considered resource allocation and mode selection issues that belong to D2D communications. Firstly, the authors proposed a mode selection algorithm to reduce the potential interference and enhance the cellular user's transmission. Underlay mode was used to analyze the D2D communication. Secondly, this mode was adopted while reusing cellular resources. Moreover, the authors presented a resource allocation scheme that minimizes interference when a power control method is deployed to enhance the D2D system's performance. Simulation results proved that system parameters greatly affect the probability of choosing an underlay mode and the switching condition of mode selection. Dai *et al.* [19], the authors employed non-orthogonal multiple access (NOMA) to improve the connectivity of the 5G cellular network. The execution condition of the successive interference cancellation decoding for NOMA cellular networks, in case the underlay D2D communications might destroy, was presented as extra interference, destroying the cellular transmission reliability. Thus, the authors developed a new mode called interlay mode as a special case of D2D mode for the NOMA system. The proposed solution in [20] aimed to maximize the sum rate of D2D pairs and meet the minimum rate requirements of NOMA-based cellular users through a dual-based iterative algorithm is promising to solve the resource allocation problem. As for security in D2D communications, it is indeed an important aspect to consider. The numerical results presented in [21] regarding the secrecy ergodic capacity (SEC) and secrecy outage probability (SOP) show that the DF relay mode can enhance security performance at long distances between transmitter and receiver nodes. The optimization of secure resource allocation in D2D communication to minimize SOP and maximize the SEC is also a crucial step in ensuring the security of these communications.

Brown [22] assumes that the BS uses omnidirectional antennas, and then investigates the impact of sectoring on the capacity of the cellular system. The results presented that sectoring can significantly improve the capacity of the system, especially when the sectoring is applied to the users with the highest channel gains, in wireless communication networks, interference is a major factor that affects the system performance. By minimizing the potential interference, the performance of system can be improved.

3. THE PROPOSED METHOD

3.1. System model

This study mainly extends our previously proposed study in [1]. The proposed resource allocation scheme is designed for a shotgun cellular system with a random distribution of users over a circular coverage area. Stochastic geometry proves that whenever the number of the users increases within the coverage area, the probability of achieving the corner points sum rate also increases rapidly. Moreover, stochastic geometry is used to study the resource allocation scheme over the cellular shotgun system, as in Figure 1. We found that, stochastic geometry is used to prove that the upper bound of capacity correlates with a certain density of users over this determined area achieving the upper bound of maximum capacity over the shotgun cellular system by using the PPP and the maximum number of users achieving the orthogonality condition between themselves over a certain coverage area, moreover the results of capacity enhancement over the operational range users over a cellular shotgun system. Similar results can be achieved with partial CSI knowledge as a non-singular case. This paper proposes a cellular system design called the shotgun system. In this system, mobile stations (MSs) are randomly distributed over a geographic area using a two-dimensional PPP. The base station (BS) uses omnidirectional antennas to cover a determined area and employs sectoring to reduce users interference and improve system performance [23]-[25]. The proposed method in this study tended to have an inordinately higher proportion of uses stochastic geometry to evaluate the number of users per sector across the coverage area of the shotgun system, which is divided into four equal sectors. The average MS density is determined by the number of receiving antennas (N_r), the sector angle (N_s), the average user density (λ), the number of ideal sectors (α), and the radius of the cellular system (r). The proposed scheme aims to assign users whose transmissions can be spatially multiplexed with minimal interference and collect all orthogonal MSs in a single cluster group (CG). Overall, the paper presents a novel approach to designing a cellular system that considers the random distribution of MSs and employs sectoring to improve system performance.

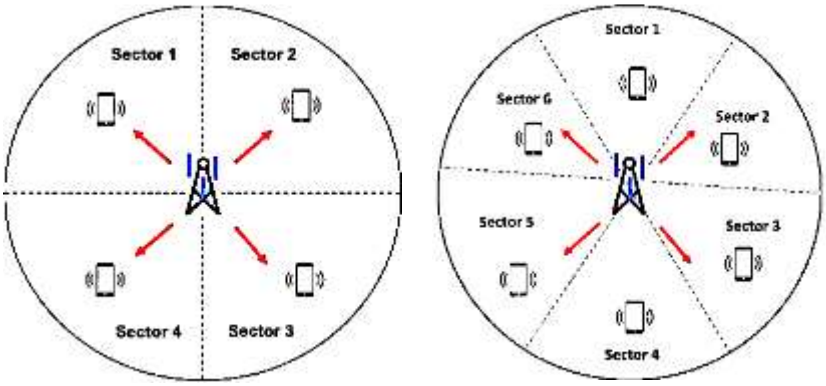

Figure 1. Distribution of MS over shotgun cellular system over four sectors and six sectors

3.2. Problem formulation

While earlier studies have explored the impact of the geolocations of nodes in the MIMO system can be considered as a singular case, although [1] attempted to compare the expression of total sum rate capacity is found for the ordinary MIMO-MAC in Rician channel that presented in (1) and we found that, the suggested partial zero-forcing scheme got in (5) to enhance the capacity over the operational range of SNR, this directly comparison between the sum rate capacity equations given in (1) and (5) did not result in a closed form solution and numeric optimization scheme. This paper aims to prove the geolocations of the

MIMO system nodes as a singular case of the situation mentioned in [1]. It can be deployed as a non-singular case using stochastic geometry probability. In fact, the effect of angle of departure and angle of arrival (AoD), (AoA) respectively have great influence maximizing the MIMO channel's capacity. While the minimum interference scenarios can be achieved with full CSI in Rician Channel under certain conditions, similar results can be achieved with partial CSI knowledge under certain conditions throughout the operation SNR range. The capacity expression with no interference can be given by in [1]. When all user channels have the same distribution, evaluate the sum rate capacity upper bound as (1):

$$\boldsymbol{C}_{sum} \le \ log_2\left(1 + \frac{\boldsymbol{P}N_r^2(1+N_t k)}{N_t(1+k)}\right) + (n-1)log_2\left(1 + \frac{\boldsymbol{P}N_r^2}{N_t(1+k)}\right) \tag{1}$$

where $n = min\{N_t, N_r\}$, P is equal power budget at all users, N_r is number receiving antennas, N_t is number of transmitting antennas, k is Rician factor. The capacity expression under the orthogonality condition of the ith user can be given by (2):

$$\boldsymbol{C}_i \le E_{\boldsymbol{H}_1,..,\boldsymbol{H}_{N_r}}\left[log_2\, det\left(I_{N_r} + \frac{P_i}{N_t} H_i H_i^{\dagger} \boldsymbol{R}_{n_i n_i}^{-1}\right)\right] \tag{2}$$

and the interference term follows as (3):

$$R_{n_i n_i} \le E_{\underline{H_{nlos.(j)}}_{j\ne i}}\left[I_{N_r} + \ A\left(\theta_{r_i}\right) \sum_{\substack{j=1 \\ j\ne i}}^{N_r} \quad \frac{P_j}{N_t} \boldsymbol{H}_{nlos.(j)} \boldsymbol{H}_{nlos.(j)}^{\dagger}\right] = \boldsymbol{I}_{N_r} + \ A\left(\theta_{r_i}\right) \frac{P(N_r-1)^n}{N_t(1+k)} \boldsymbol{I}_{N_r} \tag{3}$$

assuming it's equal user power with no interference channel distribution using the result got in (1), the can be presented as (4) and (5).

$$\boldsymbol{C}_i \le \ log_2\left(1 + \frac{\boldsymbol{P}N_r(1+N_t k)}{N_t(1+k)+P_n(N_r-1)}\right) + \ (n-1)\ log_2\left(1 \ \frac{\boldsymbol{P}N_r}{N_t(1+k)+P_n(N_r-1)}\right) \tag{4}$$

$$\boldsymbol{C}_{sum} \le \sum_{i=1}^{N_r} \quad C_i \ \le \ N_r\, log_2\left(1 + \frac{\boldsymbol{P}N_r(1+N_t k)}{N_t(1+k)+P_n(N_r-1)}\right) + N_r\ (n-1)\ log_2\left(1 + \frac{\boldsymbol{P}N_r}{N_t(1+k)+Pn(N_r-1)}\right) \tag{5}$$

The upper bound of capacity with no interference without the knowledge of CSI at the transmitter is compared with the capacity under orthogonality condition with the partial knowledge of Rician fading parameter as the Rician factor (k), the angle of departure (θ_t), and angle of arrival (θ_r). The result in [1] led to the capacity in the orthogonality condition being more enhanced than the upper bound of capacity in case of no interference condition over the operational range of SNR. As a result, the feedback model reduces the need for the feedback link's delay and rate. While the capacity of Rician fading Channel was discussed in [1] when the receiver has full mean CSI, the transmitter only has the Rician factor (k), angle of arrival (θ_r), and angle of departure (θ_t). The corner points of the capacity region of the MIMO-MAC channel are only attainable when the transmission of each user has minimal possible interference among other users. This proposed solution proved that (k, θ_t, θ_r) are enough to get the advantage of the full mean feedback model. In this case of multiple access channels (MAC), optimizing signaling strategy depends on the amount of CSI available about network users. However, this model's cost increases when the number of users increases. Therefore, this work's extension to MAC is an attractive topic from CSI feedback. This suggested scheme has discussed the impact of orthogonality condition among the users to minimize the interference among the users. The comparison between ordinary MIMO-MAC capacity in the Rician channel with no interference and the suggested partial zero-forcing scheme that relies on the orthogonality condition is done. The proposed resource allocation scheme is designed for a shotgun cellular system with a random distribution of users over a circular coverage area. Stochastic geometry proves that whenever the number of users increases within the coverage area, the probability of achieving the corner points sum rate also increases rapidly. Hence, the proposed resource allocation scheme can be deployed.

This work aims to investigate the non-singularity of such situations. While it has been shown that, in the Rician channel, full CSI is wanted to achieve the minimum interference scenarios, we show that, under certain conditions, similar results can be achieved with partial CSI knowledge across the entire range of operation signal-to-noise ratio (SNR).

3.3. Propose resource allocation scheme

The proposed method in this study tended to have an inordinately higher proportion uses stochastic geometry, the proposed resource allocation scheme is based on the exploitation of the non-singularity of situations mentioned in [1] while it can be shown that the minimum interference scenarios can be achieved with full CSI in Rician Channel under certain conditions, similar results can be achieved with partial CSI knowledge under certain conditions throughout the operation SNR range. The proposed resource allocation scheme is designed for a shotgun cellular system with a random distribution of users over a circular coverage area. Stochastic geometry proves that as the number of users increases within the coverage area, the probability of achieving the corner points sum rate also increases rapidly. Hence, the proposed resource allocation scheme can be deployed as a non-singular case. The flowchart of the proposed resource allocation scheme is shown in Figure 2, and Table 1 illustrates some of the important symbols used in this paper. The proposed resource allocation scheme is designed to address the non-singular case, meaning that it aims to allocate resources in a way that avoids interference and achieves optimal performance.

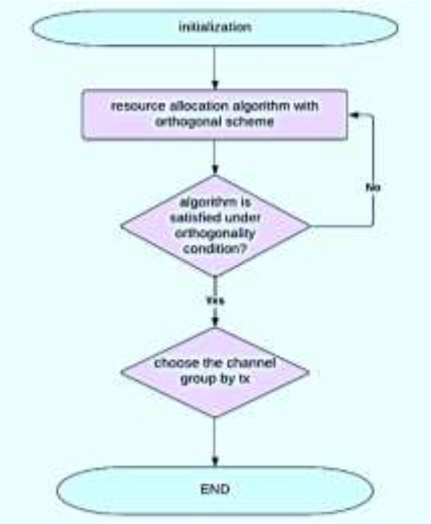

Figure 2. Flowchart for proposed resource allocation scheme algorithm

Table 1. Summary of important symbols

Symbol	Description
p	The probability of users with min interference
λ	The average intensity of users
α	Number of sectors
r	Radius of circular coverage area
Ns	Covering sectors angle
Nr	Number of receiving antennas
D2D	Device to device
AOA (θr)	Angle of arrival
AOD (θt)	Angle of departure
SEC	Security ergodic capacity
DF	Decode- and-forward
MAC	Multiple access channel
BS	Base station
MS	Mobile station
NOMA	Non-orthogonal multiple access
P	Power over cellular users
SOP	Secrecy outage probability

The network control is divided into three phases:

a) Initialization state, in which users are distributed randomly over cellular shotgun system within certain area with constant radius.
b) Resource allocation algorithm (section 3.4) is implemented by using PPP at transmitter to check the orthogonality condition. This is achieved by selecting users whose geographic location allows for spatial multiplexing.
c) Orthogonal users are elected and tagged into a single cluster group. Transmitter chooses the orthogonal users as one cluster group (CG) with minimum interference between users.
d) If the orthogonality condition not achieved the transmitter repeat to check the algorithm again until orthogonality condition will be achieved.

3.4. Analytical stochastic geometric model for cellular shotgun systems

Considering the scenario in Figure 3, the notion of a geolocations-aware shotgun cellular system is proposed. Figure 3 presents the geolocations of mobile station (MS) and its distribution. Supposing this system is a shotgun cellular system, and MS is distributed according to a two-dimensional PPP, where the average MS density is (λ) and the number of MS in the area, A, is λA. If (k) is referred to the random variable for the number of MS in area A, the probability of distribution of MS over this area within a radius (r) is given as follows:

$$P = \frac{(\lambda A)^n}{n!}\, e^{-\lambda A} \tag{6}$$

for a circular area of radius (r), the distribution probability can be rewritten as follows:

$$P = \frac{(\lambda \pi r^2)^n}{n!}\, e^{-\lambda \pi r^2} \tag{7}$$

$$P = \frac{k^n}{n!}\, e^{-k} \tag{8}$$

$$P = \left(1 - \left(\frac{(\frac{\lambda \pi r^2}{N_s})^{N_r}}{N_r!} . e^{\frac{-\lambda \pi r^2}{N_s}}\right)\right)^{N_s} \tag{9}$$

$$P = 1 - \left(e^{\frac{-\lambda \pi r^2}{N_s}}\right)^{N_s} \tag{10}$$

where K is the number of users, $K = \lambda\, \pi r^2$.

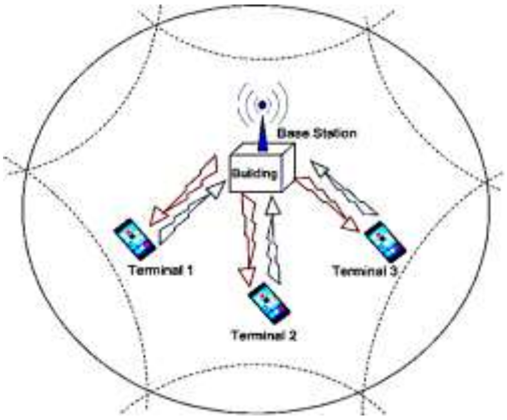

Figure 3. Shotgun cellular system for wireless networks

4. RESULTS AND DISCUSSION

By using MATLAB simulation program, our study suggests that for a circular coverage area with a radius of 10 km, the probability of having users whose transmissions can be spatially multiplexed with minimum interference increases when the number of users increases as in Figure 4. The intensity using different signaling schemes is plotted as a function of the number of users as in Figure 4. The performance of this system model is evaluated using the shotgun cellular system with a radius r = 10 km, the same setup is used to generate but with a different radius (r) = 15 km and 20 km over the same ideal number of sectoring (α) = 4 as in Figure 4. It is noted that the probability of existing one user at least in each sector achieving the minimum interference increases while the intensity is increased, so the number of users increases while intensity is grewed up.

Brown [22], using sectoring techniques decreases the interference as the BS employs multiple narrow-beam antennas each of them faces a different direction. If the number of sectors increased by changing the value of the number of sectors (α) to 6 $(\alpha = 6)$, we noticed that at the probability of existing one user at least in each sector achieving the minimum interference increases while the intensity is increased while still the number of users constant with a different radius (r) = 10 km, 15 km, and 20 km as shown in Figure 5. Moreover, the probability of having users whose transmissions can be spatially multiplexed with minimum interference is increased.

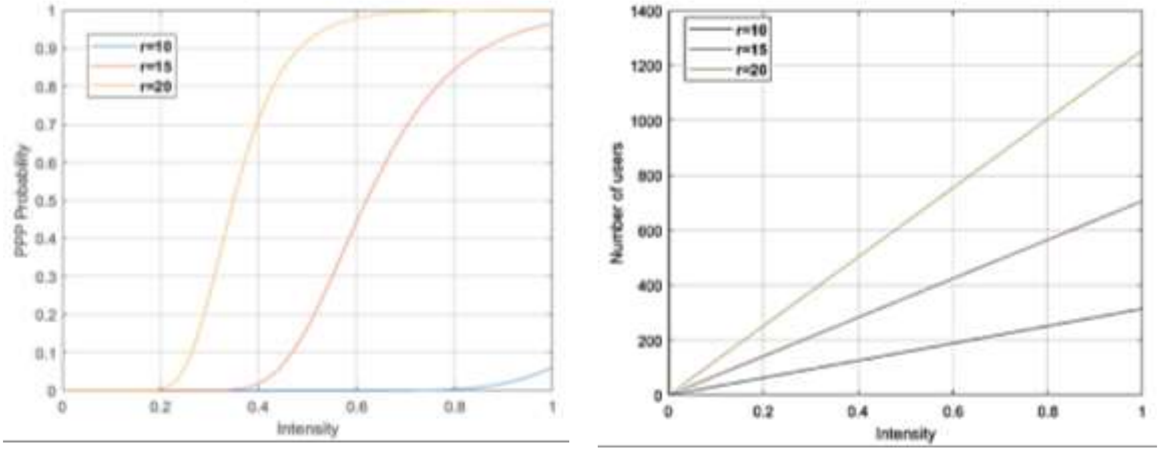

Figure 4. Number of users and PPP vs intensity for α = 4, r = 10 km, 15 km, and 20 km

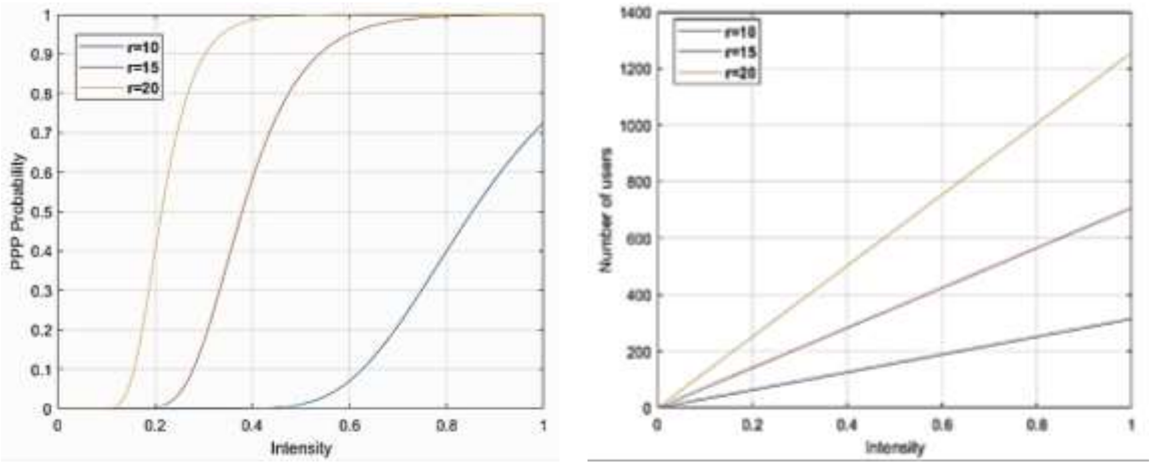

Figure 5. Number of users and PPP vs intensity for α = 6, r = 10 km, 15 km, and 20 km

The result in [1] is presented that the capacity of MIMO-MAC in the Rician channel is enhanced by studying the impact of the AoA and AoD from all receiving to all transmitting antennas and achieving orthogonality condition between the users to minimize the interference. Furthermore, the number of users is enhanced with the minimum amount of CSI parameter’s available about network users that determined by the estimating signaling method. In the results of this paper as extension work of [1], the number of users is found to be increasing due to increasing the average density and PPP increases due to intensity increase. So, we conclude that the enhancement of capacity over operational range can be deployed between a certain number of users over the cellular shotgun system and the model in [1] can be deployed as a real and non-singular case.

5. CONCLUSION

Recent observations suggest that, the PPP resource allocation scheme over cellular shotgun systems and studied the number of users over this coverage area according to the intensity of users. Our results show that for a coverage circular area with a radius of 10 km, 15 km, and 20 km, the probability of having users whose transmissions can be spatially multiplexed with minimum interference increases as the number of users grows up to 1,250 users. So, this study explored a comprehensive evidence that this phenomenon is associated with save the bandwidth resources of the channels using 5G technology, however, our findings are initial point to help the researchers approach the numerical values in future and achieve further and in-depth studies may be needed to confirm its the maximum capacity channel with minimum interference.

REFERENCES

[1] I. Gomaa, “On the capacity of MIMO-MAC in Rician channel,” *The Egyptian International Journal of Engineering Sciences and Technology*, vol. 35, no. 3, pp. 67–74, Sep. 2021, doi: 10.21608/eijest.2021.64102.1051.

[2] H. Kusumoto, H. Okada, K. Kobayashi, and M. Katayama, “Performance comparison between single-user MIMO and multi-user MIMO in wireless mesh networks,” *International Symposium on Wireless Personal Multimedia Communications, WPMC*, pp. 202–206, 2012.

[3] G. J. Foschini and M. J. Gans, “On limits of wireless communications in a fading environment when using multiple antennas,” *Wireless Personal Communications*, vol. 6, no. 3, pp. 311–335, 1998, doi: 10.1023/A:1008889222784.

[4] A. Xhafa, J. A. Del Peral-Rosado, G. Seco-Granados, and J. A. Lopez-Salcedo, “Performance of NLOS base station exclusion in cmWave 5G positioning,” in *IEEE Vehicular Technology Conference*, Apr. 2021, vol. 2021-April, pp. 1–5, doi: 10.1109/VTC2021-Spring51267.2021.9448738.

[5] E. Telatar, “Capacity of multi-antenna gaussian channels,” *European Transactions on Telecommunications*, pp. 585–595, 1999, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.38.6378.

[6] A. Goldsmith, S. A. Jafar, N. Jindal, and S. Vishwanath, “Capacity limits of MIMO channels,” *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 5, pp. 684–702, Jun. 2003, doi: 10.1109/JSAC.2003.810294.

[7] F. Baccelli and B. Blaszczyszyn, “Stochastic geometry and wireless networks: volume ii applications,” *Foundations and Trends in Networking*, vol. 4, no. 1–2, pp. 1–316, 2009, doi: 10.1561/1300000026.

[8] F. Zhao, H. Lin, C. Zhong, Z. Hadzi-Velkov, G. K. Karagiannidis, and Z. Zhang, “On the capacity of wireless powered communication systems over rician fading channels,” *IEEE Transactions on Communications*, vol. 66, no. 1, pp. 404–417, Jan. 2018, doi: 10.1109/TCOMM.2017.2754488.

[9] A. Y. Hassan, “Code-time diversity for direct sequence spread spectrum systems,” *The Scientific World Journal*, vol. 2014, pp. 1–15, 2014, doi: 10.1155/2014/146186.

[10] S. K. Jayaweera and H. V. Poor, “On the capacity of multiple-antenna systems in Rician fading,” *IEEE Transactions on Wireless Communications*, vol. 4, no. 3, pp. 1102–1111, May 2005, doi: 10.1109/TWC.2005.846970.

[11] A. El Gamal and Y.-H. Kim, “Lecture notes on network information theory,” 2010, [Online]. Available: http://arxiv.org/abs/1001.3404.

[12] A. M. Abdelaziz, “Information theoretical studies on MIMO channel with limited channel state information,” 2017, [Online]. Available: http://rave.ohiolink.edu/etdc/view?acc_num=osu1500592938716914.

[13] H. ElSawy, A. Sultan-Salem, M. S. Alouini, and M. Z. Win, “Modeling and analysis of cellular networks using stochastic geometry: a tutorial,” *IEEE Communications Surveys and Tutorials*, vol. 19, no. 1, pp. 167–203, 2017, doi: 10.1109/COMST.2016.2624939.

[14] E. N. Gilbert, “Random subdivisions of space into crystals,” *The Annals of Mathematical Statistics*, vol. 33, no. 3, pp. 958–972, Sep. 1962, doi: 10.1214/aoms/1177704464.

[15] E. N. Gilbert, “Random plane networks,” *Journal of the Society for Industrial and Applied Mathematics*, vol. 9, no. 4, pp. 533–543, Dec. 1961, doi: 10.1137/0109045.

[16] M. A. Kamal, H. W. Raza, M. M. Alam, M. M. Su’ud, and A. B. A. B. Sajak, “Resource allocation schemes for 5G network: a systematic review,” *Sensors*, vol. 21, no. 19, p. 6588, Oct. 2021, doi: 10.3390/s21196588.

[17] X. Mi, L. Xiao, M. Zhao, X. Xu, and J. Wang, “Statistical QoS-driven resource allocation and source adaptation for D2D communications underlaying OFDMA-based cellular networks,” *IEEE Access*, vol. 5, pp. 3981–3999, 2017, doi: 10.1109/ACCESS.2017.2679113.

[18] F. Jiang, B. Wang, C. Sun, Y. Liu, and R. Wang, “Mode selection and resource allocation for device-to-device communications in 5G cellular networks,” *China Communications*, vol. 13, no. 6, pp. 32–47, Jun. 2016, doi: 10.1109/CC.2016.7513201.

[19] Y. Dai, M. Sheng, J. Liu, N. Cheng, X. Shen, and Q. Yang, “Joint mode selection and resource allocation for D2D-enabled NOMA cellular networks,” *IEEE Transactions on Vehicular Technology*, vol. 68, no. 7, pp. 6721–6733, Jul. 2019, doi: 10.1109/TVT.2019.2916395.

[20] Y. Pan, C. Pan, Z. Yang, and M. Chen, “Resource allocation for D2D communications underlaying a NOMA-based cellular network,” *IEEE Wireless Communications Letters*, vol. 7, no. 1, pp. 130–133, Feb. 2018, doi: 10.1109/LWC.2017.2759114.

[21] H. Ghavami and B. Akhbari, “Secure resource allocation in device-to-device communications underlaying cellular networks,” *China Communications*, vol. 19, no. 8, pp. 149–167, Aug. 2022, doi: 10.23919/JCC.2022.08.012.

[22] T. X. Brown, “Cellular performance bounds via shotgun cellular systems,” *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 11, pp. 2443–2455, Nov. 2000, doi: 10.1109/49.895048.

[23] G. K. Chan, “Effects of sectorization on the spectrum efficiency of cellular radio systems,” *IEEE Transactions on Vehicular Technology*, vol. 41, no. 3, pp. 217–225, 1992, doi: 10.1109/25.155968.

[24] V. H. M. Donald, “Advanced mobile phone service: the cellular concept,” *Bell System Technical Journal*, vol. 58, no. 1, pp. 15–41, 1979, doi: 10.1002/j.1538-7305.1979.tb02209.x.

[25] T. S. Rappaport, A. Annamalai, R. M. Buehrer, and W. H. Tranter, “Wireless communications: past events and a future perspective,” *IEEE Communications Magazine*, vol. 40, no. 5, pp. 148–161, 2005, doi: 10.1109/mcom.2002.1006984.

BIOGRAPHIES OF AUTHORS

Ibrahim G. Gomaa received B.Sc. degree in 2005 from Military Technical College, Egypt. He worked as officer at signal department, Egyptian Army. Currently, Researcher at Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt. He can be contacted at email: ibrahimgomaa040@gmail.com.

Amr M. Abdelaziz working as a senior naval communication officer from 2005-2007. Obtaining a B.Sc. and M.Sc. from the Military Technical College in Egypt in 2005 and 2012, teaching associate at the Military Technical College from 2007 to 2014, graduate research associate at The Ohio State University from 2014 to 2017, the completion of a Ph.D. degree from The Ohio State University in 2017, currently serving as a faculty member at the Military Technical College, Egypt. He can be contacted at email: amrashry@mtc.edu.eg.

Prof. Dr. Ashraf D. Elbayoumy received the B.Eng. degree in electrical engineering from MTC, Cairo, Egypt in 1994 and master degree in speech security from MTC, Cairo, Egypt in 1999. Ph.D. degree in VoIP security from University of Bradford, UK in 2006. Currently working as a full Professor in MTC, Cairo, Egypt. He can be contacted at email: adiaa@mtc.edu.eg.

Rania A. Elsayed is an Assistant Professor at Department of Electronics and Communications, Faculty of Engineering, Zagazig University, Egypt. She has received the M.Sc. degree (2009) from the same university in speech compression via gaussian mixture model with wavelet analysis used in communication systems and Ph.D. degree (2018) in hand gestures recognition for deaf persons from the Faculty of Engineering, Zagazig University (Egypt). She can be contacted at email: rania_ahmed@zu.edu.eg.