MIMO Antenna Design for 5G Communication Systems Using Salp Swarm Algorithm

Achilles D. Boursianis
ELEDIA Research Center, ELEDIA@AUTH
Department of Physics
Aristotle University of Thessaloniki
Thessaloniki, Greece
bachi@physics.auth.gr

Sotirios K. Goudos
ELEDIA Research Center, ELEDIA@AUTH
Department of Physics
Aristotle University of Thessaloniki
Thessaloniki, Greece
sgoudo@physics.auth.gr

Traianos V. Yioultsis
Department of Electrical and Computer Engineering
Aristotle University of Thessaloniki
Thessaloniki, Greece
traianos@auth.gr

Katherine Siakavara
Department of Physics
Aristotle University of Thessaloniki
Thessaloniki, Greece
skv@auth.gr

Paolo Rocca
ELEDIA@UniTN - DISI
University of Trento
Trento, Italy
paolo.rocca@unitn.it

2020 International Workshop on Antenna Technology (iWAT) 978-1-7281-2640-1/20/$31.00 ©2020 IEEE 10.1109/iWAT48004.2020.1570618331

***Abstract*—Multiple Input Multiple Output (MIMO) antennas will be a part of every new user device in 5G networks. In this paper, we design a MIMO antenna for 5G networks using a nature-inspired algorithm, namely the Salp Swarm Algorithm (SSA). We select a bow tie antenna as the element of the MIMO operating in n257 frequency band (center frequency at 28GHz). Firstly, we design and optimize the antenna element using the SSA algorithm. Secondly, a MIMO antenna is designed using the optimal dimensions of the antenna element. Numerical results demonstrate that the proposed MIMO antenna has a small size and exhibits wideband operation in the desired frequency band.**

***Index Terms*—5G mobile communications, bow tie antenna, MIMO antenna, salp swarm algorithm, swarm intelligence algorithms.**

I. Introduction

The main user requirement in 5G networks will be, among others, high data rates in terms of Gbps [1]. Such rates will require operation in millimeter-wave bands and Multiple Input Multiple Output (MIMO) Antennas [2] - [4]. The main characteristic of these antennas will be small size and wideband operation.

Bow-tie antennas exhibit several advantages, like simplicity in structure, low profile, light in weight, and easy to fabricate [5]. They have been used in the literature in several types of wireless applications [6]. Due to the previously mentioned advantages, we have selected to design and optimize a bow-tie antenna operating in the 28GHz frequency band for 5G applications. The bow-tie antenna requires the definition of several geometrical parameters to achieve an acceptable performance. Such a problem can be addressed with the use of an optimization technique.

In this paper, the Salp Swarm Algorithm (SSA) is applied, which was recently introduced in [7]. SS algorithm imitates the salps swarming behavior during their navigation or forage in oceans. To the best of our knowledge, SSA is applied to a antenna design problem for the first time. Firstly, we design the bow-tie element using the SS algorithm. Then, we use the best element geometry obtained by the Salp Swarm optimization algorithm to design a 2×2 MIMO antenna operating at 5G communication systems.

The rest of this paper is organized as follows. Section II gives a brief description of SSA. Section III describes the antenna design procedure, whereas Section IV summarizes the conclusion of our work.

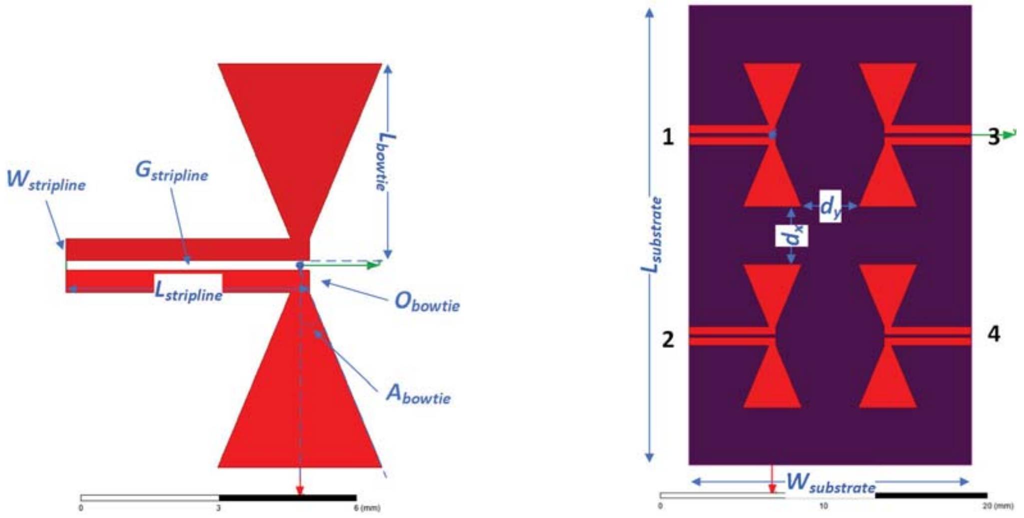
II. Salp Swarm Algorithm Description

Salp Swarm Algorithm is inspired by the swarming behavior (navigation or forage) of salps in oceans [7]. The SS algorithm models the salps chains by splitting the whole population into two distinct groups; the leader and the followers [7]. As the definitions imply, the leader salp guides the salp population (i.e. leader is the population member that has achieved the best score in the objective function), whereas the followers follow the leader directly or indirectly, by following other followers (i.e. followers are the population members with worse score that the leader in the objective function).

In the Salp Swarm algorithm, each salp is described by a N-dimensional vector that corresponds to a possible solution of the optimization problem. The population member (salp) with the best vector position found in the iteration process is declared as 'food' position. The algorithm divides the total population into two equally sized groups of $M_{pop}/2$, where M_{pop} is the population size. The fitness value of the leader salp in the population is calculated by the following expression:

$$y_k^1 = \begin{cases} A_k - f_1\big((b_k^{max} - b_k^{min})f_2 + b_k^{min}\big), f_3 < 0.5 \\ A_k + f_1\big((b_k^{max} - b_k^{min})f_2 + b_k^{min}\big), f_3 \geq 0.5 \end{cases} \quad (1)$$

where y_k^1 indicates the position of the leader salp (the salp with the best score in the objective function) in the k-th dimension, A_k denotes the food source position in the k-th dimension,



(a) (b)

Fig. 1. Geometry of the proposed antenna operating in the 28GHz frequency band derived by SSA: (a) Bow-tie antenna element, (b) Bow-tie MIMO antenna ($L_{susbstrate} = 28.68$mm, $W_{susbstrate} = 17.62$mm, $d_x = d_y = 3.60$mm).

and b_k^{max}, b_k^{min} are the boundaries (maximum and minimum value respectively) in the k-th dimension. The parameter f_1, which is important in the SS algorithm because it controls both the exploration and the exploitation of the search space, is expressed by:

$$f_1 = 2e^{-\left(\frac{4It}{It_{\max}}\right)^2} \tag{2}$$

where It is the current iteration and It_{max} the maximum number of iterations. Moreover, $f_2, f_3 \in [0, 1]$ are parameters with uniformly distributed random values. They control two different features: a) the tendency of the the next position in k-th dimension (i.e. if it will be towards positive or negative infinity) and b) the step size. Finally, the fitness value (position vector) of the followers is given by:

$$\bar{y}^j = \frac{\bar{y}^j + \bar{y}^{j-1}}{2} \tag{3}$$

III. Numerical Results

The first step in the optimization process includes the optimization of the antenna element. Fig. 1a illustrates the antenna element geometry and Fig. 1b the geometry of the MIMO antenna. The proposed element is a bow-tie antenna operating in the n257 (28GHz) frequency band. It is designed on a single substrate layer of Taconic material with $\epsilon_r = 2.21$ and thickness equal to 1.58mm. A ground plane is placed beneath the substrate, thus completing the antenna element design. in our model, we apply boundary conditions of finite conductivity (copper) in both the antenna element (and in MIMO antenna as well) and the ground plane.

From the Fig. 1, we can derive that, to fully describe the antenna element design, several geometrical parameters are required. As a result, we apply an optimization technique by utilizing the Salp Swarm Algorithm to obtain the best solution. The applied algorithm is used in conjunction with a 3D Electromagnetic Field Simulator for RF and wireless design (ANSYS HFSS by utilizing a HFSS-MATLAB-API library toolbox [8]. We set the population size of the SSA equal to $M_{pop} = 40$ and the maximum number of iterations $It_{max} = 1000$. Table I lists the optimal solution values of the geometrical variables described in Fig. 1, which are derived by applying the previously mentioned optimization technique. The objective function which defines the design problem of the proposed antenna element in the MIMO antenna is given by the following form:

$$F(\bar{x}) = \\ max\left(S_{11}^{28GHz}(\bar{x})\right) + \Xi \times max\left(0, S_{11}^{28GHz}(\bar{x}) - L_{dB}\right) \tag{4}$$

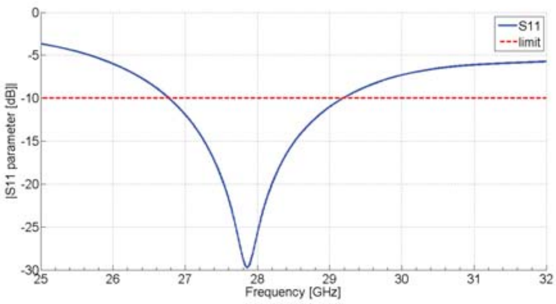
where $\bar{x}$ is the solution vector of the selected antenna geometry, S_{11}^{28GHz} is the value of the reflection coefficient (S_{11} parameter) at the desired frequency, L_{dB} is the arbitrarily defined limit of the reflection coefficient (in our case we have set $L_{dB} = -10dB$), and Ξ is a penalty number (in our case we have set $\Xi = 1E + 10$).

Fig. 2a depicts the reflection coefficient (S_{11} parameter)

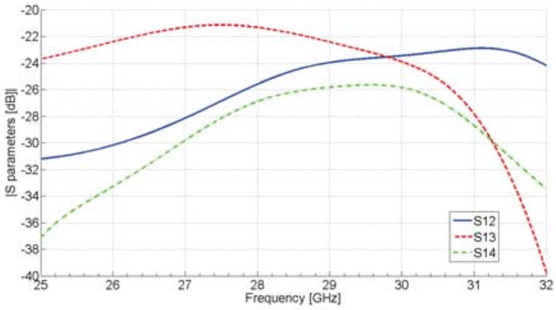
TABLE I
Final geometrical values (best solution) of the proposed element in 5G MIMO antenna derived by SSA.

Parameter	Value
L_{bowtie}	4.37mm
A_{bowtie}	0.3947rad
O_{bowtie}	0.21mm
$L_{stripline}$	5.40mm
$W_{stripline}$	0.50mm
$G_{stripline}$	0.20mm

of the MIMO antenna (the antenna element geometry (best solution) is obtained by SSA), whereas Fig. 2b presents the S_{1j} parameters (j≠1) of the described MIMO antenna. From



(a)



(b)

Fig. 2. S parameters of the presented MIMO antenna design operating in the n257 (28GHz) frequency band (antenna element design was obtained by SSA): (a) $S11$ parameter (reflection coefficient) versus frequency of the MIMO antenna, (b) $S1j$ (j≠1) parameters (mutual coupling) versus frequency of the MIMO antenna.

the presented graph of S_{11} parameter, we can derive that the proposed MIMO antenna exhibits wideband operation ($-10dB$ bandwidth equal to 2.41GHz). Consequently, from the S_{1j} parameters graph, we can conclude that the mutual coupling (isolation between the ports of the MIMO antenna) is less than $-20dB$ across the whole desired frequency band. As a result, the proposed antenna is suitable for MIMO applications.

Fig. 3 illustrates the surface current distribution of the best antenna element solution achieved by applying the Salp Swarm algorithm. From the presented graph, it is clear that the surface current of the bow-tie element is maximized mostly in the main body, and minimized at the fringes of the antenna.

Additional numerical results, including a comparative study between the SSA-based design method and various classical approaches, such as Differential Evolution (DE), Biogeography Based Optimization (BBO), and Grey Wolf Optimizer (GWO), will be reported in the extended paper.

IV. Conclusion

In this paper, we have presented a new antenna design operating in the n257 (center frequency at 28GHz) frequency band, which is suitable for MIMO applications in the forthcoming 5G communications systems. The proposed antenna

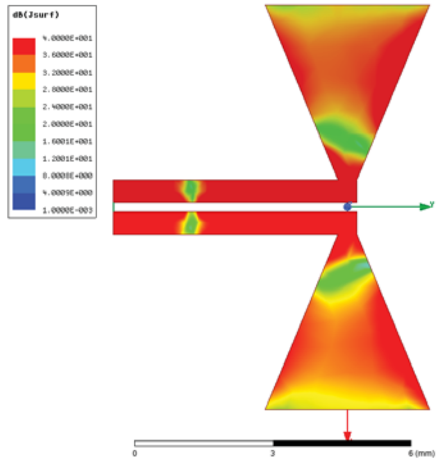


Fig. 3. Surface current distribution of the best antenna element obtained by SSA at 28 GHz.

element is optimized based on a design framework using the Salp Swarm algorithm. From the derived results, we can conclude that the proposed MIMO antenna is tuned at the desired frequency band, exhibits satisfactory isolation (mutual coupling) between its ports, and achieves a well acceptable performance in the surface current distribution. Future work includes the optimization of the MIMO antenna design, as well as the fabrication and experimental validation of the proposed system.

Acknowledgment

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T1EDK-05274).

References

[1] T. S. Rappaport et al., "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in IEEE Access, vol. 1, pp. 335-349, 2013. doi: 10.1109/ACCESS.2013.2260813

[2] Z. Ren, S. Wu and A. Zhao, "Triple Band MIMO Antenna System for 5G Mobile Terminals," 2019 International Workshop on Antenna Technology (iWAT), Miami, FL, USA, 2019, pp. 163-165. doi: 10.1109/IWAT.2019.8730605

[3] Y. Liu, Y. Lu, Y. Zhang and S. Gong, "MIMO Antenna Array for 5G Smartphone Applications," 2019 13th European Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 2019, pp. 1-3.

[4] Z. Ren, A. Zhao and S. Wu, "Dual-Band MIMO Antenna System for 5G Mobile Terminals," 2019 13th European Conference on Antennas and Propagation (EuCAP), Krakow, Poland, 2019, pp. 1-4.

[5] T. Li, H. Zhai, X. Wang, L. Li and C. Liang, "Frequency-Reconfigurable Bow-Tie Antenna for Bluetooth, WiMAX, and WLAN Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 171-174, 2015. doi: 10.1109/LAWP.2014.2359199

[6] M. Wu and M. Chuang, "Multibroadband Slotted Bow-Tie Monopole Antenna," in IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 887-890, 2015. doi: 10.1109/LAWP.2014.2383441

[7] S. Mirjalili, A. H. Gandomi, S. Z. Mirjalili, S. Saremi, H. Faris, S. M. Mirjalili, "Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems," Advances in Engineering Software, vol. 114, pp. 163-191, 2017. doi: 10.1016/j.advengsoft.2017.07.002.

[8] V. Ramasami, 2017. [Online]. Available: https://github.com/yuip/hfss-api/.