



Optimization Of Nano-Antenna For 5g Wireless Communications Using Svhop

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Abstract: 5G is an advanced wireless technology that significantly enhances capacity, offering extremely low latency, high data rates, and superior quality of service. The performance of each 5G device heavily relies on the design of the nano-antenna, which plays a crucial role in optimizing communication efficiency, channel capacity, and spectrum efficiency. Various strategies have been developed to improve antenna performance. However, achieving a design that is compact, cost-effective, offers enhanced bandwidth and gain, and minimizes radiation losses remains a challenging task. To address these challenges and improve nano-antenna efficiency, a novel approach known as Snobby Variance Multi-objective Harris Hawks Optimization (SVHOP) is introduced. This technique initializes populations of Harris hawks (i.e., nano-antennas) and evaluates their fitness based on multi-objective functions, including parameters such as distance, thickness, width, length, incident light wavelength, and gain. Elitism selection is employed within the Harris hawks optimization to randomly select the nano-antenna with the best fitness. The global optimum solution is then determined based on position updates. The proposed SVHOP technique is simulated using MATLAB, with performance metrics such as heat loss, thermal loss, SWR, electric field, and radiation efficiency. The simulation results show that SVHOP significantly improves the nano-antenna's performance, reducing heat loss, thermal loss, SWR, and electric field while enhancing efficiency relative to wavelength.

Index Terms - 5G wireless communication, Nano-Antenna Design, Jensen Shannon Divergence.

Introduction

As communication technologies continue to evolve and user demand for compact communication devices rises, there has been a shift in design strategies to create more efficient, compact, and robust antenna structures. To meet the diverse needs of modern communication, the design and analysis of plasmonic nano-patch antennas on graphene materials have become increasingly crucial.

In [1], a graphene nano-patch antenna design was proposed to enhance gain by adjusting chemical potential and resonating frequencies, making it well-suited for terahertz communication. A compact, dual-band, and dual-polarized millimeter-wave patch antenna was presented in [2], featuring decoupling structures ideal for 5G mobile terminal applications. Additionally, in [3], a highly compact quad-band MIMO antenna was designed, offering higher gain and superior data management capacity for wireless systems.

In [4], an eight-element array antenna design was developed with a single-layer frequency selective surface (FSS) to achieve improved gain for 5G applications. A hybrid terahertz plasmonic nano-scale antenna based on graphene was proposed in [5], aiming to maximize gain by varying conductivity through gate bias voltage. In [6], a multiple input multiple output (MIMO) antenna array was modeled for a 5G mm-wave communication network to enhance radiation efficiency, though loss analysis was not conducted. A single-patch nano antenna, operating at optical frequencies and providing better gain performance, was presented in [7]. In [8], a compact

eight-element antenna array for triple-band MIMO operation was designed, but the antenna did not meet the requirements for ultra-thin 5G mobile terminals with narrow frames and wide screens. The antipodal Vivaldi antenna, designed using graphene material in [9], was intended for wide-band communication but was suited only for low-THz applications. Lastly, a switched-beam nano antenna was designed in [10] for THz communication systems; however, it was unable to implement physical-layer collaboration between user-side switched-beam graphene antennas and the environment-side hypersurfaces in THz applications.

1.1. Contribution of the Work

The primary contributions of the proposed SVHOP technique are as follows:

- A novel SVHOP technique is introduced for solving the optimal identification of antennas with multiple objective functions.
- The Snobby Variance multi-objective Harris hawks optimization (SVHOP) is employed to determine the optimal nano-antenna based on various multi-objective functions, including distance, thickness, width, length, incident light wavelength, and gain. This approach aims to enhance radiation efficiency while minimizing heat and thermal losses.
- An elitism selection strategy is implemented to identify the optimal solution based on superior fitness. Jensen Shannon divergence is used for position updates to identify the global optimum solution.
- A simulation test is conducted to validate the performance, comparing the simulation and analytical results across different performance metrics.

1.2. Organization of the Paper

The structure of this paper is organized as follows:

- Section 2 discusses related works.
- Section 3 provides a brief description of the proposed SVHOP technique.
- Section 4 outlines the simulation settings.
- Section 5 presents and analyzes the simulation results using various performance metrics.
- Finally, Section 6 concludes the paper.

I. RELATED WORK

A novel MIMO antenna operating at the 3500 MHz band for 5G mobile terminals was presented in [11], aimed at improving radiation efficiency. In [12], a very wideband 8-antenna array was developed for future 5G NR (New Radio) mobile devices, achieving excellent efficiency and peak channel capacity. A simple tri-band microstrip patch antenna was modeled in [13] for millimeter-wave communication in 5G devices.

An optimization-based approach for enhancing the efficiency of antenna structures was explored in [14]. A new 8-antenna array design for smartphone applications was introduced in [15]. In [16], an mm-wave wideband antenna array was developed for 5G device-to-device communications.

In [17], a complementary triangular hybrid plasmonic nano-antenna design was proposed, along with a theoretical analysis, to enhance efficiency and minimize errors. A novel THz plasmonic nano-antenna array architecture was designed in [18], targeting THz applications. Additionally, a broadband optical nano-antenna covering a wide range of optical communication wavelengths was designed in [19] for nano-phonic applications.

A high-gain superstrate antenna array, known for its extremely low cost and excellent performance metrics, was designed in [20]. However, the antenna structure from this design was not easily integrated into modern 5G transceivers.

II. METHODOLOGY

The extensive advancements in 5th generation (5G) technology represent a significant technological revolution aimed at meeting the growing demand for high-speed communication and innovative wireless applications. 5G is poised to be the next-generation technology, offering extremely low latency, high data rates, and improved quality of service. In 5G communication, the design and development of nano-antennas are crucial due to their role in enabling high channel capacity and faster data speeds. Nano-antennas operate at very small wavelengths, typically in the nanometer range, and are compact in size.

One major challenge is the suboptimal radiation properties of compact antennas, often caused by losses inherent in the antenna design. Consequently, designing antennas for 5G communication requires a balance between simulation and analytical characteristics to minimize heat and thermal losses. Unlike traditional radio frequency antennas, the nano-antenna should be compact, cost-effective, and capable of covering the required 5G bands while offering improved bandwidth, gain, and minimal radiation losses. Motivated by this need, a novel SVHOP technique is introduced for optimal antenna identification, aiming to minimize losses and enhance data communication efficiency in the 5G network.

Figure 1 illustrates the architecture of the proposed SVHOP technique, which applies Snobby Variance Multi-objective Harris Hawks Optimization to solve optimal antenna identification problems. To enhance data transmission speeds in 5G networks, the optimal nano-antenna is identified based on multiple objective functions, including distance, thickness, width, length, wavelength of incident light, and gain.

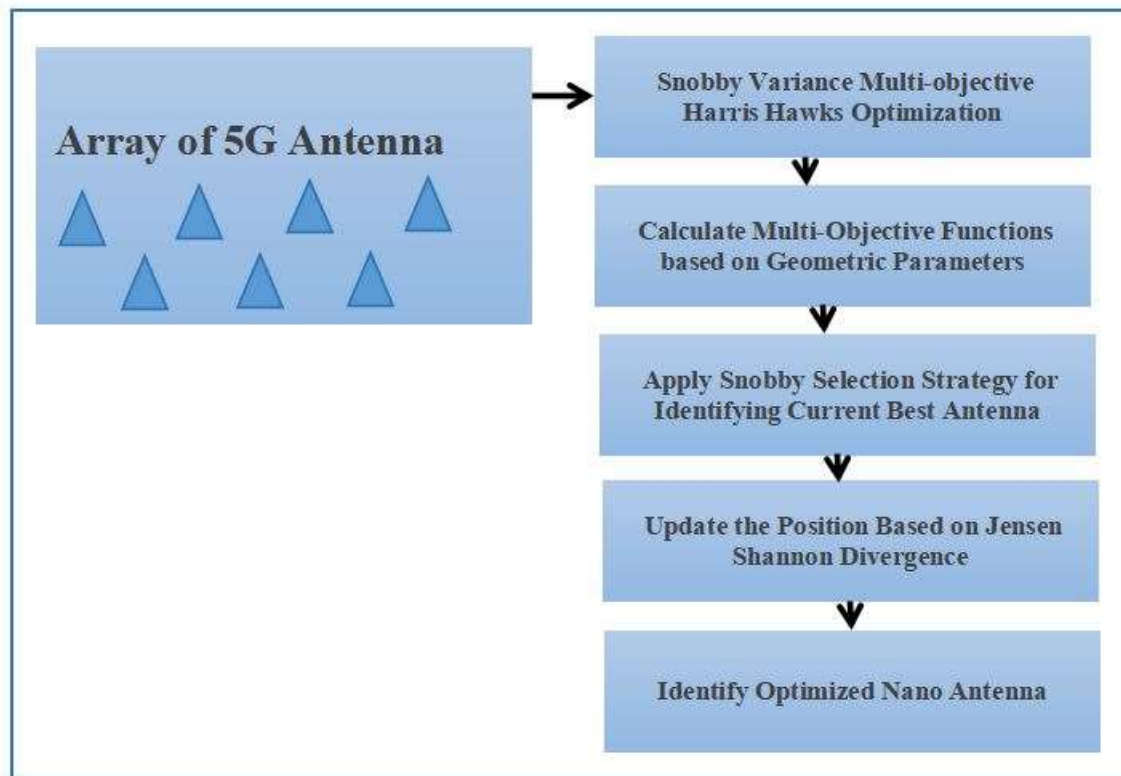


Figure 1: Architecture of Proposed SVHOP Technique

The Snobby Variance Multi-objective Harris Hawks Optimization (SVHOP) is a novel, bio-inspired swarm intelligence algorithm, inspired by the group hunting behaviors of hawks. This algorithm features a hierarchical structure, with a dominant female hawk at the top, followed by a male and then other members of the group. Their collaborative hunting enables them to survive in harsh environments, such as deserts, where prey is scarce. The group takes turns hunting, surrounding, and attacking the prey. Once the prey is located, other hawks are notified through visual signals, and the group continues to circle the prey until it is captured.

In the context of SVHOP, the hawks represent antennas, and the prey corresponds to the multi-objective functions of the antenna in the network. The key advantage of SVHOP is its ability to efficiently find the optimal location of the prey in the search space. Additionally, the algorithm is flexible and can be applied to various input types. Unlike other optimization methods, the proposed SVHOP incorporates an Elitism selection strategy to identify the best-performing individuals (hawks) based on their fitness values. This reduces the algorithm's complexity and accelerates convergence speeds. The optimization process begins by initializing a population of n Harris hawks (i.e., antennas) within the search space. After initializing the population, the fitness of each antenna is evaluated based on multiple objective functions, including distance, length, width, thickness, wavelength of incident light, and antenna gain.

3.1 Exploration Phase

The first stage of the optimization process is the exploration phase, which models the Harris hawks' behavior of waiting, searching, and detecting their prey. Harris hawks use their keen eyesight to track and detect prey, though it is not always easy to find. As a result, the hawks may wait and search in the desert for extended periods to identify their prey.

In the Harris Hawks Optimization (HHO) algorithm, the hawks represent candidate solutions, and the best solution at each step is selected based on fitness. The position of the Harris hawks during the exploration phase is updated according to the following equation:

$$P_{t+1} = \{Pr(t) - m_1 | Pr(t) - 2m_2P(t) | \text{ if } z \geq 0$$

$$P_{t+1} = Pr(t) - P_m(t) - m_3(lb + m_4(ub - lb)) \text{ if } z < 0$$

Where, P_{t+1} is the updated position of the Harris hawk. $P(t)$ is the current position of the Harris hawk. $Pr(t)$ is the position of the prey, m_1, m_2, m_3, m_4 are random numbers within the range $[0, 1]$. Lb and ub are the lower and upper bounds of the search space. $P_m(t)$ represents the average position of the current population of hawks. The elitism selection method is used to identify the best hawks (individuals) from the population based on fitness values for further processing. The selection is carried out by setting a fitness threshold.

3.2 Transition from exploration to exploitation

The proposed optimization algorithm transfers from exploration to exploitation hence the energy of the prey is decreased.

3.3 Exploitation phase

The third stage of the optimization algorithm is the exploitation phase. The exploitation phase is divided into four strategies including the soft besiege, hard besiege, soft besiege with progressive rapid dives, and hard besiege with progressive rapid dives. Let us consider $m \geq 0.5$ and the energy $E \geq 0.5$ hence this is called a soft besiege and the position gets updated as given below,

$$P(t+1) = \Delta P(t) - E |K Pr(t) - P(t)| \quad (13)$$

Where, $P(t+1)$ updated position of Harris' hawks, E denotes the energy of a prey, K denotes the jump strength of the prey, $Pr(t)$ denotes a location of the prey, $\Delta P(t)$ denotes a difference between the current location of prey and the location of Harris' hawks. The distance is identified by using Jensen–Shannon divergence

$$\Delta P(t) = 1/2 |Pr(t) - P(t)| \quad (14)$$

The second hard besiege strategy is

performed with the $m \geq 0.5$ and the energy $E < 0.5$. Therefore, the position gets updated. $\Delta P(t)$ denotes a difference between the current location of prey and the location of Harris' hawks. The third strategy soft besiege with progressive rapid dives is executed with the condition of $m < 0.5$ and the energy $E \geq 0.5$. Therefore, the position of the hawks is obtained. Finally, the optimal best location is identified. This process is executed until the termination criteria are satisfied. As a result, an optimal nano-antenna for 5G communication is designed.

III. SIMULATION SETTINGS

In this section, the SVHOP simulation is carried out using the MATLAB simulator. To understand the plasmonic resonance of a nano-optical antenna, it is essential to consider the relevant parameters and material properties. A variety of parameters are utilized to explore functional plasmonic devices through brute-force parameter simulation. A model-based automated design optimization framework is crucial for designing nano-optical transducers. The SVHOP is implemented by integrating the commercial electromagnetic analysis tool, Ansoft HFSS, with the MATLAB optimization toolbox. These two optimization tools are combined via a MATLAB-based scripting interface to iteratively search for the optimal geometric parameters of dipole and bowtie antennas, utilizing Sequential Quadratic Programming (SQP) and Harris Hawks Optimization.

Ansoft HFSS software is used to identify key parameters such as S-parameters, resonant frequency, and field distributions. The nano-antenna's characteristics—such as directivity, field enhancement, far-field radiation patterns, and polarization—are achieved in a manner similar to RF and microwave antennas. The material choice for the antenna is significant due to surface plasmonic effects, with a metal chosen for its high conductivity and a suitable dielectric material. For Finite Element Method (FEM) analysis, a mesh size of 0.2 times the wavelength is used, with the maximum element size selected to be half the minimum skin depth to improve accuracy.

The optimization process enhances the field intensity $|E(x=0, y=0, z=0)|$ $|E(x=0, y=0, z=0)|$, with geometric length and wavelength bounds set between $[20, 450]$ and $[200, 2000]$, respectively. Convergence is achieved within 20 iterations and 10 generations for both Sequential Quadratic Programming (SQP) and the Harris Hawks Optimization framework.

IV. RESULTS AND DISCUSSION

In this section, the analysis of SVHOP obtained from the simulation is shown for wavelength of 200 to 2000 nm. The heat loss with respect to wavelength is shown in table 1.

Table 4.1: Tabulation for Heat Loss versus Wavelength

Wavelength h	Heat Loss (W) *10 ⁻¹⁸	
	Simulation	Analytical
400	13.5	12.6
420	14.2	13.8
440	15.4	14.8
460	14.6	14.1
480	15.5	14.7
500	16.7	15.6
520	10	9
540	8	6
560	6	4
580	4	3
600	3	2

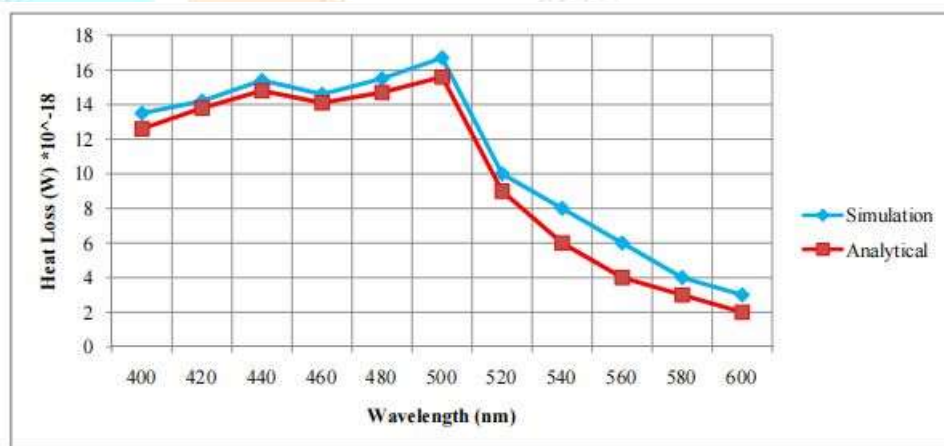


Figure 2. Graphical Illustration of Heat Loss

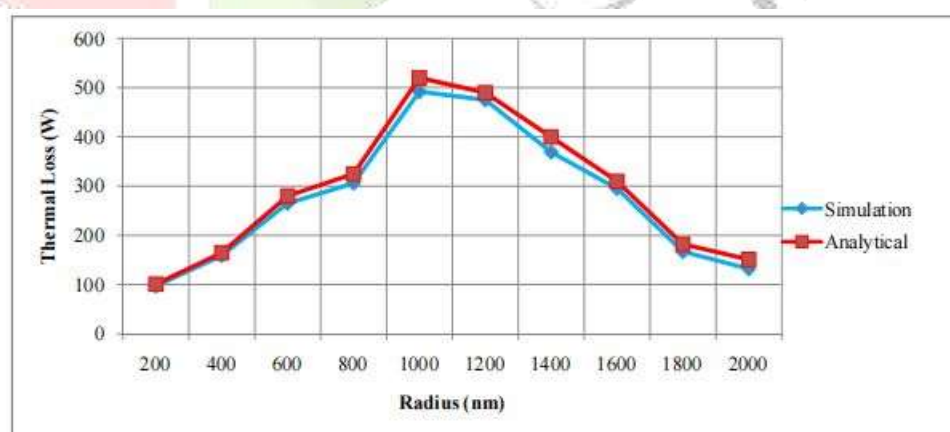


Figure 3. Graphical Illustration of Thermal Loss

Table 1 and Figure 2 present the performance analysis of heat loss as a function of wavelength (in nm). As shown in Figure 2, the wavelength is plotted along the x-axis, and heat loss values are represented on the y-axis. At longer wavelengths, heat losses are observed to be minimal. The optimal antenna performance is calculated based on multiple objective functions. Heat loss is assessed by considering various factors, such as changes in parabola radii, dielectric constants, field radiation patterns, and polarization effects due to the wavefront. It is evident that the emission patterns are non-linear, primarily due to the non-uniformities introduced by the finite element method in the parabolic configuration's curvature. As the radius decreases, the radiation pattern also becomes smaller, which leads to a reduction in heat loss.

Table 4.1: Tabulation for Thermal Loss versus Wavelength

Wavelength h	Thermal Loss (W)	
	Simulation	Analytical
200	97	101
400	159	165
600	265	280
800	306	325
1000	492	520
1200	475	490
1400	369	400
1600	295	310
1800	167	182
2000	132	151

Table 2 and Figure 3 present the simulation and analytical results for thermal loss as a function of radius (in nm). The simulation results were obtained using the parametric sweep function, which explores different parabola radii, as shown in Figure 3. When the radius is less than 1000 nm, thermal losses increase, and the scattered field contributes to the gain. However, when the radius exceeds 1000 nm, thermal losses decrease. Thus, thermal loss is inversely proportional to the radius for values greater than 1000 nm.

Impedance matching between the antenna and the source or waveguide is evaluated using the Standing Wave Ratio (SWR) parameter. SWR is defined as the ratio of the peak amplitude to the minimum amplitude of the standing wave. The SWR is influenced by the dielectric permittivity relationship between the antenna and waveguide. The central radius varies with the change in the opening angle. For instance, when $\theta = 5^\circ$, the antenna's bandwidth is characterized using RF antenna theory. The wavelength range corresponding to the SWR below -6dB is found to be between 800 nm and 1200 nm.

IV. CONCLUSION

A highly compact nano-antenna with enhanced gain for 5G mobile communication is identified using the SVHOP technique. The analysis and mathematical modeling of the nano patch antenna are explored through Snobby Variance Multi-Objective Harris Hawks Optimization models. This proposed optimization technique determines the optimal nano-antenna by evaluating fitness, leading to the identification of the best nano-antenna through position updates. As a result, the overall efficiency improves with minimal loss. Simulations were carried out in MATLAB, evaluating various performance metrics. The simulation and analytical results confirm the effectiveness of the proposed SVHOP technique, showcasing higher radiation efficiency, a better standing wave ratio, and reduced heat and thermal losses.

REFERENCES

- [1] S. Kavitha, K. V. S. S. S. Sairam & Ashish Singh, "Graphene plasmonic nano-antenna for terahertz communication", SN Applied Sciences, Springer, Volume 4, 2022, pages 1-11. <https://doi.org/10.1007/s42452-022-04986-1>
- [2] Yuqi He, Sihan Lv, Luyu Zhao, Guan-Long Huang, Xiaoming Chen, and Wei Lin, "A compact dual-band and dual-polarized millimeter-wave beam scanning antenna array for 5G mobile terminals," IEEE Access, Volume 9, Pages 109042 -109052. <https://doi.org/10.1109/ACCESS.2021.3100933>
- [3] Sanjukta Nej, Anumoy Ghosh, Sarosh Ahmad, Adnan Ghaffar and Mousa Hussein, "Compact Quad Band MIMO Antenna Design with Enhanced Gain for Wireless Communications", Sensors, Volume 22, Issue 19, 2022, Pages 1-18. <https://doi.org/10.3390/s22197143>
- [4] Raza Ullah, Sadiq Ullah, Rizwan Ullah, Iftikhar Ud Din, Babar Kamal, Muhammad Altaf Hussain Khan and Ladislau Matekovits, "Wideband and High Gain Array Antenna for 5G Smart Phone Applications Using Frequency Selective Surface", IEEE Access, Volume 10, Pages 86117 – 86126. <https://doi.org/10.1109/ACCESS.2022.3196687>
- [5] Richard Victor Biswas and Farhadur Arifin, "Highly Directive Graphene Based Hybrid Plasmonic Nano-antenna for Terahertz Applications", AIUB Journal of Science and Engineering, Volume 21, Issue 1, 2022, Pages 54 – 62. <https://doi.org/10.53799/ajse.v21i1.290>

- [6] Jalal Khan, SadiqUllah, Usman Ali, Farooq Ahmad Tahir, Ildiko Peter, and LadislauMatekovits, "Design of a Millimeter-Wave MIMO Antenna Array for 5GCommunication Terminals", *Sensors*, Volume 22, Issue 7, 2022, Pages 1-14. <https://doi.org/10.3390/s22072768>
- [7] QudsiaRubani, Gh. RasoolBegh, Sindhu Hak Gupta, "Design and investigation of a MIMO Nano-antenna operating atoptical frequency", *Optik*, Elsevier, Volume 223, 2020, Pages 1-8. <https://doi.org/10.1016/j.ijleo.2020.165481>
- [8] Hongwei Wang,Ruiheng Zhang, Yong Luo,Guangli Yang, "Compact eight-element antennaaarray for triple-band MIMO operation in 5G mobile terminals," *IEEEAccess*, Volume 8, 2020, Pages 19433 – 19449. <https://doi.org/10.1109/ACCESS.2020.2967651>
- [9] Gaurav Bansal, AnupmaMarwaha, Amanpreet Singh, "A graphene-based multiband antipodal Vivaldi nano-antenna for UWB applications", *Journal of Computational Electronics*,Springer, Volume 19, 2020, Pages709–718. <https://doi.org/10.1007/s10825-020-01460-2>
- [10] Sasmita Dash, GoutamSoni, AmalenduPatnaik, Christos Liaskos, Andreas Pitsillides& Ian F. Akyildiz, "Switched-Beam Graphene PlasmonicNano-antenna in the Terahertz Wave Region", *Plasmonics*, Springer, Volume 16, 2021 , Pages 1855–1864. <https://doi.org/10.1007/s11468-021-01449-y>
- [11] Zhan Xu andChangjiang Deng, "High-isolated MIMO antenna design based on pattern diversity for 5G mobile terminals," *IEEE Antennas and Wireless Propagation Letters* , Volume 19, Issue 3, 2020, Pages 467–471. <https://doi.org/10.1109/LAWP.2020.2966734>
- [12] Chow-Yen-Desmond Sim,Heng-You Liu, Ci-Jin Huang, "Wideband MIMO Antenna Array Design for Future Mobile Devices Operating in the 5G NR Frequency Bands n77/n78/n79 and LTE Band 46," *IEEE Antennas and Wireless Propagation Letters*,Volume 19, Issue 1, 2020, Pages 74 – 78. <https://doi.org/10.1109/LAWP.2019.2953334>
- [13] DhurghamAbdulridha Jawad Al-Khaffaf, Ihsan A. Alshimaysawe, "Miniaturised tri-band microstrippatch antenna design for radio andmillimetre waves of 5G devices", Volume 21, Issue 3, 2021, Pages 1594~1601. <https://doi.org/10.11591/ijeecs.v21.i3.pp1594-1601>
- [14] Anna Pietrenko-Dabrowska and SlawomirKoziel, "Cost-Efficient EM-Driven Size Reduction of Antenna Structuresby Multi-Fidelity Simulation Models", *Electronics*, 2021, Volume 10, Pages 1-18. <https://doi.org/10.3390/electronics10131536>
- [15] H. Chen, Y. Tsai, C. Sim, and C. Kuo, "Broadband 8-antenna array designfor sub-6GHz 5G NR bands metal-frame smartphone applications," *IEEE Antennas and Wireless Propagation Letters* , Volume 19, Issue: 7, 2020, Pages 1078–1082.. <https://doi.org/10.1109/LAWP.2020.2988898>
- [16] Ao Li and Kwai-Man Luk, "Single-Layer Wideband End-Fire Dual-Polarized Antenna Array for Device-to-Device Communication in 5G Wireless Systems", *IEEE Transactions on Vehicular Technology*, Volume 69, Issue 5, 2020, Pages 5142 –5150. <https://doi.org/10.1109/TVT.2020.2979636>
- [17] Maryam Khodadadi andNajmehNozhat, "Theoretical Analysis of a Super-Mode Waveguide and Design of a Complementary Triangular Hybrid Plasmonic Nano-Antenna", *IEEE Journal of Selected Topics in Quantum Electronics* , Volume 27, Issue 1, 2021, Pages 1-10. <https://doi.org/10.1109/JSTQE.2020.3007311>
- [18] Arjun Singh, Michael Andrello, Ngwe Thawdar,JosepMiquelJornet, "Design and OperationofaGraphene-BasedPlasmonic Nano-Antenna Array for Communication in theTerahertzB and", *IEEE Journal on Selected Areas in Communications* , Volume 38, Issue 9, 2020, Pages 2104 – 2117. <https://doi.org/10.1109/JSAC.2020.3000881>
- [19] Inzamam Ahmad, ShakirUllah, Jalal ud din, SadiqUllah, WaseemUllah, Usman Habib,Salahuddin Khan and JaumeAnguera , "Maple-Leaf Shaped Broadband Optical NanoAntenna withHybrid Plasmonic Feed for Nano-Photonic Applications", *Applied Science*, Volume 11, 2021, <https://doi.org/10.3390/app11198893>
- [20] Yazan Al-Alem, Ahmed A. Kishk, "Low-Cost High-Gain Superstrate Antenna Array for 5G Applications", *IEEE Antennas and Wireless Propagation Letters* , Volume 19, Issue 11, 2020, Pages 1920 – 1923. <https://doi.org/10.1109/LAWP.2020.2974455>