Modified Patch Antenna Design Using Moth Search Algorithm for RF Energy Harvesting Applications

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

Stavros Koulouridis
Electrical and Computer Engineering Department
University of Patras
Patras, Greece
koulouridis@upatras.gr

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

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

2020 International Workshop on Antenna Technology (iWAT) 978-1-7281-2640-1/20/$31.00 ©2020 IEEE 10.1109/iWAT48004.2020.1570609565

***Abstract*—Radio frequency energy harvesting is a well-promising technique to power wireless sensor network devices that require small amounts of energy to operate. It can be utilized as an alternative technique for power-constrained systems, such as wireless sensor networks with limited battery lifetime, by extending their energy supply. In outdoor environments, the dominant ambient radio wave sources are the broadcasting and the mobile communication networks. In this paper, we apply an optimization technique by utilizing Moth Search algorithm to design a modified microstrip patch antenna of three varying slots. The proposed antenna exhibits tuning operation in the LoRa (Long Range) and the cellular communications frequency bands of GSM-1800 and UMTS. Numerical results exhibit an acceptable performance of the proposed antenna for RF energy harvesting applications.**

***Index Terms*—patch antenna, RF energy harvesting, moth search algorithm, microstrip antenna optimization.**

I. Introduction

Nowadays, wireless sensor networks devices that use modern technology, like Internet of Things (IoT), require less and less power for their operation [1]. To extend the utilization of theses devices, i.e. to reduce their battery replacement during wireless network operation, several techniques have been developed. Radio Frequency (RF) Energy Harvesting (EH) is one of these techniques, which is mostly based on ambient radio wave sources for battery replenishment in wireless network systems [2]. Despite the fact that RF EH is a rather newly introduced technology, a noteworthy work has been reported in the literature.

Patch antenna design has been widely used as an RF energy harvester in various applications of different frequency bands [3] - [5]. Based on its comparative advantages, like ease of fabrication, relatively low cost, and medium complexity, it has been established as an attractive technique for RF EH applications as well. Besides the values of reflection coefficient (S_{11} parameter) of the system, the impedance matching, as well as realized gain, are also important parameters of the antenna to harvest satisfactory values of energy from the environment.

Moth Search (MS) is a newly introduced metaheuristic algorithm for global optimization problems [6]. It is a bio-inspired algorithm that is based on two distinctive movement features of moths in nature; the phototaxis, i.e. a movement of a living organism (mostly referred to flying insects) towards to or away from a source of light, and the Lévy flight, i.e.a random path in which the step-lengths have a probability distribution whose tails are not exponentially bounded. To the best of the authors knowledge, this is the first time that the MS algorithm is applied to optimize the design of a modified patch antenna for RF EH applications.

The rest of this paper is organized as follows. Section II briefly describes the mathematical model of Moth Search algorithm. Section III depicts the antenna design procedure, as well as preliminary numerical results of the best obtained solution. Finally, the conclusion of our presented work is outlined in Section IV.

II. Moth Search Algorithm Description

The Moth Search Algorithm (MSA) models the different flying movements of moths (insects belong to the Lepidoptera) by splitting their population NP into two equal sub-populations based on their fitness function (solution ranking in ascending order). The best solution (moth with the best fitness function value) in assigned to the light source. In other words, the 1st sub-population is considered to be closer to the best solution, and the the 2nd sub-population is considered faraway from the light source.

Based on the classification of moths, the position of the moth j at generation g in 1st sub-population (Lévy flights) is given by:

$$m_j^{g+1} = m_j^g + f^{sc} L(x) \tag{1}$$

where m_j^g and m_j^{g+1} are the current and the next position at generation g, f^{sc} is a scale factor associated to the optimization problem, and $L(x)$ is the Lévy distribution defined by (2):

$$L(x) = \frac{(beta-1)\Gamma(beta-1)sin(\frac{\pi(beta-1)}{2})}{\pi x^{beta}} \tag{2}$$

where $beta \in (1, 3]$ is an index number, Γ is the gamma function, and $x > 0$. Scale factor f^{sc} is given by:

$$f^{sc} = \frac{step_{max}}{g^2} \tag{3}$$

where $step_{max}$ is the maximum step size. In our problem, we have set the value of $beta$ equal to 1.5 and the value of $step_{max}$ equal to 1.

Accordingly, the the position of the moth j at generation g in 2nd sub-population (straight flight) is formulated by:

$$m_j^{g+1} = \begin{cases} \left(m_j^g + f^{ac} \times (m_{best}^g - m_j^g)\right), & rand < 0.5 \\ \left(m_j^g + \frac{1}{f^{ac}} \times (m_{best}^g - m_j^g)\right), & rand \geq 0.5 \end{cases} \tag{4}$$

where m_{best}^g is the best solution (the moth with the best position) at generation g, and f^{ac} is an acceleration factor associated to the optimization problem and is given by:

$$f^{ac} = \frac{\sqrt{5}-1}{2} \tag{5}$$

In (4), the position vector of the $g+1$ generation is controlled by a random number $rand \in [0, 1]$, thus having a probability of 50% to be updated by one of the two equation parts.

III. Numerical Results

To find the best solution of the modified patch antenna design for RF EH applications, we utilize the Moth Search algorithm. The population size NP is set to 50 and the solution vector D of the optimization problem is set to 13. The stopping criterion of the method is the maximum number of function evaluations $MaxFES$, which is equal to 1000. The MS algorithm is combined with a 3D electromagnetic solver (ANSYS HFSS [7]) by applying a HFSS-MATLAB wrapper toolbox [8]. The objective function which defines the design problem of the modified patch antenna is given by the following form:

$$\begin{aligned} F(\bar{x}) = \\ max\left(S_{11}^{867MHz}(\bar{x}), S_{11}^{1800MHz}(\bar{x}), S_{11}^{2100MHz}(\bar{x})\right) \\ +\Psi \times max\left(0, S_{11}^{867MHz}(\bar{x}) - L_{dB}\right) \\ +\Psi \times max\left(0, S_{11}^{1800MHz}(\bar{x}) - L_{dB}\right) \\ +\Psi \times max\left(0, S_{11}^{2100MHz}(\bar{x}) - L_{dB}\right) \end{aligned} \tag{6}$$

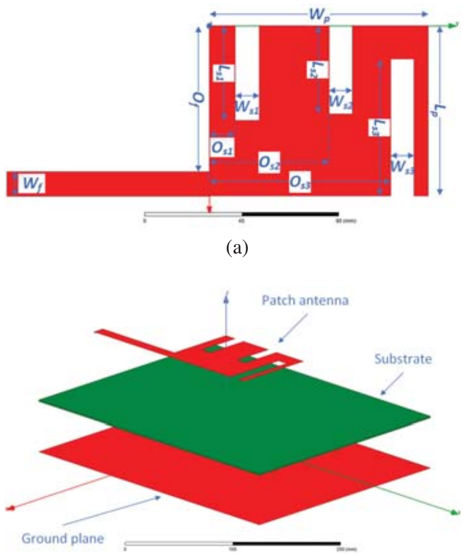
where $\bar{x}$ is the solution vector of the selected antenna geometry at each iteration, S_{11}^{867MHz}, $S_{11}^{1800MHz}$, and $S_{11}^{2100MHz}$ are the values of the reflection coefficient (S_{11} parameter) at the desired frequencies, L_{dB} is the arbitrarily defined limit of the reflection coefficient (in our case we have set $L_{dB} = -10dB$), and Ψ is a penalty number (in our case we have set $\Psi = 1E+10$).

TABLE I
Final values (best solution) of the proposed modified patch antenna derived by MS algorithm.

Parameter	Value (mm)	Parameter	Value (mm)
L_p	80.29	W_p	103.41
L_{s1}	44.76	W_{s1}	11.45
L_{s2}	41.71	W_{s2}	11.03
L_{s3}	64.70	W_{s3}	10.96
W_f	11.58	O_{s1}	12.20
O_{s2}	56.60	O_{s3}	85.70
O_f	68.71		

Fig. 1 depicts the geometry, whereas Table I lists the optimal solution of the proposed modified path antenna derived by the MS algorithm. The proposed antenna consists of a single patch with three varying slots that formulate the modified structure of the microstrip patch antenna. It is worth noting that the length of the feeder is selected to match the impedance between the source and the antenna. Finally, the antenna is placed above an FR4 substrate layer ($e_r = 4.4$, $thickness = 1.6mm$, $tan\delta = 0.02$, $dimensions : x = 228.83mm, y = 294.72mm$), whereas a ground plane (with the same dimensions as the FR4 substrate layer) is located beneath the substrate layer.

Fig. 2 illustrates the reflection coefficient (S_{11} parameter) of the modified patch antenna design versus frequency. From the presented graph, it is apparent that the proposed antenna is tuned at three different frequencies (866.4 MHz: -30.26 dB, 1814 MHz: -27.36 dB, 1957 MHz: -41.35 dB), which



(a)

(b)

Fig. 1. Proposed modified patch antenna design obtained by the MS algorithm. (a) Optimal geometry of the antenna (The parameters that have been included in the optimization process are remarked), (b) Expanded view of the proposed antenna.

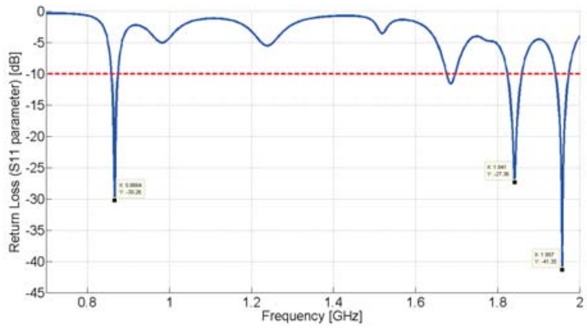


Fig. 2. Reflection coefficient (S_{11} parameter) versus frequency of the proposed modified patch antenna obtained by MS algorithm (blue solid line: S_{11} parameter, red dash line: -10 dB limit).

are within the European LoRaWAN downlink frequency band (863 - 870 MHz), the GSM-1800 cellular communications downlink frequency band (1805 - 1880 MHz), and the UMTS mobile cellular system for networks uplink frequency band (1920.3 - 1965.3 MHz).

Fig. 3 portrays the realized gain of the modified patch antenna design obtained by the MS algorithm. From the illustrated figure we can derive that the proposed design of the modified microstrip patch antenna exhibits broadside beamwidth and achieves acceptable gain values. As a result, the proposed antenna can be performed as an energy harvester in the previously mentioned tuning frequencies satisfactorily.

Additional simulation results, including radiation pattern, surface current distribution and realized gain versus frequency of the proposed antenna, as well as a comparative plot of average convergence rate between MSA and legacy optimization algorithms, will be reported in the extended paper.

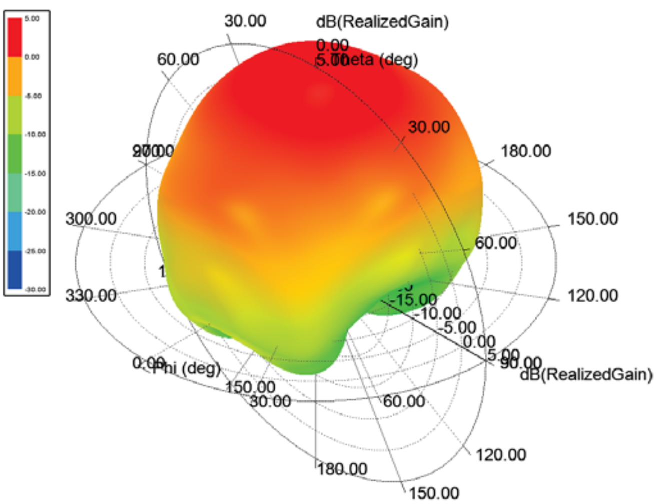


Fig. 3. 3D polar plot of the realized gain of the proposed modified patch antenna derived by MS algorithm.

IV. Conclusion

In this paper, we have presented a modified microstrip patch antenna design using a newly introduced metaheuristic algorithm, the so-called Moth Search algorithm. The proposed antenna consists of a single patch with three varying slots. From the obtained results, we can conclude that the antenna operates in the frequency bands of LoRa downlink, GSM-1800 cellular communications downlink, and UMTS mobile cellular systems uplink. Moreover, it delivers broadside operation and achieves satisfactory values of the realized gain. This proposed antenna can be easily utilized in IoT sensor networks form smart cities of urban smart farming. Future work includes the fabrication of the proposed antenna prototype, whereas the mechanical structure of the proposed antenna will be presented. Finally, the experimental validation of the system will be assessed.

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] A. Harb, ”Energy harvesting: State-of-the-art,” Renewable Energy, Elsevier, vol. 36(10), pages 2641-2654, 2011.
[2] X. Lu, P. Wang, D. Niyato, D. I. Kim and Z. Han, ”Wireless Networks With RF Energy Harvesting: A Contemporary Survey,” in IEEE Communications Surveys & Tutorials, vol. 17, no. 2, pp. 757-789, Second quarter 2015. doi: 10.1109/COMST.2014.2368999
[3] H. J. Visser and R. J. M. Vullers, ”RF Energy Harvesting and Transport for Wireless Sensor Network Applications: Principles and Requirements,” in Proceedings of the IEEE, vol. 101, no. 6, pp. 1410-1423, June 2013. doi: 10.1109/JPROC.2013.2250891
[4] Z. W. Sim, R. Shuttleworth, M. J. Alexander, and B. D. Grieve, ”Compact Patch Antenna Design for Outdoor RF Energy Harvesting in Wireless Sensor Networks,” Progress In Electromagnetics Research, vol. 105, pp. 273-294, 2010. doi: 10.2528/PIER10052509
[5] M. Arrawatia, M. S. Baghini and G. Kumar, ”Differential Microstrip Antenna for RF Energy Harvesting,” in IEEE Transactions on Antennas and Propagation, vol. 63, no. 4, pp. 1581-1588, April 2015. doi: 10.1109/TAP.2015.2399939
[6] GG. Wang, ”Moth search algorithm: a bio-inspired metaheuristic algorithm for global optimization problems,” in Memetic Computing, vol. 10, no. 2, pp. 151–164, 2018. doi: 10.1007/s12293-016-0212-3
[7] ANSYS Electromagnetics Suite Release 19.2.0, 2018.
[8] V. Ramasami, 2017. [Online]. Available: https://github.com/yuip/hfss-api/.