MIMO Antenna Optimization: From Configuring Structure to Sizing with the aid of Neural Network

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***Abstract*—In the last decades, massive multiple-input multi-output (MIMO) designs play important role and this trend will continue in next-generation mobile technologies. Designing high-performance MIMOs is significant since these types of antennas include multiple radiating elements. For these complex configurations, intelligent-based optimization methods can tackle the problem of designing. This paper devotes to designing and optimizing the configuration and design parameters of a MIMO antenna, respectively. Firstly bottom-up optimization (BUO) approach is executed successfully for constructing the general configuration of the MIMO antenna and afterwards, artificial neural network (ANN) is utilized for obtaining the design parameters with the optimal values. The proposed method leads to generate the optimal topology with size values in a reduced effort by designers. The presented approach is operated leading to design and optimize a MIMO antenna with 15.3 GHz bandwidth (13.7 - 29 GHz).**

***Index Terms*—Multiple-Input Multi-Output (MIMO), Bottom-Up Optimization (BUO), Artificial Neural Network (ANN)**

I. Introduction

In communication systems, massive multiple-input multi-output (MIMO) antennas are widely and executed successfully for increasing the capacity of exchanged data [1]. The massive MIMO antennas lead to overcoming the losses in fifth-generation (5G) mobile applications [2] and provide the opportunity for lower latency with energy efficiency [3], [4]. Typically, the configuration of MIMO antennas are complex where they are used more in massive radio-frequency (RF) chains and wireless technologies [5].

Developing the massive radio-frequency (RF) chains through MIMO antennas seems complex due to the configuration and structure of MIMO antennas [5] to fulfill advanced constrains.

In the recently published papers, various solutions are presented for designing antennas and making use of optimizer algorithms. Some methods as generic algorithm [6] swarm optimization [7] are known optimization methods for this purpose. Designing antennas with these types of algorithms lasts long and reqiuires significant computational effort.

In this paper, a two-step optimization method is executed for firstly configuring the general structure of the MIMO antenna, and then sizing all the presented design parameters in the structure of MIMO antenna. In the first step, the bottom-up optimization (BUO) algorithm is employed for configuring the structure of presented antenna. In a second step, artificial neural network (ANN) is used for predicting the optimal values for the determining variables describing the antenna geometry. The presented optimization process is performed through two tools: electronic design automation (EDA) tool, here CST, and also numerical analyzer, here MATLAB. The reason of combining these tools is to reduce the overall effort of RF designs.

The paper is organized as follows: Section II presents the proposed optimization approach. Section III explains the simulation results of optimized MIMO antenna. Section IV presents the overall conclusions around the presented work.

II. A General View Around the Proposed Optimization Method

MIMO antennas are complex substructures in a wireless communication system. Hence, an advanced approach is required for designing these systems. This section devotes to presenting the proposed method that leads to reducing the design efforts by engineers. Firstly, the BUO method is executed successfully for building the structure of MIMO antenna. Afterwards, the ANN is trained for achieving the optimal design parameters straightforwardly. For easily access to the main idea of the proposed method, a flowchart depicted in Fig. 1 is provided.

A. Bottom-up optimization (BUO) method

The BUO algorithm devotes to start with an initial antenna design as shown in Fig. 2 and then increasing the number of radiators, sequentially [8] [9]. In our specific application, sequentially increase up to four antennas is followed, started from two initial radiators. Figure 3 presents the configured MIMO antenna.

B. Artificial neural network (ANN) method

The learning-based method is one of the sub-division of the optimization approaches that is getting benefits from the machine learning concept. The ANN is introducing this

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content and determines the relationship between the input and output data. Recently, ANN is employed in various RF designs and has proved its effectiveness for example in [10]–[13] due to its modeling accuracy. Obtaining the large bandwidth of RF designs is not straightforward and requires additional computational effort with respect to narrow band

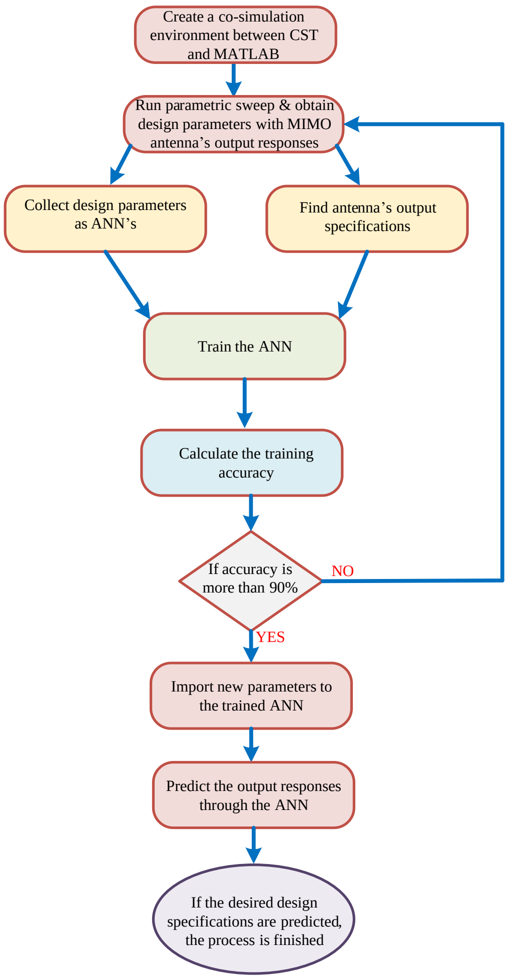

Fig. 1. The general flowchart of the proposed method.

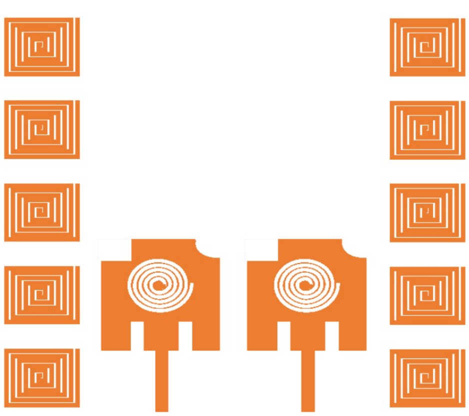

Fig. 2. Initial antenna design.

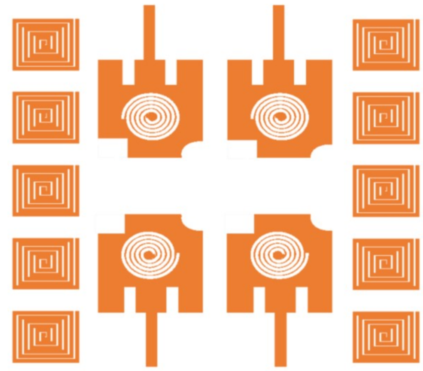

Fig. 3. The configured MIMO antenna through the BUO method.

systems. For reducing this effort, the ANN is trained and constructed with the aim of estimating all included variables in the configured MIMO antenna. This ANN would be useful enough for antenna modeling in the large frequency band. For this case, all variables presented in Fig. 3 are used as the input layer specifications; the the output layer predicts the output specifications of the MIMO antenna in terms of S_{11} and gain. All variables that are used in configuring antenna are iterated randomly and this suitable amount of data is used as the input/output data for constructing the ANN. Figure 4 presents the constructed ANN for estimating the optimal values for the various variables leading to achieve desire simulation results.

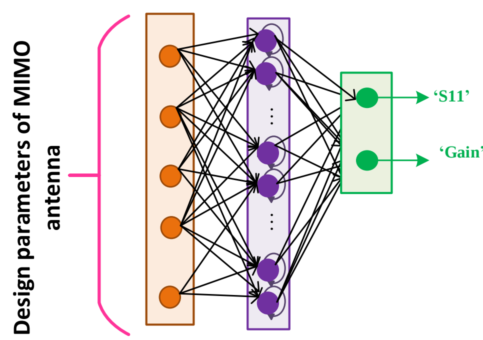

Fig. 4. A general structure of proposed ANN.

III. Simulation Results

The BUO method is employed and results in the optimal four single antennas. After obtaining the topology, the ANN is trained using 1000 data. The rule of thumb is used for determining the number of neurons where 550 neurons are used in the single hidden layer. Below, the achieved simulation results after employing our proposed approach are presented and discussed.

The MIMO antenna design shown in Fig. 5 is built on the copper grounded $84 \times 70mm^2$ and dielectric FR-4 substrate with 1.6 mm thickness and $\tan\delta = 0.025$ and $\epsilon = 4.3$. The main structure is a microstrip patch antenna with a circular spiral located in the center with a number of 6 turns. The single patch is made of copper; two columns of copper rectangular spirals with 6 turns each are placed on the right and left side of the patch. E4ach radiator is excited by a the coaxial cable as it is illustrated in Fig. 5 with designed parameters defined as reported in Tab. I.

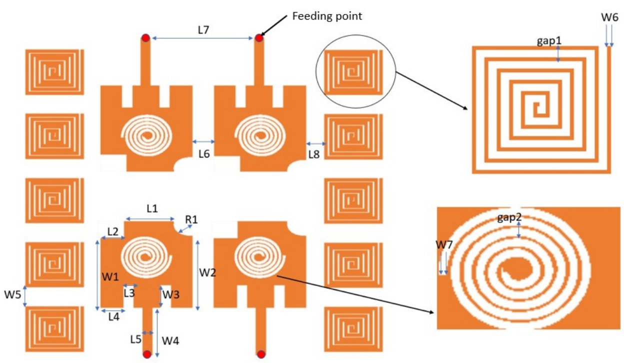

Fig. 5. Parameter description of optimized MIMO antenna.

TABLE I
VALUES OF CONFIGURED MIMO ANTENNA IN FIG.5

width	value (mm)	length	value (mm)
W_1	19	L_1	10
W_2	19	L_2	5
W_3	6	L_3	1
W_4	9	L_4	6
W_5	4.8	L_5	2
W_6	0.3	L_6	2
W_7	0.5	L_7	18
gap_1	0.5	gap_2	0.5
-	-	L_8	3

The simulation is conducted through CST software and the outcomes are explained in Fig. 6 and Fig.7 for S11 and S21, respectively. The obtained bandwidth for the optimized structure in Fig. 6 is from 13.7 GHz to 29 GHz (15.3 GHz) which can be considered an ultra-wide band. The E-plane radiation patterns for three different frequencies as 13.7, 16.23, and 29 GHz are represented in Fig. 8 and Fig. 9 that are demonstrating two incidence angles such as $\phi = 0$ and 90°, respectively.

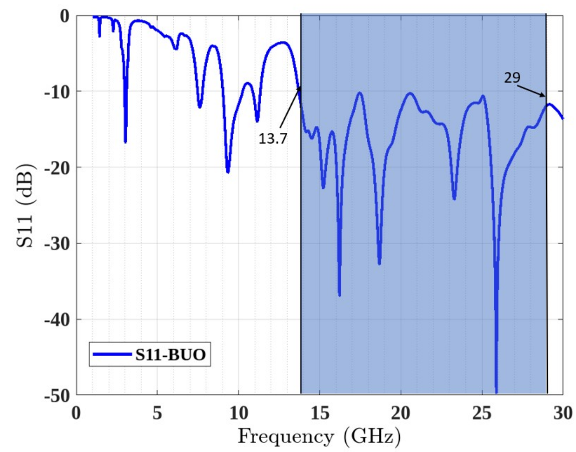

Fig. 6. S_{11} for MIMO through BUO

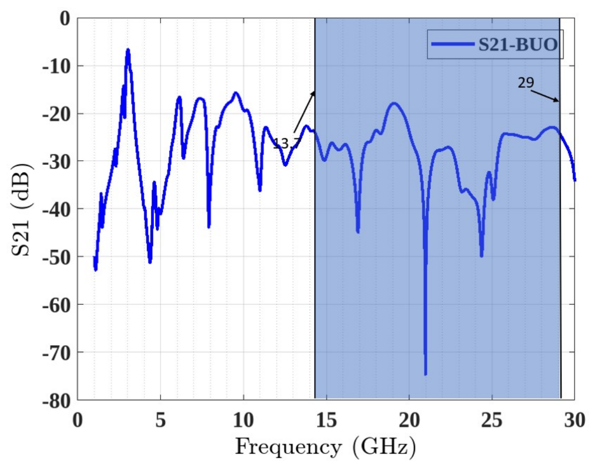

Fig. 7. S_{21} for MIMO through BUO

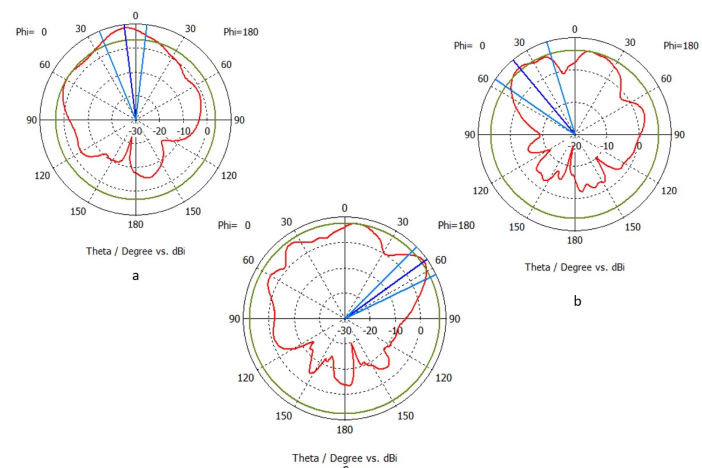

Fig. 8. Radiation pattern for E plane at $\phi = 0$ for a= 13.7 GHz, b=16.23 GHz, and c=29 GHz

IV. CONCLUSION

In this work, we develop a new methodology for designing and optimizing MIMO antenna where configuration develop-

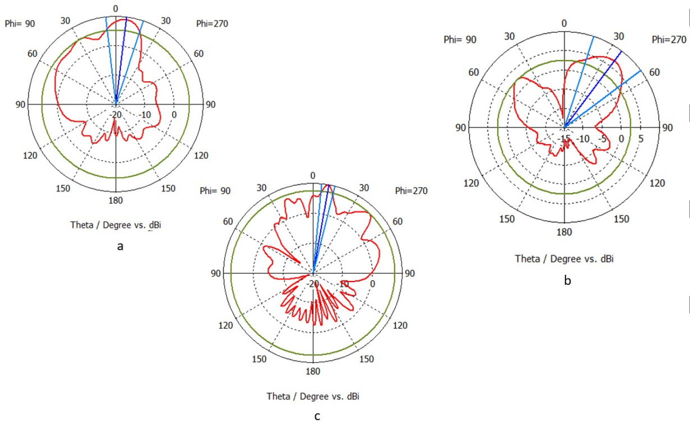

Fig. 9. Radiation pattern for E plane at $\phi = 90$ for a= 13.7 GHz, b=16.23 GHz, and c=29 GHz

ment and sizing of antenna are executed successfully. In the first phase, the algorithm namely as BUO is performed for building the initial structure of MIMO antenna. Afterwards, an intelligent-based method (i.e., ANN) is constructed for sizing the design parameters generated from the BUO approach. The proposed approach is able to reduce time-to-market in designing high-dimensional designs and provides an automated optimization environment. This method is validated by designing a MIMO antenna at a frequency band from 13.7 GHz to 29 GHz.

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