Investigating Redundancies in Reconfigurable Antennas Designed for MIMO Systems

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ABSTRACT: In this paper we investigate a new approach in optimizing the number of switches in reconfigurable antennas designed for MIMO (Multiple Input Multiple Output) applications. Reducing the number of switches in reconfigurable antenna structures can lead to cost effective designs and reduce losses. Here a new optimization technique based on graph theory is introduced. A specific example is presented and analyzed to prove the validity of the new approach.

INTRODUCTION

The evolution of wireless communication systems and the need for better multiple input multiple output (MIMO) systems has forced antenna designers to create new and innovative reconfigurable antenna designs applied specifically for MIMO communication systems. These systems with associated technologies such as smart antennas, and adaptive coding and modulation techniques enhance channel capacity, diversity, and robustness of wireless communications as has been proven by many recent research results both theoretically and experimentally [1][4]
In this paper a reconfigurable antenna designed for multiple input multiple output channels is studied and optimized using graph models. This optimization technique was discussed in [2] and it is based on graph modeling reconfigurable antennas which leads to removing redundant parts from the antenna structure. One of the main objectives of this technique is to reduce the number of electronic elements used in a reconfigurable antenna such as switches and capacitors to reduce costs and losses added by these elements.

A RECONFIGURABLE ANTENNA DESIGNED FOR MULTIPLE INPUT MULTIPLE OUTPUT SYSTEMS

The example antenna we want to discuss is the antenna detailed in [3].This antenna is defined as a multifunctional MEMS reconfigurable pixel antenna. The antenna is a highly MEMS-reconfigurable antenna which provides two functionalities: reconfiguration of its modes of radiation and reconfiguration of the operating frequency. The proposed antenna uses a 13 × 13 matrix of metallic pixels interconnected through MEMS switches in which circular patches of different radius are mapped on it. Each metallic pixel has dimensions 1.2 × 1.2 mm and they are separated 2 mm from each other, to provide enough space to allocate the MEMS switches and interconnecting lines. The MEMS switches around each pixel are activated or deactivated depending on the DC voltage that is supplied to these pixels. The DC connectivity is done through bias lines that connect the pixels to the back side of the substrate, as shown in Fig.1. In order to interconnect two metallic pixels, the voltage difference among them has to be around 30V. The metallic pixels and the bias lines are connected through RF (Radio Frequency) resistive lines made of Ni-Chrome alloy. These lines are able to stop the RF signals while allowing the DC signal to go through. The substrate used is a Quartz substrate of dimensions 2 × 2 in, and thickness of 1.575 mm with a dielectric constant of 3.78 .
This antenna can generate five orthogonal radiation patterns at approximately any frequency between 6 and 7 GHz. These patterns are those generated by the modes n=1, n=2 and n=0, all of them with $\phi_0 = 0^\circ$, n=1 with $\phi_0 = 90^\circ$, and n=2 with $\phi_0 = 45^\circ$, as defined in [5]. At any fixed frequency between 6 and 7 GHz 5 radiation states can be selected. This multimode functionality of this antenna is a useful feature for Reconfigurable MIMO (Multiple-Input Multiple-Output) systems using antenna diversity techniques [3].
The simulated θ and ϕ of the flattered 3-D far field pattern for the n=1, n=1 with $\phi_0 = 90^\circ$,n=2, n=2 with $\phi_0 = 45^\circ$ and n=0 modes are shown in Fig.2.

MODELING RECONFIGURABLE ANTENNAS USING GRAPHS

The first step in the optimization process is to graph model the antenna in question. A graph is a collection of vertices connected together by lines called edges or links. A simple labeled graph is represented by G = (V, E) where V is a set of vertices, and E is a set of pairs or edges of V. A graph may be either directed or undirected. In a directed graph, the edges have a determined direction while in an undirected graph edges may be traversed in either direction. Fig. 3 shows an undirected graph of 7 vertices (V1,V2,V3,V4,V5,V6,V7) connected by 8 edges. The vertices represent physical

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entities such as antenna parts and the edges indicate the connection between them activated by switches.
Edges may have weights associated with them in order to represent costs or benefits that are to be minimized or maximized. For example if a switch is connecting two parts of an antenna system then a weight might represent the connection distinctive direction.
The antenna we discussed in the previous section is a multifunctional antenna that has 13×13 elements that can be connected and disconnected through MEMS. This antenna has a lot of functions and applications and can be used either to tune frequency between 4.5 and 7 GHz or to change the radiation pattern modes at any fixed frequency in that range.

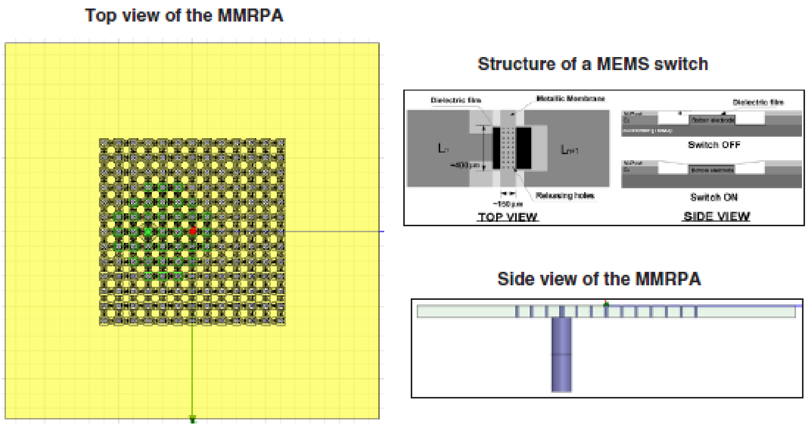

Fig.1 Structure of the multifunctional MEMS-reconfigurable pixel antenna (Antenna1) [3]

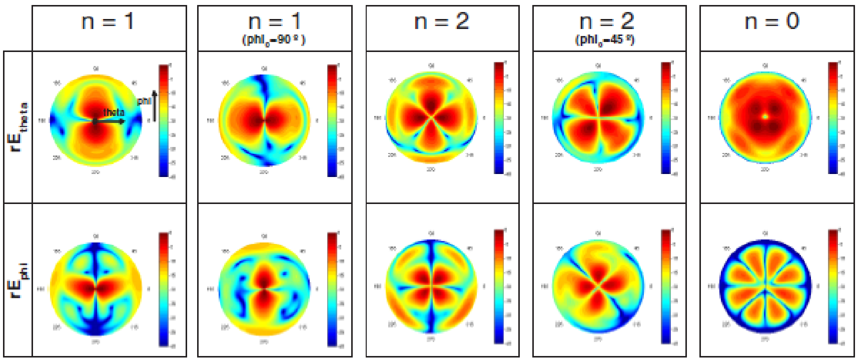

Fig.2 Flattered 3-D radiation pattern with respective antenna configurations [3]

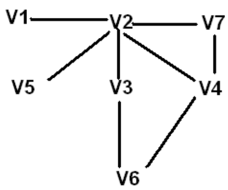

Fig.3. An example of an undirected graph

To graph model this antenna we consider the different parts constituting this antenna as vertices. These vertices are connected by weighted undirected edges. The graph model of this antenna is shown in Fig.4.

REDUCING REDUNDANCIES IN RECONFIGURABLE ANTENNAS USING GRAPH MODELS

The approach that we use to reduce redundancies in a reconfigurable antenna enables the optimization of the number of switches in the antenna. The technique aims at removing redundancies from the structure in order to reduce costs and losses. The objective is always to determine the existence of redundant elements in a structure and to eliminate them. A part is defined as redundant in a reconfigurable antenna if its presence gives the antenna more functions than required and its removal does not affect the antenna's desired performance. The removal of a part from the antenna structure may require a change in the dimensions of the remaining parts in order to preserve the antenna original characteristics. In [2] an example is presented on how to identify an element as redundant by comparing the number of unique paths in a graph with the number of required functions from the antenna.

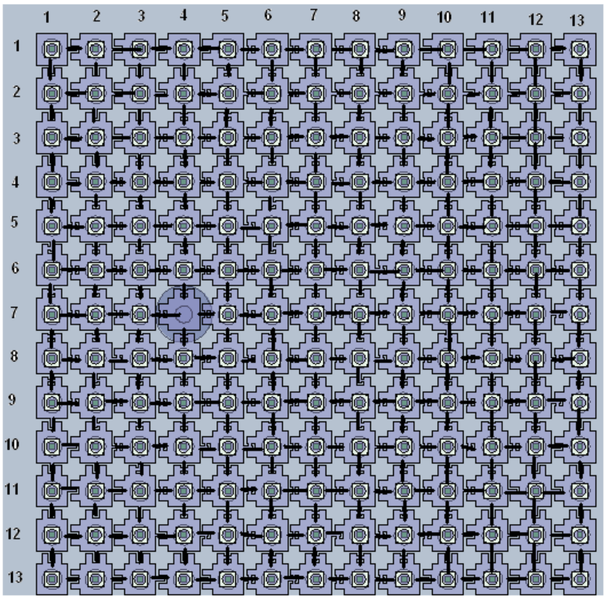

Fig.4 The graph model of the antenna in [3] for all possible configurations

The optimization process that is discussed in [2] takes into consideration one reconfiguration functionality at a time. For example this antenna exhibits frequency tuning as well as pattern/ polarization diversity for fixed frequencies. In our analysis of this antenna we will take into consideration the pattern/ polarization diversity characteristics only for a fixed frequency. Fig.5 shows the different configurations required from the antenna to achieve the different radiation pattern characteristics shown in Fig.2. We note that the required configurations are only 5.Since the number of required configurations is only 5 applying Eq. 1 to this antenna will give us the number of parts required to achieve the desired configurations.

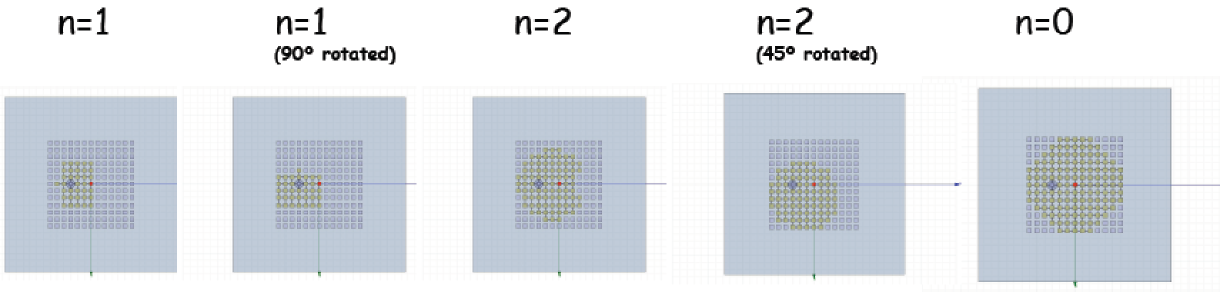

Fig.5 Different configurations required from the antenna

$$N = \left\lceil \frac{1+\sqrt{1+8\times(NAC-1)}}{2} \right\rceil = \left\lceil \frac{1+\sqrt{1+8\times(5-1)}}{2} \right\rceil = 4 \quad (1)$$

The number of configurations required to achieve 5 different antenna functions is only 4. The shape of the antenna with four parts will be very different from the one shown in Fig.4 and needs to be simulated and investigated extensively. However that doesn't cover the scope of this paper where the requirement is to keep the same topology of the antenna and optimize the number of switches used.

In order to preserve the same antenna topology we divided the antenna into 27 different sections as shown in Fig.6. Inside each section the different square patches are connected together constantly which eliminates the need for switches inside each section. Switches will only be used to connect the sections together. Using this technique the number of switches will be reduced and instead of having 312 switches connecting the different parts of the antenna we

will have 219 switches connecting the different sections of this antenna. This technique takes into consideration only one reconfiguration functionality of the antenna which in this case is radiation pattern/ polarization diversity that changes between five different configurations. The number of switches was reduced by almost a 100 switches.
The connection of section 1 to section 2 excites the n=1 mode while the connection of sections 1, 2, 3, 8, 12, 13 and 14 excites mode n=1 with ϕ=90˚. The connection between sections 1, 2, 3, 4 ,5, 6 ,7, 8, 9, 10, 15, 17 and 27 results in the mode n= 2, while the connection of sections 1, 2, 3, 4, 5, 8, 9, 13, 14, 15, 17, 19, 20, 21, 22, 23, 24 and 27 excites in the mode n=2 with ϕ=45˚. The connection of all the 27 sections will result in the mode n=0.

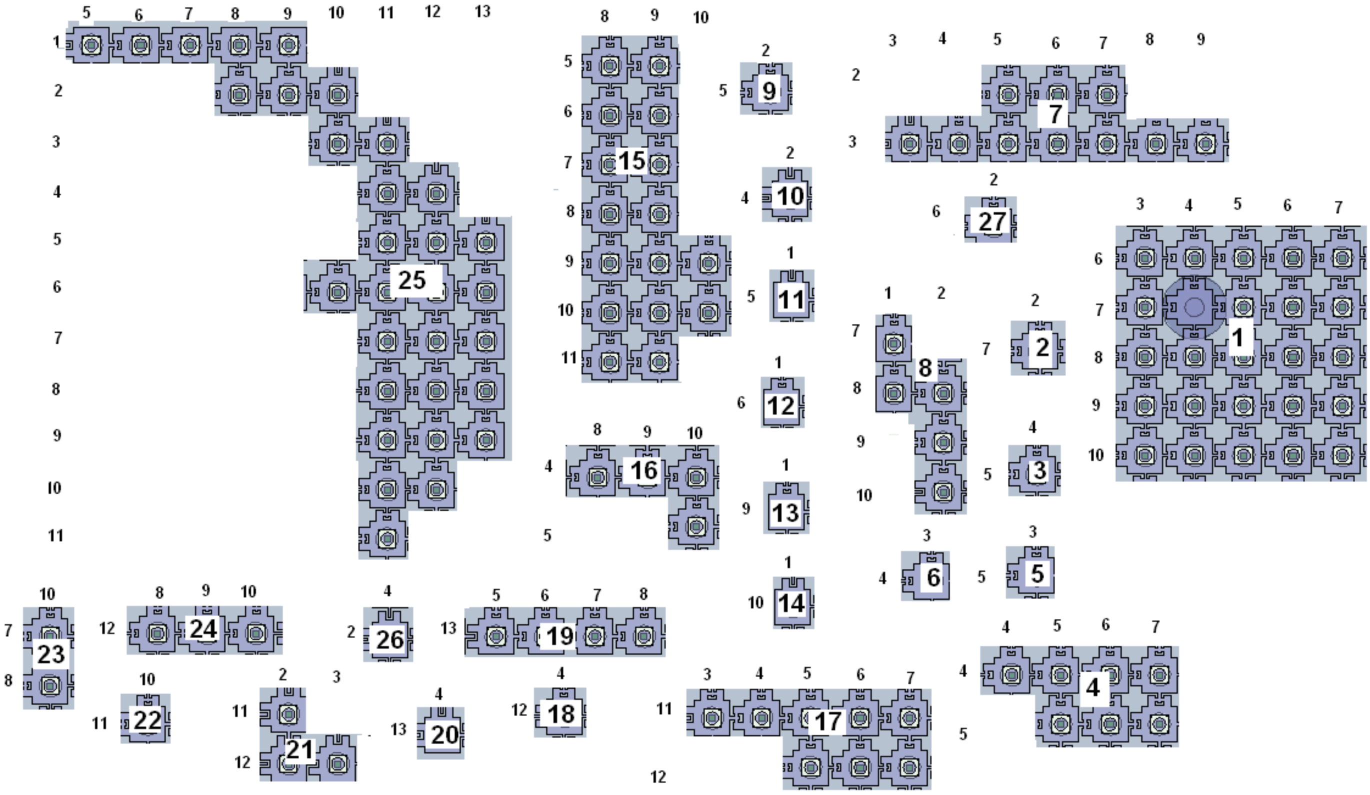

Fig. 6 Different antenna sections

CONCLUSION

In this paper a new approach for optimizing the number of switches required in a reconfigurable antenna with applications in MIMO is presented. This technique is based on graph modeling. As an example a very versatile multifunctional antenna with 169 parts and 312 switches is analyzed. We show how some parts can be eliminated and still maintain the functionality and versatility of the original antenna. Our approach can be used as a guide in designing reconfigurable antennas with a minimum number of switches.

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