Evolutionary Optimized Pixelated Antennas for 5G IoT Communication

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***Abstract*— We present the simulation and optimization of asymmetrical pixelated antennas for 5G Internet of Things applications. Results from a large scale study are presented showing the achievable bandwidth of pixelated asymmetric antennas - using shifted cross shaped elements - with respect to antenna size. This dataset is used to determine the size in which the pixelated antenna is allowed to evolve in to fulfill a bandwidth subscribed by the 5G N20 band. The antenna is optimized autonomously by our software employing evolutionary algorithms leading to an excellent agreement between simulations and measurements.**

***Keywords*— 5G mobile communication, simulation, antenna measurements, antenna radiation patters, genetic algorithm, evolutionary computation, internet of things**

I. Introduction

Pixelated (fragmented) antennas have become a widely studied topic over the last years, due to the potential of a highly automated optimization process [1], [2], [3]. While there are many possibilities for optimizing a pixelated structure, such as Particle Swarm Optimization (PSO), evolutionary algorithms have proven to be a very good candidate [2], [4], [5]. It has been shown that pixelated antennas created by using evolutionary algorithms are able to outperform conventional topologies [4], but as of now only few structures for 5G communication have been optimized [6].

5G connections enhance sensor Internet of Things (IoT) capabilities to robots, actuators and drones and feature many benefits to our modern interconnected world. For the IoT one of the most important factors is a massive connection density [7], [8]. This becomes evident by observing the increasing number of devices connected in the IoT, which already featured 7.74 billion devices in 2019 [9]. Furthermore, in densely populated areas a massive amount of IoT devices has to be connected and cities becoming smart can feature a lot of connected devices.

The available frequency bands for 5G communication are divided into two distinct ranges:

- Frequency Range 1 (FR1): below $6\,\mathrm{GHz}$
- Frequency Range 2 (FR2): $24.25\,\mathrm{GHz}$ - $52.6\,\mathrm{GHz}$

For this work the N20-band in FR1 was chosen, as it is a popular choice for facilitating IoT-applications. Whereas down- and up-link are different, with $806\,\mathrm{MHz}$ and $847\,\mathrm{MHz}$ center frequency respectively, the bandwidth is the same with $30\,\mathrm{MHz}$. Details can be seen in Table 1.

In order to fit this band the center frequency of the antenna to be designed was chosen to be $826.5\,\mathrm{MHz}$ with a $-10\,\mathrm{dB}$ bandwidth of $71\,\mathrm{MHz}$.

Table 1. Details on the N20-band.

Band	Downlink [MHz]			Uplink [MHz]		
	Low	Middle	High	Low	Middle	High
n20	791	806	821	832	847	862

The design process was, human input of boundary conditions (like antenna- and pixel size) and optimization goals (like resonant frequency) aside, completely automated using a previously reported optimization technique employing evolutionary algorithms [4]. Prior to optimization, a large scale study was carried out with antennas optimized for only $868\,\mathrm{MHz}$ observing the $-10\,\mathrm{dB}$ bandwidth with respect to antenna size. In this publication we show the possibility of using this large scale study - generalized with respect to wavelength - to determine the initial antenna size to fit the 5G N20 band. Simulation results are compared with measurements obtained in an anechoic chamber showing a high degree of accordance.

II. Evolutionary Algorithm

The employed procedure has been described before in detail, which is why only a short summary will be given here [4]. In a first step a pre-defined area is subdivided into cross-shaped pixels. Crosses have an inherent advantage over other geometries, because singularities are avoided, which in turn improves the simulation and measurement accuracy, as exemplified in Fig. 1. Every cross has a Boolean value that represents a conductive or non-conductive element (0,1), where a value of 1 corresponds to a $35\,\mu\mathrm{m}$ thick copper layer placed on top of a substrate. All boolean values of a pixelated area are combined into a matrix, which can be then optimized using an evolutionary algorithm.

The algorithm itself is implemented in Matlab. At the beginning of the optimization, the evolutionary algorithm generates a random initial population. Antenna parameters such as reflection coefficient or antenna gain of this initial population are simulated by Sonnet Software and then handed

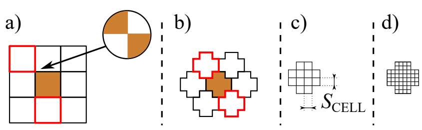

Fig. 1. a) shows rectangular pixels which feature singularities. In b) our chosen method of using cross shaped pixels is seen, which gets rid singularities. In c) the seperation of the cross into different Sonnet cells with the size S_{cell} is seen. If more resolutin is wished the cell size is halved as depicted in d).

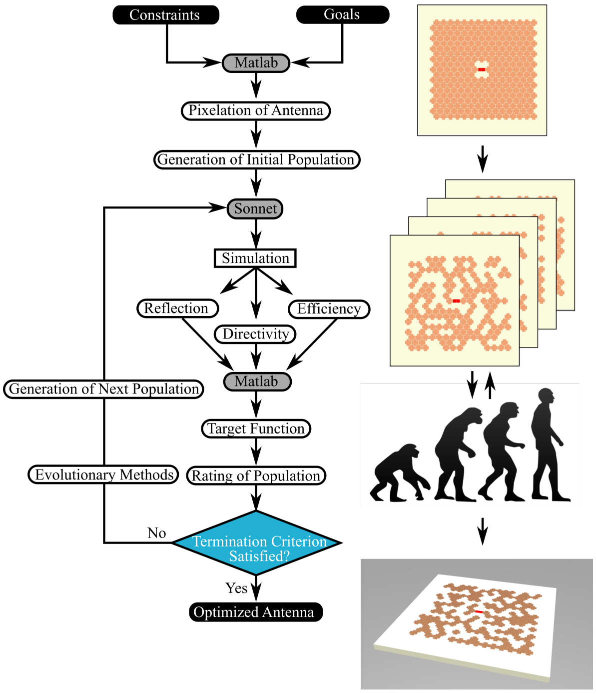

Fig. 2. A flowchart of the employed optimization technique.

back to Matlab, where a fitness function is calculated. This fitness in turn is used as an input for evolutionary methods like selection, crossover and mutation, that are employed to create a second population. This process is repeated until a termination criterion is reached, after which the final structure can be manufactured using a PCB mill. A flowchart of the optimization method is shown in Fig. 2.

III. Design Considerations

In previous studies, a scaling law for the number of needed pixels for a certain antenna size, as well as a lower bound for the resolution (cell size S_{cell} depicted in Fig. 1), where the simulation accuracy does not improve when the cell size used in Sonnet is further decreased, was deduced and found to be $0.58\,\%$ of the wavelength. [4] Based on these initial findings a systematic study has been performed in order to deduce optimal boundary conditions for antennas of certain resonance frequencies and co-dependencies of the various parameters. As a part of this study 400 antennas with different sizes were optimized for $868\,\text{MHz}$ and their simulated $-10\,\text{dB}$ bandwidth was extracted. These results can be seen in Fig. 3. Depicted are the upper and lower bounds of the achievable bandwidth (dashed lines) as well as the median bandwidth

Table 2. Geometrical parameters used for a single objective optimization X denotes the number of pixels in X direction, X the number of pixels in Y direction, and N the total number of pixels involved in the optimization process. The choosen pixel size was $6.84\,\text{mm}$. The width, the height and the diagonal dimension of the antenna are W,H and D respectively.

X	Y	N	Pixel Size [mm]	W [mm]	H [mm]	D/λ [%]
13	17	130	6.2	83.7	80.6	32.03

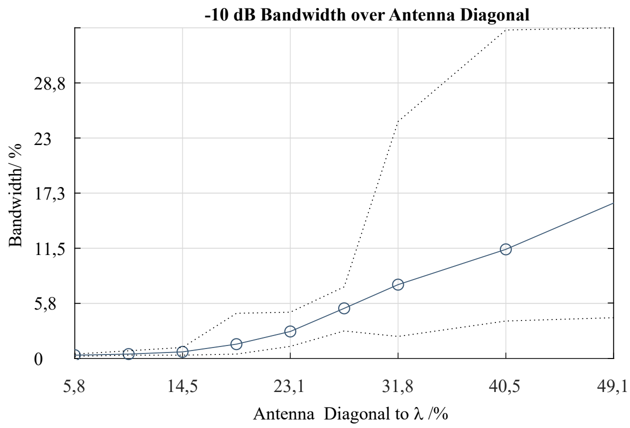

Fig. 3. 10dB bandwidth for various antenna widths. Median and upper as well as lower bound of the bandwidth are depicted as blue solid and black dashed line respectively. The data was gathered by simulating multiple antennas for a single resonance frequency at $868\,\text{MHz}$ with a S_{11} of $-20\,\text{dB}$.

(solid line) with respect to antenna diagonal in percent of wavelength. Scaling the results to percent of wavelength allows the deduction of geometric parameters for different resonant frequencies. However, from this study can be seen, that the bandwidths upper and lower bound deviate heavily. Therefore, the antenna is optimized by minimizing the mean value of the reflection coefficient within the 5G N20 boundaries to a target of $-10\,\text{dB}$.

For this study geometric parameters for a 5G N20 downlink band antenna were deduced from Fig. 3, which can be seen in Table 2. The antenna dimensions for the optimization are chosen to fulfill a median antenna bandwidth as depicted in Fig. 3 of at least $71\,\text{MHz}$ at $826.5\,\text{MHz}$ in order to fit the 5G N20 Band.

The substrate for the fabrication of the antenna is a $1\,\text{mm}$ thick NEMA grade FR-4 substrate (ISOLA, DE104). At $1\,\text{GHz}$ it exhibits a relative permittivity of 4.37 with a loss tangent of 0.022.

IV. Results

The resulting structure, based on the parameters of Table 2, can be seen in Fig. 4. This antenna was measured with a vector network analyzer [ZNB8, Rohde & Schwarz] by employing

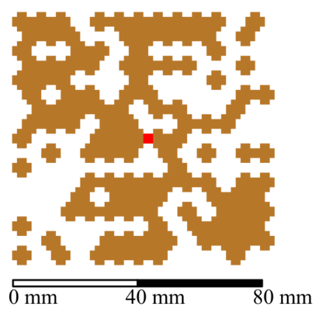

Fig. 4. Final structure of a fully optimized antenna. The port located in the middle is marked by a red squared box.

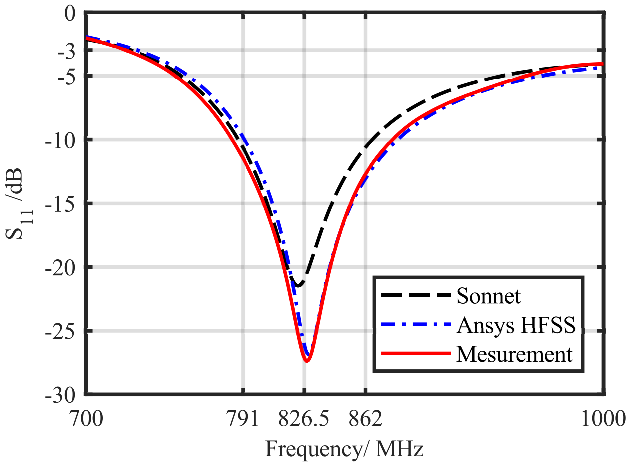

Fig. 5. Comparison of the measured S_{11} parameter (solid red) and simulations in Sonnet (dashed black) and ANSYS (dash-dotted blue).

a bazooka (otherwise known as sleeve) balun for the gain measurements designed for $826.5\,\mathrm{MHz}$ as well as a text fixture for asymmetrical differential impedance measurements [10]. The used measurement methods are described with more detail in [4]. The measured differential reflection coefficient S_{11} is depicted in Fig. 5 which shows an error between simulation in Sonnet and measurement of only $0.6\,\%$ and a hardly visible error between Ansys and measurement with respect to the resonance frequency. The measured antenna features a $-10\,\mathrm{dB}$ bandwidth of $93\,\mathrm{MHz}$ ranging from 785 up to $878\,\mathrm{MHz}$ which fits the prescribed boundaries of the 5G N20 band.

Antenna gain patterns were simulated with ANSYS and measured for elevation ($\phi = 0°$ and $90°$) and azimuth ($\theta = 90°$) angles as depicted in Fig. 6. A visible high agreement between measurement and simulation is seen. The maximum gain is measured to be $2.63\,\mathrm{dBi}$ and simulated to be $1.8\,\mathrm{dBi}$. The mean absolute error between measurement and simulation is $0.49\,\mathrm{dB}$ for elevation with $\phi = 0°$, $1.77\,\mathrm{dB}$ for elevation with $\phi = 90°$ and $2.45\,\mathrm{dB}$ for azimuth.

V. Conclusion

This paper shows the possibility of employing evolutionary algorithms for the design and optimization of asymmetrical pixelated antennas designed for 5G IoT-Applications in the N20 band by choosing an area the antenna is allowed to evolve in given from a presented large scale study. The agreement between simulation and measurements is excellent, which further establishes this method as a viable candidate for the automated generation of antennas. The achieved gain is measured to be $2.63\,\mathrm{dBi}$ at $826.5\,\mathrm{MHz}$. The antenna features a by Ansys HFSS simulated radiation efficiency of $95.7\,\%$ and the $-10\,\mathrm{dB}$ bandwidth is $93\,\mathrm{MHz}$.

The advantage of the proposed procedure is not only the high degree of automation, with only minimum input needed, but also the low computation time. For the antenna presented in this study approximately 35 minutes were needed for the full optimization with a Lenovo Legion 5 notebook including a AMD processor [Ryzen 7 4800H, AMD]. In contrast to previous studies [6], an optimal geometry was deduced from a large data set containing the, with pixelated antennas, achievable bandwidth with respect to antenna size.

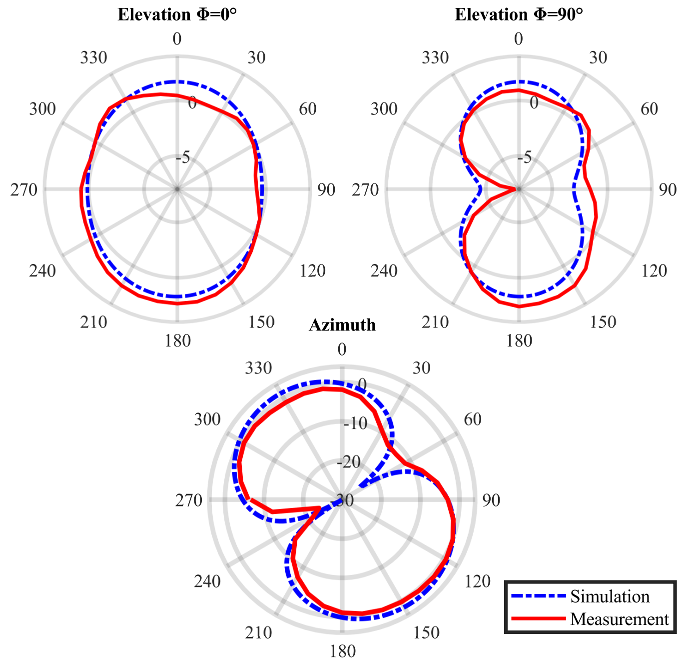

Fig. 6. Antenna gain plot for elevation ($\phi = 0°$, $\phi = 90°$) and azimuth angles. Simulations made with ANSYS (dash-dotted blue) are compared to measurements (solid red).

Further studies will focus on the generation of a large scale study in which antennas are optimized for bandwidth not for a single frequency.

Acknowledgment

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