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Spatial Data Focusing using time resources

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***Abstract*—This paper presents a new technique that aims to focus the transmitted data rather than the transmitted power. This scheme, known as Spatial Data Focusing, enables the broadcasting of information to specific spatial locations, using fewer antenna elements compared to classical beamforming techniques. By doing so, it overcomes the performance of classical power focusing techniques in terms of information beamwidth, i.e., the angular range within which the Bit Error Rate (BER) is below a given threshold. In particular, we show that, with the use of a 3-antenna array only, an information beamwidth (BER< 10^{-3}) of 5° is obtained.**

I. INTRODUCTION

Transmitting wireless information that is only retrievable within specific spatial locations is an interesting feature, known as geocasting, that many applications can benefit from. This property allows the users to receive data related to the positions where they are without being localized, as long as they stand in the predefined zone. This approach is therefore compliant with privacy issues and also enables geocasting in areas where positioning systems are typically not available, e.g., indoor environments.

To do so, base stations have to exhibit spatial focusing properties. It is generally obtained via antenna arrays implementing beamforming techniques, so that base stations can radiate signals toward particular directions only. However, it exists a fundamental physical restriction, the electric size of the array, that determines the radiated beamwidth. Achieving narrow beams of radiated power often leads to the use of unpractically large antenna arrays [1].

In order to overcome this problem, this paper presents a Spatial Data Focusing (SDF) scheme that aims to focus data instead of power toward physical locations. It thus allows obtaining narrow information-beams, in terms of Bit Error Rate (BER), with limited infrastructure. SDF can be implemented using Directional Modulation (DM) techniques. DM was introduced in order to enhance the physical layer security for wireless communications. The main idea consists in scrambling the received constellations in all unwanted communication directions while keeping constellations intact in the directions of legitimate communications. By doing so, even with a highly sensitive receiver, it would not be possible to recover the data from the sidelobe directions of the transmitting array. Several methods were developed in order to synthesize the DM technique and can be separated in two categories: 1) Radiation reconfigurable DM transmitters that directly modify the antenna radiating structures to modulate the far field at the symbol rate, and 2) Excitation reconfigurable DM transmitters, i.e., the DM behavior is implemented with the antenna array excitation weights [2].

The first type of DM transmitters was studied by Babakhani et al. in [3], [4]. Nevertheless, this kind of DM transmitters are difficult to synthesize due to the necessity to deal with the complex interactions between the near-field environment of the antenna and the resulting far-field radiated pattern of the system. The second DM category offers more flexibility in its synthesis. The excitation weights are designed via an iterative optimization process in order to obtain a desired far-field radiation pattern and to scramble the constellations in the unwanted communication directions. The excitation reconfigurable DM transmitters can be synthesized in an architecture independent fashion via the orthogonal vector concept presented in [5]. Different DM synthesis techniques are presented in [2].

However, the computation of the excitation weights is complex and the DM transmitters performance is not optimal for small antenna array. In fact, the width of the information beam is of the same order of magnitude as the main lobe achieved by the antenna array. Angular selectivity is therefore not necessarily increased with this approach.

In this paper, a new original technique, known as Spatial Data Focusing, is introduced to overcome this issue. In particular, a time-domain approach of the SDF scheme will be investigated. In section II, a theoretical description of the SDF concept is explained. Simulation results are shown and interpreted in section III.

II. TIME DOMAIN APPROACH OF SPATIAL DATA FOCUSING

In order to implement the SDF scheme, the symbol stream is mapped onto an N-dimensional space. To create such a space, the time domain is used. If we denotes the symbol period by T, each of the N projections of the symbol will modulate a root raised cosine pulse of duration T/N that will be sent via a particular antenna with a relative delay of T/N. Hence, one obtains time-orthogonality [1]. For example, if one has a 3-antenna array at the transmitter side, each symbol will be mapped onto a 3-dimensional space. The projection of the symbol onto the first dimension will be sent via the first antenna, the second symbol component will be sent via the second antenna but delayed by $T/3$, and the third symbol component will be sent via the third antenna but also delayed by $T/3$ compared to the second antenna. Fig. 1 shows the architecture of a base station implementing a N-dimensional SDF communication scheme.

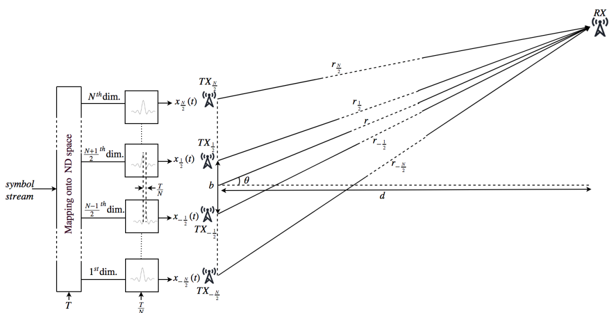

Fig. 1. Architecture of an N-dimensional SDF communication scheme

If the receiver is aligned with respect to the array center, i.e., $\theta = 0°$, all the symbol components will reach it with a relative delay of T/N. Therefore, the time orthogonality will be maintained leading to a non-distorted received constellation. The data will therefore be intelligible. However, if the receiver moves away from broadside, i.e., $\theta \neq 0°$, the symbol components will not be received with a relative delay of T/N. Hence, at the receiver side, the time orthogonality will be lost and the constellation will be scrambled. Consequently the Bit Error Rate (BER) will become high and the information will be erroneously decoded.

To the best of the authors' knowledge's, it is the first time that the temporal dimension is used to create an N-dimensional symbol stream in order to wirelessly broadcast data that is only retrievable within specific spatial locations. This shows the main difference between DM and SDF.

III. Simulations and Results

This section presents two Matlab simulation results implementing a SDF scheme with N dimensions. These were obtained in a free space environment.

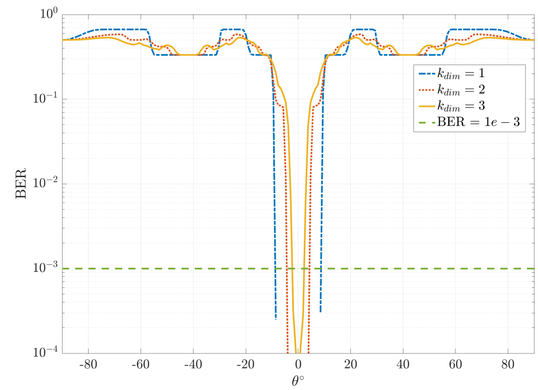

Fig. 2. BER versus θ, $N = 3$ antennas, SNR = 25 dB, $b = 0.75\lambda_c$, $f_d = 20$ MHz, $f_c = 2.45$ GHz

Fig. 2 shows the evolution of the BER in function of the receiver's position for different constellation sizes. Here, a 3-antenna array is used to transmit the information and the parameter k_{dim} represents the number of coded bits per dimension. Consequently, the number of coded bits per transmitted symbol is equal to $N\ .\ k_{dim}$. As expected, one observes that the beamwidth gets narrower as the constellation size increases. In particular, with only 3 antennas, one can obtain an information beamwidth, where the BER is below 10^{-3}, of only $5°$ around the desired communication direction.

Fig. 3 shows the performances, in terms of BER versus receiver's position, of the SDF communication scheme when the number of transmitting antennas varies.

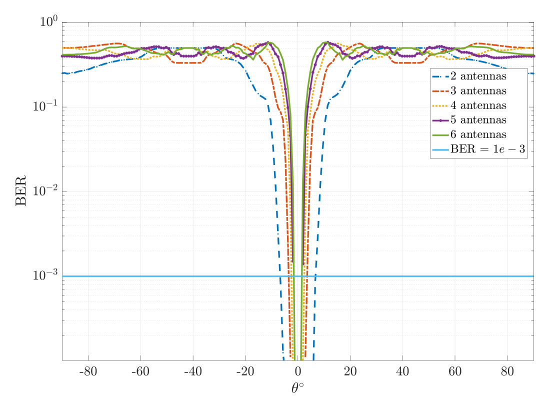

Fig. 3. BER versus θ, $N = 3$ antennas, $k_{dim} = 2$, SNR = 25 dB, $b = 0.75\lambda_c$, $f_d = 20$ MHz, $f_c = 2.45$GHz

As expected, when the number of transmitting antennas increases, i.e., the number of dimensions increases, the information beamwidth also decreases. With 2 antennas, the achieved beamwidth is about $13°$ while with 6 antennas, it is $3°$. This highlights the potential of performing geocasting using reasonable-size arrays.

IV. Conclusions and Perspectives

This paper presents a new promising technique allowing the wireless transmission of spatially focused data. By combining multidimensional modulation schemes and antenna arrays, it was shown that narrow information beamwidths can be obtained with BER sufficiently low to reliably communicate. The SDF approach allows to overcome the classical beamforming issues faced in geocasting scenarios. So far, the SDF method is only studied in free-space environments and with only one legitimate receiver. Further studies will investigate the multi-users problem, in real propagation channel conditions.

References

[1] J. Sarrazin, S. Golstein, M. Odhiambo, P. De Doncker, F. Horlin, *"Spatial Data Focusing: an alternative to Beamforming for geocasting scenarios"*, IEEE Antennas and Propagation Symposium, Boston, 2018.

[2] Y Ding, V. Fusco, *"Developments in Directional Modulation Technology"* FERMAT, 2016.

[3] A.Babakhani, D.B. Rutledge, A. Hajimiri, *"Transmitter Architectures Based on Near-Field Direct Antenna Modulation."*, IEEE Journal Of Solid- State Circuits, pp. 2674-2692, December 2008.

[4] A.Babakhani, D.B. Rutledge, A. Hajimiri, *"Near- Field Direct Antenna Modulation"*, IEEE Microwaves Magazine, February 2008.

[5] Y. Ding, V. Fusco, *"Vector Approach for the Analysis and Synthesis of Directional Modulation Transmitters"*, IEEE Transactions on Antennas And Propagation, Vol. 62, No. 1, January 2014.