Physical Communication 26 (2018) 31–39

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

Antenna array thinning for interference mitigation in multi-directional antenna subset modulation

Amr Akl [a], Ahmed Elnakib [b], Sherif Kishk [b],*

[a] Qarun Petroleum Co., New Maadi, Cairo, 11728, Egypt
[b] ECE Department, Mansoura University, 35516 Mansoura, Egypt

ARTICLE INFO

Article history:
Received 15 March 2017
Received in revised form 27 October 2017
Accepted 17 November 2017
Available online 23 November 2017

Keywords:
Millimeter-wave
Antenna subset modulation
Convex optimization
Directional modulation
Physical layer security

ABSTRACT

Due to the increasing demand for wireless communications, millimeter-wave band has gained a great attention recently. Also, achieving secure wireless communications is of high importance. Antenna subset modulation is a low complexity single beam directional modulation technique suitable for millimeter-wave wireless communications, whereas multi-beam antenna subset modulation is a multi-directional, generalized form of antenna subset modulation. In this paper, interference mitigation for multi-beam antenna subset modulation via side lobe level reduction is introduced. A method for designing thinned arrays with minimum side lobe levels for antenna subset modulation is introduced and generalized for multi-beam antenna subset modulation. A new variable constraint is applied to the optimization problem to control the localization of optimum solution within the antenna array. Two solutions are introduced, convex optimization combined with local search and local search assisted genetic algorithm. Simulation results show the superiority of the proposed algorithms compared to simulated annealing algorithm and traditional genetic algorithm.

1. Introduction

Transmitting data securely is a remarkable requirement of wireless communications. Traditionally, transmission security is achieved by implementing complex cryptographic algorithms in network upper layers, but nowadays physical layer security has emerged as a mean for increasing wireless communication secrecy [1,2]. Recently, directional modulation (DM) has been intensively investigated as a physical-layer secure modulation technique for wireless communications [3–9]. A system implementing DM transmits distorted constellations in all directions, except along a desired direction where no distortion occurs and the signal can be received with low bit error rates.

Recently, the underutilized very high frequency millimeter wave band has gained a significant interest due to the rapidly increasing demand on wireless communications [10–12]. At such high frequency bands, the small wavelengths nature can be exploited to pack large antenna arrays in both receivers and transmitters to achieve the desired directivity to overcome high propagation loss [12,13]. Antenna Subset Modulation (ASM) is a low complexity directional modulation technique introduced as secure modulation method suitable for millimeter wave wireless communications [14]. In ASM the transmitter benefits from a large antenna array to transmit a prescribed constellation along a certain desired direction and scrambled constellations along other directions by randomly selecting an antenna subset in the symbol rate. Multi-beam antenna subset modulation (MASM) is a generalized form of ASM in which the antenna array is partitioned in the symbol rate to subarrays, which are allowed to overlap, and used to transmit data streams to multiple target receivers located along different angles [15]. The secrecy rate of ASM and interference levels at target receivers of MASM are highly affected by the side lobe levels of antenna array radiation pattern, hence choosing antennas subsets with the lowest possible side lobe levels can be used to improve the performance of ASM and MASM. Opposed to traditional sparse array synthesis algorithms which deal with designing non-uniform antenna array having the minimum number of specific pattern elements; the synthesis of ASM sparse array aims to find the antennas subsets with the minimum side lobe levels to achieve the maximum possible secrecy rate, whereas the synthesis of MASM sparse subarrays aims to find antenna subsets with minimum side lobe level to minimize interference levels at target receivers.

In the literature, various optimization techniques have been proposed for array thinning extending from genetic algorithm [16,17], to dynamic programming [18] and simulated annealing (SA) [19–22]. Moreover, Analytic methods for array thinning like almost difference sets (ADS) has been implemented

---

* Corresponding author.
E-mail addresses: aramadan@qarun.net (A. Akl), nakib@mans.edu.eg (A. Elnakib), shkishk@mans.edu.eg (S. Kishk).

https://doi.org/10.1016/j.phycom.2017.11.005
1874-4907/

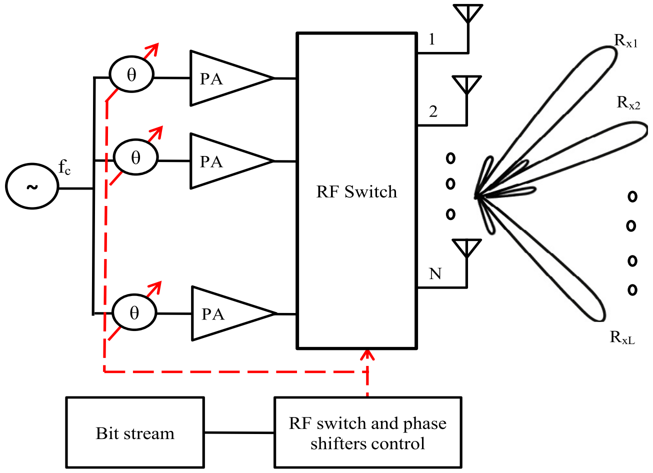

Fig. 1. An illustration for MASM.

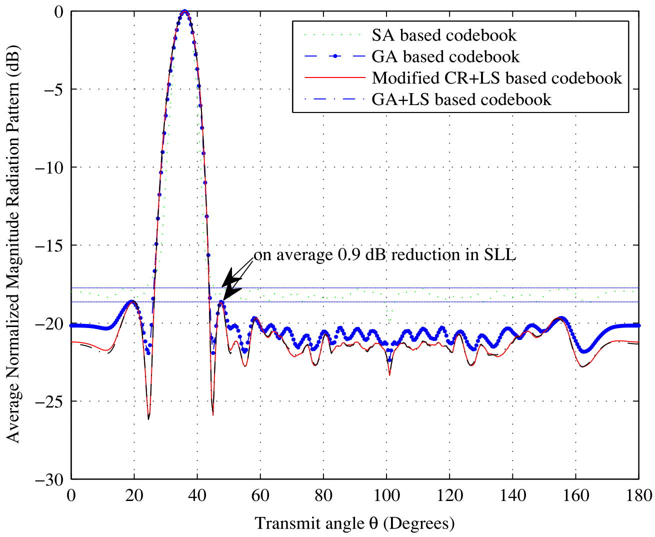

Fig. 2. Average radiation patterns for four codebooks synthesized by Modified CR+LS SA, GA and GA+LS.

for both linear arrays [23] and planar arrays [24]. Furthermore, Bayesian compressive sensing (BCS) technique has been used in thinning of antenna arrays that match certain user-defined patterns [25,26]. Also, convex optimization and l_1 norm minimization has been proposed as antenna array Synthesis algorithm [27–31]. The convex optimization based algorithm given in [31] is very useful for a general millimeter wave system. However, it only gives a single solution. Hence, this algorithm [31] is not suitable for ASM where it is needed to construct a codebook of antennas subsets with minimum side lobe levels.

In this paper, a method for antenna array partitioning for MASM based on selecting subarrays with minimum side lobe levels is introduced and demonstrated by simulations. First, an improvement for the algorithm introduced in [31] is presented by imposing a new variable constraint. The introduced constraint makes the proposed algorithms more flexible to produce the required ASM codebook. Two solutions for the modified optimization problem based on genetic algorithm assisted with local search and convex optimization are introduced. Then, the algorithms are generalized for MASM. The performed simulations show that the proposed algorithms performs better than simulated annealing and traditional genetic algorithm in terms of symbol error rate at target receivers of MASM. The manuscript is organized as follows. Section 2 introduces array thinning problem formulation. Section 3 presents the proposed solution for ASM. Section 4 Generalized the solution for MASM. Section 5 presents and discusses simulation results. Finally, Section 6 concludes the work done in this paper.

2. Array thinning problem formulation

Consider a transmitter equipped with an antenna array with N isotropic transmit antennas spaced uniformly by d. It is required to construct a codebook of antennas subsets each consists of M antennas and $M < N$, such that the side lobes of the array factor $F(\theta)$ are minimized. In general, it is required to solve the following discrete, non-convex optimization problem over the “zero–one” coefficients of array elements:

$$\text{minimize} \quad \max|\text{SLL}| \tag{1}$$

where SLL is the side lobe level, and

$$\max|\text{SLL}| = \max_{\theta\in\Omega} |F(\theta)| \tag{2}$$

where Ω is the set of angles outside the main lobe where it is required to minimize the radiation pattern.

In ASM case, the synthesis of thinned array is a binary optimization problem results in selecting specific elements in the array. Recalling the equation of discretized minimization of the SLL with antenna selection [31]

$$\underset{\mathbf{b};\ \sum_{k=1}^{N} b_k=M,\ b_k\in\{0,1\}}{\text{minimize}} \quad \|\mathbf{H}_\Omega \mathbf{b}\|_\infty \tag{3}$$

where $\mathbf{H}_\Omega$ is a matrix of size $|\Omega|xN$ that contains all the steering vectors corresponding to a given array geometry and to the discretized directions for which SLL minimization takes places for angles $\theta_i \in \Omega, i = 1, \dots, |\Omega|$, $\mathbf{H}_\Omega^H = [\mathbf{h}(\theta_1)\ \mathbf{h}(\theta_2)\cdots\ \mathbf{h}(\theta_{|\Omega|})]$, $\|\mathbf{y}\|_\infty = \max_i |y_i|$ is the l_∞ norm and the binary variable $\mathbf{b}$ denotes the antenna selection pattern and is restricted to the selection of M out of N antennas. The problem given by (3) can be solved using GA or can be relaxed to convex one and solved using convex optimization. The binary constraint in (3) is relaxed using binary relaxation, and adding a regularization term which acts as a reweighted l_1 penalty term [32], the optimization problem can be rewritten as:

$$\underset{\mathbf{b};\ \sum_{k=1}^{N} b_k=M,\ b_k\in[0,1]}{\text{minimize}} \quad \|\mathbf{H}_\Omega \mathbf{b}\|_\infty + M^{-1}\mathbf{w}^T\mathbf{b} \tag{4}$$

where (4) is solved iteratively and $\mathbf{w}$ is the weight vector. Initially the weight vector is set to $\mathbf{w} = 1$ and is renewed for every iteration as $\mathbf{w} = 1 - \mathbf{b}$. The objective of the regularization term is to drive the entries of vector $\mathbf{b}$ that are close to zero to be exactly zero while larger entries are driven to reach the magnitude of one [31]. Solving (3) using GA or solving the convex problem, (4), using the algorithm given in [31] gives only a single optimum solution. Although this solution is very useful for a general millimeter wave system, this is not the case for ASM where it is desired to form a codebook of antenna subsets, of sufficient size, with minimum side lobe levels.

In the next section, a new solution for this problem suitable for constructing a codebook for antennas subsets of ASM is proposed.

3. Proposed solution For ASM

In this section a method for array thinning in ASM is proposed. A new variable constraint is added to the optimization problem to make it suitable for generating multiple near optimum solutions. Two algorithms for solving the new optimization problem are