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On Antenna Subset Modulation: Its Single and Multi-beam Capabilities

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ABSTRACT

Due to the increasing demand for wireless communications, both millimeter-wave band and spectral efficiency of transmission schemes have gained a great concern recently. Also, achieving secure wireless communications is of high importance. Recently, physical layer security has been intensively investigated as an extra layer of protection for wireless communications. Directional (DM) has been proposed as a mean to implement physical layer security. A special type of DM suitable for millimeter-wave wireless communications is antenna subset modulation (ASM) in which the small wavelength nature in millimeter-wave band is exploited to equip a transmitter with a large antenna array. By randomly choosing few elements of the array for transmitting a symbol, secure communication in a single direction is obtained. Using only a few portion of the antenna array in transmission makes this large array underutilized. the unused portion of the antenna array can be exploited to increase the spectral efficiency of ASM. In this paper, we introduce a survey on last advances on ASM and address its multi-directional transmission capabilities. An architecture for multi-directional ASM is introduced. Randomized and optimized antenna subset selection techniques are introduced and demonstrated by simulations.

Key words : Physical layer security, Directional modulation, Milli-meter wave, Antenna subset modulation.

1. INTRODUCTION

The current advances in technology increase the desire of people to freely access information and entertainment with high speeds, which in turn greatly increases the demand for high throughput wireless communications. Due to the rapid growth of wireless communications demand, the sub-3 GHz spectrum is becoming very crowded. While many recent wireline communication systems can provide multi-gigabit-second transmission throughput on the expense of expensive infrastructure, the recent alternative, cheep wireless communication system cannot provide multi-gigabit data transfer rate at sub-3 GHz spectrum. All of this motivated the use of the underutilized (3-300GHz) spectrum, referred to as Millimeter-wave (mmWave) bands, to provide the bandwidth needed for broadband wireless communications for the upcoming decades. The vast amount of unused mmWave spectrum allows large bandwidth allocation, which directly results in high rates of data transfer. Further, the availability of CMOS Technology that can be used in mmWave bands with suitable cost and the ability to equip transmitters and receivers with large, steerable antenna arrays, due to much smaller wavelength, supports the viability of mmWave wireless communications [1], [2]. The abundance of the unexploited frequencies in the mmWave bands can be used in many applications ,such as Wireless Local Area Networks (WLANs), Fixed Wireless Access (FWA), the uncompressed multimedia streaming, such as the high-definition multimedia interface (HDMI), and Wireless Personal Area Networks (WPANs) [3], [4].

With most of wireline communications going to be replaced by mmWave wireless communications in the near future, the need for a more secure wireless communications becomes a must. Traditionally, security of wireless communications 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 [5], [6]. Recently, directional modulation (DM) has been intensively investigated as a physical-layer secure modulation technique for wireless communications [7]-[11]. A system implementing DM transmits distorted signals in all directions, except along a desired direction where no distortion occurs and the signal can be received with low bit error rates. ASM is a power efficient single-beam DM technique suitable for mmWave wireless communications. While conventional phased array transmits the same signal in all directions, ASM transmitter benefits from a large antenna array to transmit a scrambled constellation in all directions except along a certain direction where the target receiver exist by choosing a few number of its array antennas in the symbol rate [12], [13]. Therefore, any eavesdropper located outside the main lobe receives the modulated signal with high symbol error rate and cannot recover the transmitted information. Using only a few portion of the antenna array in transmission makes this large array underutilized. The unused portion of the antenna array can be exploited to increase the spectral efficiency of ASM

In this paper we introduce a survey on last advances on ASM and address its multi-directional transmission capabilities. An architecture for multi-beam antenna subset modulation (MASM) system transmitting same data to different receivers is proposed. Two techniques for antenna subset selection are introduced one based on randomized selection and the other is based on simulated annealing optimization algorithm. Simulation results are used to show the performance of randomized and optimized MASM. The rest of paper is organized as follows. Section 2 introduces a survey on single beam ASM. Section 3 introduces multi-beam antenna subset modulation. Section 3 introduces and discusses simulation results. Finally, section 5 concludes the work.

2. SINGLE BEAM ANTENNA SUBSET MODULATION

Previous work in [12]-[20] is restricted to single-beam transmission. The authors in [14] introduced a new beamforming technique for ASM in micro-wave systems. The proposed beamforming method is based on ignoring antennas with minimum channel gains; also the outage probabilities of connection and secrecy were derived. In [15] authors introduced a secure transmission scheme for a slow fading, multi-input single output mmWave channel with multi-path propagation using artificial noise, while in [16] they investigated the maximization of secrecy rate through an on-off transmission scheme. Authors in [17] introduced two physical layer security methods suitable for mmWave vehicular communication systems. In the first technique, instead of using only a few antennas for transmission and leaving other antennas idle, like ASM, the authors benefit from a phased antenna array to send information signal to a target vehicle using a random subset of antennas while the remaining antennas are used to randomize the far field radiation pattern at other directions. This approach differ from ASM in that there are no idle antennas. In the second technique, a phased array with hybrid digital/analog precoders is used to beamform information signal towards the target receiver and simultaneously transmits artificial noise in potential threat directions. Authors in [18], [19] introduced a new secure wireless transmission technique called Silent antenna hoping (SAH). The main differences between this proposed technique and ASM are that only one antenna is switched off at a time, and the modulation happens in baseband stage and hence not restricted to phase modulation and can perform amplitude and phase modulation like QAM. Also, there is no correlation between data rate and antenna switching rate. In [20] authors proposed an iterative FFT based optimization algorithm for selecting antenna subsets with minimum side lobe levels. Authors showed that their proposed algorithm outperforms simulated annealing algorithm.

Like any security algorithm ASM has weak points that need some enhancements. Authors of [21] showed that ASM is not immune to a receiver capable of making multiple measurements at different receiving angles. They also suggested that the immunity of ASM to this kind of attacks increases by increasing side lobe levels. As a result of that multi-directional ASM transmitting different data streams to spaced spatially receivers may be immune to such attacks.

3. MULTI-BEAM ANTENNA SUBSET MODULATION

3.1 Review

Spectral efficiency of transmission schemes is a remarkable requirement for contemporary wireless communication systems. Spatial domain has been used as a mean of separation to increase the spectral efficiency of wireless communications. The underutilized antenna array of ASM can be used to increase system throughput while maintaining secure communications by transmitting data to different, spaced spatially receivers. The antenna array is partioned, in the symbol rate, to subarrays that are allowed to overlap and each subarray is used to transmit data to a unique receiver.

The concept of Multi-beam secure wireless communications has been previously investigated in DM [22]-[25]. Authors in [22] introduced a technique for multi-beam DM using phased array with orthogonal vector approach. In this method independent data streams are transmitted towards spatially spaced receivers while an orthogonal vector randomly chosen from the null space of the conjugate of receivers channel matrix is used to randomize far field radiation pattern in other directions. This approach differs from our proposed technique, MASM, in (i) For the approach introduced in [22] the beamforming weights have variable magnitude and phase, while in MASM only phase is changing, (ii) part of the transmission power is assigned to the randomization orthogonal vector, while in MASM the power is only used for transmission and randomization is obtained from changing antennas dedicated to each receiver. Authors in [23] exploit an antenna array to simultaneously transmit different data streams towards different receivers. Due to simultaneous transmission of different symbols, the far field radiation pattern seen at non-receiving directions is randomized. They also generalized the technique for multi-path propagation channel in [24]. This technique also differs from MASM in (i) Beamforming vector calculation is time and power consuming process resulting in weights with variable magnitude and phase, while in MASM only phase is changing, (ii) The randomization is function of the modulation order and the number of beams, while in MASM the randomization is mainly a function of the number of antennas. In [25] authors introduced a multi-directional secure communication system using direct antenna modulation technique based on antenna array and four state phase shifters (2 bit phase shifters). The authors demonstrate that using this method there are some transmission angels, so called angles of convergence, at which all the combinations of phase shifter state result in a reduced constellation points equal to $(\text{number of antennas} + 1)^2$. This technique also differs from MASM in (i) The randomization is function of the number phase shifter states, (ii) The receivers directions must coincide with the directions of angles of convergence, while in MASM the receivers can exist in any direction outside the main lobe of each other.

3.2 MASM Channel Model

Consider a transmitter equipped with a linear antenna array having N isotropic transmit antennas, which are uniformly spaced by d and N RF chains, each consists of a phase shifter, a power amplifier and an RF switch included to enable single beam transmission. The large antenna array is randomly partitioned in the symbol rate to subarrays that are allowed to overlap. Then, each subarray is used to transmit the same data securely to one of L target receivers located along Ldifferent azimuth angles θ_{T_l}, $l = 1, \dots, L$, each equipped with a single antenna; such that $N = L \times M$ where M is the number of antennas dedicated to each receiver that are randomly chosen at the symbol rate. For every symbol, the transmitter randomly forms L unique subsets each consists of M antennas from its N available antennas. In addition, the system adjusts the beam-forming network of every subset such that it transmits toward its dedicated receiver. An illustration for the system is shown in Figure 1.The elevation angle is not taken into consideration, since it is assumed that the array is positioned in x-y plane. Assuming a narrow band channel with perfect synchronization, the received signal along any direction θ can be expressed as:

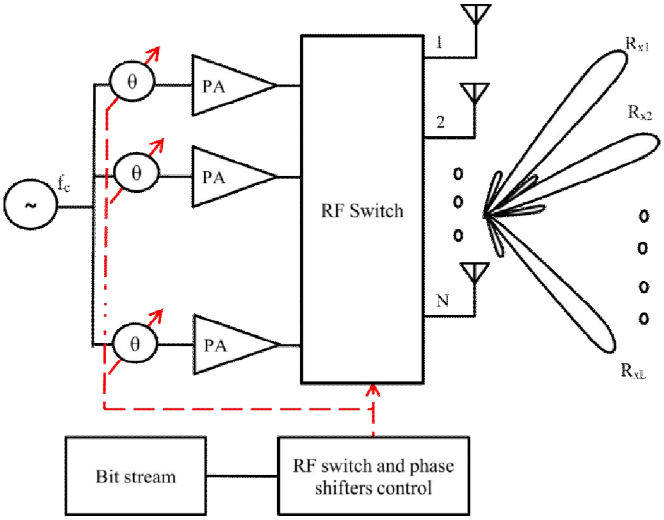

Figure 1: MASM System Architecture

$$Y(\theta) = \sum_{l=1}^{L} y_l(\theta) \tag{1}$$

Where $y_l(\theta)$ is the signal received from the l^{th} antenna subset, in noiseless case, and can be expressed as

$$y_l(\theta) = \boldsymbol{g_l}(\theta)^H \boldsymbol{x} \tag{2}$$

where $\boldsymbol{g_l}(\theta)^H$, $l = 1, \dots, L$, is $1 \times N$ channel vector for a receiver located along any arbitrary direction θ given by

$$\boldsymbol{g_l}(\theta)^H = [e^{-j\left(\frac{N-1}{2}\right)\frac{2\pi d}{\lambda}\cos(\theta)}, e^{-j\left(\frac{N-1}{2}-1\right)\frac{2\pi d}{\lambda}\cos(\theta)}, \dots \\ \dots, e^{j\left(\frac{N-1}{2}\right)\frac{2\pi d}{\lambda}\cos(\theta)}] \tag{3}$$

And $\boldsymbol{x}$ is $N \times 1$ transmit signal vector, for PSK signaling is given as

$$\boldsymbol{x} = \sqrt{E_s} e^{j\phi} \boldsymbol{v_l} \tag{4}$$

Where $\sqrt{E_s} e^{j\phi} \boldsymbol{v_l}$ is the transmitted symbol to the L different receivers, E_s is the energy per symbol and $\boldsymbol{v_l}$ is the weighting vector dedicated to the l^{th} antenna subset, given as

$$\boldsymbol{v_l} = \frac{1}{M} \boldsymbol{b_l} \circ \boldsymbol{g_l}(\theta_{T_l}) \tag{5}$$

Where $\boldsymbol{b_l}$, $l = 1, \dots, L$, is $N \times 1$ randomly chosen vector of zeros and ones such that $\|\boldsymbol{b_l}\|_1 = M$ and $\boldsymbol{b_i} \cdot \boldsymbol{b_j} = 0$. Where $\|\boldsymbol{z}\|_1$ stands for the $l_1$norm of the vector $\boldsymbol{z}$, $\boldsymbol{b_i} \cdot \boldsymbol{b_j}$ stands for the inner product of two vectors, and $\boldsymbol{A} \circ \boldsymbol{B}$ stands for Hadamard (entrywise) product.

As will be shown in the next simulation section for MASM with high signal to noise ratio transmission, the symbol error rate (SER) at a target receiver is dominated by the interference projected from the antennas subsets dedicated to other receivers. Hence, decreasing the interference level, sidelobe levels (SLL), will in turn leads to a lower SER. A lower interference can be achieved by choosing for each receiver the subsets with the minimum SLL property. Choosing antenna subset with minimum SLL can be accomplished by using heuristic search algorithms like simulated annealing (SA) [13], [26]. Instead of randomly choosing antenna subsets, a codebook with sufficient length of antenna subsets with minimum SLL is constructed using simulated annealing algorithm.

4. RESULTS AND DISCUSSIONS

In this section simulation results for randomized and optimized MASM is introduced and discussed. For sake of simplicity and without loss of generality, the results are shown for three beams MASM. The three target receivers are located along angles$\theta_{T_1} = 35^\circ$, $\theta_{T_2} = 90^\circ$ and $\theta_{T_3} = 145^\circ$, and N, M are chosen to be 120 and 40 respectively. In Figure 2, the symbol error rates (SER) of randomized MASM along the three desired angles and three undesired angles are plotted versus signal to noise ratio (SNR). It obvious from figure that a multi-directional secure communication is achieved along desired directions, while eavesdroppers along other directions receive the signal with high SER.

In Figure 3, SER of MASM with antenna subsets selection optimized using SA along a desired direction $\theta_{T_1} = 35^\circ$ is plotted versus SNR. Also, the SER for randomized MASM along desire angle $\theta_{T_1} = 35^\circ$ is shown on the same figure. It is evident from the figure that using SA optimization technique, the SER at target receivers is dramatically decreased.

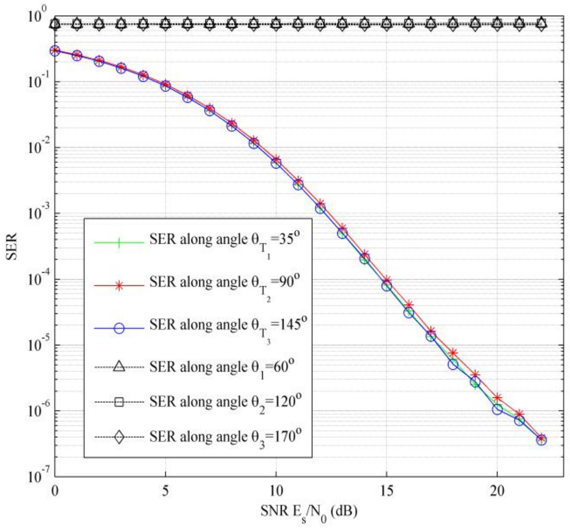

Figure 2: SER of randomized MASM along desire and undesired directions

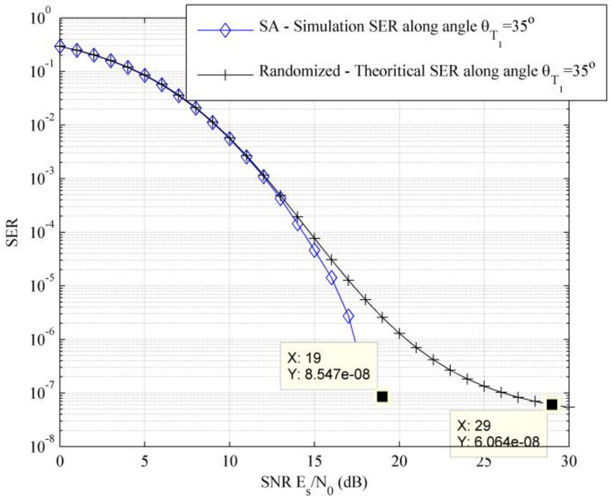

Figure 3: SER for MASM optimized using SA

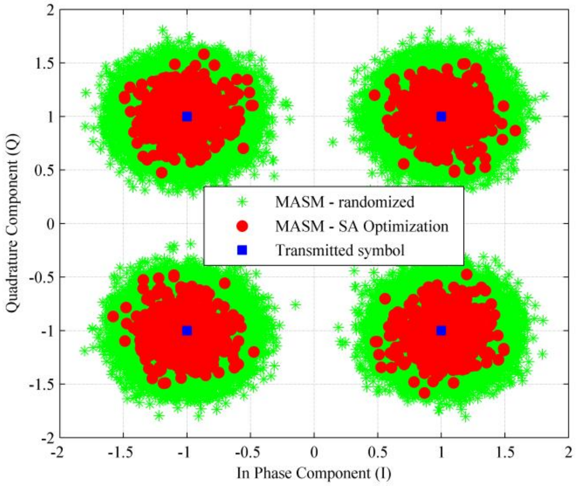

Figure 4: received signal constellation at target receiver

In Figure 4, the received signal constellation at a target receiver located along angle $\theta_{T_1} = 35^{\circ}$ for both randomized and optimized MASM. It is clear from the figure that using SA optimization technique the variance of signal is decreased which in turn reduces SER as previously illustrated in Figure 3.

5. CONCLUSION

In this work, a survey on ASM is introduced. A multi-directional version of ASM is proposed. Simulation results are used to demonstrate the difference in performance between two proposed antenna subsets selection techniques. Simulation results show that MASM achieve multi-directional secure communication. Also, results show that using optimization techniques to select antenna subsets with the minimum SLL achieves small received signal constellation variance along desired direction which in turn guarantees a smaller SER than randomized selection. Future work includes investigating the effect of increasing *M*, *L* and *N* on SER at target receivers. Also, deriving the statistical model and secrecy capacity is an interesting research area.

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