Phased-Array Transmission for Secure mmWave Wireless Communication via Polygon Mirror Flip

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Abstract—In this paper, a quick approach based on polygon mirror flip is presented and implemented for millimeter-wave secure communication. A known set of the transmitting weight vector is used to reconstruct the polygon, followed by a mirror flip operation. To ensure that the phase solution is possible, the mirror flip procedure employs the sum of the vector set as the mirror axis vector, ensuring that only the phase of the vector polygon is changed, not the size of its edges. This approach is similar to directional modulation (DM) in that it allows data to be received precisely at the predicted time but distorts it if it is received in an unexpected location. Furthermore, when a high number of transmitting antennas are present, the approach retains a short computation time.

I. Introduction

Millimeter-wave has been widely used in the Internet era due to its extremely wide bandwidth and free spectrum [1]–[3]. Even though millimeter-wave transmission is a new wireless transmission technique, it is just as vulnerable to eavesdropping as regular wireless systems, resulting in data loss. Physical Layer Secure (PLS) technology is a critical solution to this challenge [4]–[6].

In recent years, PLS technology has made great progress [7]–[18]. The authors of [10] [11] presented a phased-array-based DM approach for transmitting information by varying the weights of each antenna. The authors of [12] [13] presented a polygon-construction-based transmit weighting approach, which creates transmit weights in the multipath situation by generating polygons. The authors of [14] suggested an orthogonal vector approach for direction modulation, which is used in conjunction with the artificial noise concept to accomplish direction modulation.

Millimeter-wave has a short wavelength, allowing a high number of antennas to be integrated. A new technique called antenna subset modulation (ASM) is presented in [15], with the core notion of driving the antenna subset to modulate the beam pattern. The authors of [17] [18] formulated the SNR and SER of a subset of antennas to further improve the security performance of the system.

It is worth noting that only [12] can transmit data safely in the multi-path situation. When faced with a large number of antennas, however, the running time of the method in [12] for creating the transmit weight vector is long. In this paper, we present a method for quickly constructing the transmitting weight vector based on polygon mirror flip, which is based on the method in [12]. If a set of the transmitting weight vector is already known, the mirror flip operation can quickly generate a new transmitting weight vector, which can then be encrypted for transmission. Because the mirror flip operation only involves simple operations, the new weight vectors can be constructed fast, and the method is applicable in both single and multi-path scenarios.

II. Preliminaries

A. System model

Suppose there is a multiple-input single-output (MISO) system with N transmitting antennas and single receiving antenna. We consider a uniform linear array (ULA). The data is transmitted to the desired receiver (Bob) in the presence of Q potential eavesdroppers (Eves). The signals received by Bob and the q-th Eve at discrete time k are written by

$$y_d(k) = \mathbf{h}^{\mathrm{H}}\mathbf{x}(k) + \eta(k) \tag{1}$$

$$y_q(k) = \mathbf{g}_q^{\mathrm{H}}\mathbf{x}(k) + \nu_q(k),\ q = 1, \cdots, Q \tag{2}$$

where $\mathbf{h} \in \mathbb{C}^N$ is the channel vector between the transmitter and Bob, $\mathbf{g}_q$ represents the channel vector between the transmitter and the q-th Eve, $\mathbf{x}$ is the transmit signal vector, $\eta \sim \mathcal{CN}(0, \sigma_d^2)$ and $\nu_q \sim \mathcal{CN}(0, \sigma_q^2)$.

Consider an extended Saleh-Valenzuela geometric model with multipath channels, where the channel vector is

$$\mathbf{h} = \sqrt{1/L_d}\sum_{l=1}^{L_d}\alpha_l\mathbf{a}(\psi_l) \tag{3}$$

where L_d is the number of channel paths, $\alpha_l \sim \mathcal{CN}(0, 1)$ is the gain of the l-th path, ψ_l is the angle of departure (AoD) of the l-th path, $\mathbf{a}(\psi) \in \mathbb{C}^N$ represents the array response vector at ψ as

$$\mathbf{a}(\psi) = \left[1, e^{j2\pi d\sin(\psi)/\lambda}, \cdots, e^{j2\pi(N-1)d\sin(\psi)/\lambda}\right]^{\mathrm{T}} \tag{4}$$

where λ is the wavelength, d stands for the distance between adjacent sensors. The channel vector $\mathbf{g}_q$ has a similar expression to $\mathbf{h}$.

We consider a basic phased array system. The symbol received by Bob at time instant k is

$$y_d(k) = \mathbf{h}^{\mathrm{H}}\mathbf{w}(k)x(k) + \eta(k) \tag{5}$$

where $\mathbf{w}$ is the transmitting weight vector, $x(k) = \sqrt{E_s}e^{j\zeta(k)}$ is the modulated transmitting signal. $\sqrt{E_s}$

denotes the baseband modulation amplitude, $\zeta(k)$ is the phase value of the transmitted message.

The data emitted by the transmitting weight vector can be easily eavesdropped, hence the time-varying transmitting weight vector is required for system security.

B. Geometrical interpretation of solving the weight vector

Denote $\varphi_n = \angle w_n$ and $\vartheta_n = \angle h_n$, $n = 1, \cdots, N$. One can express $\mathbf{h}^{\mathrm{H}}\mathbf{w}$ as

$$\mathbf{h}^{\mathrm{H}}\mathbf{w} = \sum_{n=1}^{N} h_n^* e^{j\varphi_n} = \sum_{n=1}^{N} |h_n| e^{j(\varphi_n - \vartheta_n)} \tag{6}$$

where h_n represents the n-th entry of $\mathbf{h}$, $n = 1, \cdots, N$. Define

$$\phi_n \triangleq (\varphi_n - \vartheta_n)_{2\pi},\ n = 1, \cdots, N. \tag{7}$$

Then, a qualified weight vector $\mathbf{w}$ can be obtained by solving Equation (8) with respect to the phases $\phi_1, \cdots, \phi_N$:

$$\sum_{n=1}^{N} |h_n| e^{j\phi_n} = |h_0| \tag{8}$$

where $|h_0|$ is the beam gain at Bob. In the complex plane, $|h_n|e^{j\phi_n}$ in (8) corresponds to a vector, denoted as $\overrightarrow{|h_n|e^{j\phi_n}} \triangleq \left[\Re(|h_n|e^{j\phi_n}), \Im(|h_n|e^{j\phi_n})\right]^{\mathrm{T}}$. With this geometric concept, one can rewrite (8) as

$$\overrightarrow{|h_0|e^{j\phi_{0,\star}}} + \sum_{n=1}^{N} \overrightarrow{|h_n|e^{j\phi_n}} = \overrightarrow{\mathbf{0}} \tag{9}$$

where $\phi_{0,\star} \triangleq \pi$ is defined for the use convenience.

To solve Equation (9), the author of [12] proposed a method based on polygon construction to obtain the phase solution. We can obtain the ultimate φ_n once we know ϕ_n and ϑ_n, and the transmitting weight vector can be written as $\mathbf{w} = [e^{j\varphi_1}, \cdots, e^{j\varphi_N}]^{\mathrm{T}}$. Different from the polygon construction algorithm in [12], in this paper we present a new method for transmitting weight design via polygon mirror flip.

III. A Geometric Solution via Polygon Mirror Flip

A. Principle of polygon mirror flip

In general, any drawing can be flipped mirror image along one axis to produce a drawing with the same shape as the original. Assuming that there is a complex vector $\overrightarrow{|b|e^{j\phi}}$, its corresponding two-dimensional coordinate is expressed as $\mathbf{b} \triangleq [\Re(|b|e^{j\phi}), \Im(|b|e^{j\phi})]^{\mathrm{T}} = [b_R, b_I]^{\mathrm{T}}$, and the mirror axis is $\mathbf{c} = [c_R, c_I]^{\mathrm{T}}$. There exists a *householder* matrix, denoted as

$$\mathbf{H}_{2\times 2} = \mathbf{I} - 2\mathbf{u}\mathbf{u}^T \tag{10}$$

where

$$\mathbf{u} = [u_R, u_I]^{\mathrm{T}} = \frac{[-c_I, c_R]^{\mathrm{T}}}{\|\mathbf{c}\|} \tag{11}$$

The mirror vector of $\mathbf{b}$ with respect to $\mathbf{c}$ is $\mathbf{Hb}$. We define $\mathcal{T}_{\mathbf{c}}(\mathbf{b})$ as the mirror vector of $\mathbf{b}$ with respect to $\mathbf{c}$ because the mirror flip operation will be referenced multiple times later.

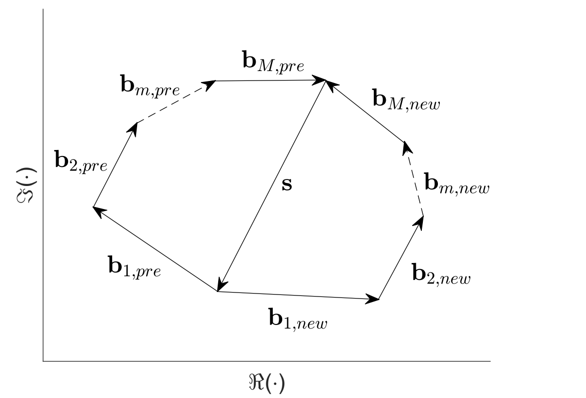


Fig. 1. Mirror flip operation

In the following, we will extend that to the case of numerous vectors. Suppose we know in advance that there is a set of vectors $\mathbf{b}_{pre} = [\mathbf{b}_{1,pre}^{\mathrm{T}}, \ldots, \mathbf{b}_{M,pre}^{\mathrm{T}}]_{2M\times 1}^{\mathrm{T}}$, where $\mathbf{b}_{m,pre}$ is the two-dimensional coordinate representation of the complex vector $\overrightarrow{|b_{m,pre}|e^{j\phi_{m,pre}}}$. $\mathbf{b}_{m,pre} \triangleq [\Re(|b_{m,pre}|e^{j\phi_{m,pre}}), \Im(|b_{m,pre}|e^{j\phi_{m,pre}})]^{\mathrm{T}}$, $\forall m \in \{1, \ldots, M\}$. Define a mirror axis vector as

$$\mathbf{s} = \sum_{m=1}^{M} \mathbf{b}_{m,pre} \tag{12}$$

To put it another way, the mirror axis is the vector sum of the complex vector group. After the mirror flip, the new vector group is

$$\begin{aligned}\mathbf{b}_{new} &= [\mathcal{T}_{\mathbf{s}}(\mathbf{b}_{1,pre})^{\mathrm{T}}, \ldots, \mathcal{T}_{\mathbf{s}}(\mathbf{b}_{M,pre})^{\mathrm{T}}]_{2M\times 1}^{\mathrm{T}} \\ &= [\mathbf{b}_{1,new}^{\mathrm{T}}, \ldots, \mathbf{b}_{M,new}^{\mathrm{T}}]^{\mathrm{T}}\end{aligned} \tag{13}$$

The sum of the new vector group is

$$\sum_{m=1}^{M} \mathcal{T}_{\mathbf{s}}(\mathbf{b}_{m,pre}) \tag{14}$$

The sum of the complex vector sets after the mirror flip is still $\mathbf{s}$ since the mirror flip operation only changes the direction of the original vector, not its size. Figure 1 can likewise be used to make the relevant conclusion, i.e.

$$\sum_{m=1}^{M} \mathcal{T}_{\mathbf{s}}(\mathbf{b}_{m,pre}) = \mathbf{s} = \sum_{m=1}^{M} \mathbf{b}_{m,pre} \tag{15}$$

To summarize, the mirror flip operation allows the discovery of novel phase solutions by altering the direction of each vector without changing the total size of its vector group.

B. Construct weight vector via polygon mirror flip

Following the system model and associated notation in Section II, the complex vector group of $\mathbf{h}$ and $\mathbf{w}$ can be expressed as

$$\widetilde{\mathbf{v}}_{pre} = [\mathbf{v}_{1,pre}^{\mathrm{T}}, \ldots, \mathbf{v}_{N,pre}^{\mathrm{T}}]_{2N\times 1}^{\mathrm{T}} \tag{16}$$

where $\mathbf{v}_{n,pre}$ is the two-dimensional coordinate representation of $\overrightarrow{|h_n|e^{j\phi_n}}$, $\mathbf{v}_{n,pre} \triangleq \left[\Re(|h_n|e^{j\phi_n}), \Im(|h_n|e^{j\phi_n})\right]^{\mathrm{T}} = [v_{n,pre,R}, v_{n,pre,I}]^{\mathrm{T}}$, $\phi_{n,pre} = (\varphi_n + \vartheta_n)_{2\pi},\ n = 1, \cdots, N$. Based on the preceding conclusions, we only need to perform a mirror flip operation on the set of complex vectors in (9) to obtain a new set of weighted phase solutions. Specify the mirror axis vector as

$$\widetilde{\mathbf{s}} = \sum_{n=1}^{N} \mathbf{v}_{n,pre} \tag{17}$$

where $\widetilde{\mathbf{s}}$ is the two-dimensional coordinate representation of $\overrightarrow{\sum_{n=1}^{N} |h_n|e^{j\phi_n}}$. After the mirror flip, the new complex vector group is

$$\widetilde{\mathbf{v}}_{new} = [\mathcal{T}_{\widetilde{\mathbf{s}}}(\mathbf{v}_{1,pre})^{\mathrm{T}}, \ldots, \mathcal{T}_{\widetilde{\mathbf{s}}}(\mathbf{v}_{N,pre})^{\mathrm{T}}]_{2N\times 1}^{\mathrm{T}} \tag{18}$$

The new phase solution, according to the above mirror flip theory, still satisfies Equation (9). So the new phase solution of the weight vector is denoted as

$$\widetilde{\varphi}_{n,new} = (\widetilde{\phi}_{n,new} + \vartheta_n)_{2\pi},\ n = 1, \cdots, N. \tag{19}$$

As a result, the new weight vector can be built as $\widetilde{\mathbf{w}}_{new} = [e^{j\widetilde{\varphi}_{1,new}}, \cdots, e^{j\widetilde{\varphi}_{N,new}}]^{\mathrm{T}}$.

By mirror flipping the complete collection of complex vectors, the approach above creates a new weight vector. However, with this strategy, we can only get one set of solutions, and we require various weight vectors at time instant k.

Since the mirror flip operation does not transform the size and vector sum of the complex vector group, we envisage grouping $\mathbf{v}_{pre} = [\mathbf{v}_{1,pre}^{\mathrm{T}}, \ldots, \mathbf{v}_{N,pre}^{\mathrm{T}}]_{2N\times 1}^{\mathrm{T}}$ and then mirror flipping each group of complex vectors separately, using the vector sum of each group as the mirror axis. Each group gets a new phase in this way, as long as the total of the final vectors stays the same. The number of groups and vectors in each group are fully random throughout the procedure, hence the final phase solution is completely random as well.

To start, we partition the $\mathbf{v}_{pre}$ into K groups, with $\mathbf{v}_{pre}^{(k)} = [\mathbf{v}_1^{(k)\,\mathrm{T}}, \ldots, \mathbf{v}_{L_k}^{(k)\,\mathrm{T}}]^{\mathrm{T}}$ being the k-th group. The mirror axis vector of the k-th group can be written as

$$\mathbf{s}_k = \sum_{L_k=1}^{L_k} \mathbf{v}_{L_k}^{(k)}, L_k \geq 2, k = 1, \ldots, K. \tag{20}$$

Then the *householder* matrix of the k-th group is:

$$\mathbf{H}_{2\times 2}^{(k)} = \mathbf{I} - 2\mathbf{u}\mathbf{u}^{\mathrm{T}} \tag{21}$$

where

$$\mathbf{u} = [u_R, u_I]^{\mathrm{T}} = \frac{[-s_{k,I}, s_{k,R}]^{\mathrm{T}}}{\|\mathbf{s_k}\|} \tag{22}$$

After the mirror flip, the new complex vector group is

$$\begin{aligned}\mathbf{v}_{new}^{(k)} &= [\mathbf{I}_{L_k} \otimes \mathbf{H}_{2\times 2}^{(k)}]\mathbf{v}_{pre}^{(k)} \\ &= [\mathcal{T}_{\mathbf{s}_k}(\mathbf{v}_1^{(k)})^{\mathrm{T}}, \ldots, \mathcal{T}_{\mathbf{s}_k}(\mathbf{v}_{L_k}^{(k)})^{\mathrm{T}}]^{\mathrm{T}} \\ &\sum_{k=1}^{K} L_k = N,\ L_k \geq 2,\ k = 1, \ldots, K.\end{aligned} \tag{23}$$

Given that the new phase is solved by grouping and then mirror flipping, the grouped vectors must be combined in their original order. To make things easier, we will use a permutation matrix to group the entire set of vectors, then do a mirror flip, and finally utilize the permutation matrix to finish the order reset.

Assume we have a permutation matrix $\mathbf{P}$, so that the grouping operations can be simplified to

$$\begin{aligned}\mathbf{P}\mathbf{v}_{pre} &= \mathbf{P}[\mathbf{v}_{1,pre}^{\mathrm{T}}, \ldots, \mathbf{v}_{N,pre}^{\mathrm{T}}]^{\mathrm{T}} \\ &= [\mathbf{v}_{pre}^{(1)\,\mathrm{T}}, \mathbf{v}_{pre}^{(2)\,\mathrm{T}}, \ldots, \mathbf{v}_{pre}^{(K)\,\mathrm{T}}]^{\mathrm{T}}\end{aligned} \tag{24}$$

The overall mirror matrix can be written as

$$\mathbf{Y} = \begin{bmatrix} \mathbf{I}_{L_1} \otimes \mathbf{H}_{2\times 2}^{(1)} & \mathbf{0} & \ldots & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_{L_2} \otimes \mathbf{H}_{2\times 2}^{(2)} & \ldots & \mathbf{0} \\ \vdots & \vdots & \ddots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \ldots & \mathbf{I}_{L_K} \otimes \mathbf{H}_{2\times 2}^{(K)} \end{bmatrix} \tag{25}$$

$\mathbf{Y}\mathbf{P}\mathbf{v}_{pre}$ is the matrix following the mirror flip. A last sequential recovery is required for the entire, so the final new complex vector group is

$$\mathbf{v}_{new} = \mathbf{P}^{\mathrm{T}}\mathbf{Y}\mathbf{P}\mathbf{v}_{pre} \tag{26}$$

$$= [\mathbf{v}_{1,new}^{\mathrm{T}}, \ldots, \mathbf{v}_{N,new}^{\mathrm{T}}]^{\mathrm{T}} \tag{27}$$

where $\mathbf{v}_{n,new}$ is the two-dimensional coordinate representation of $\overrightarrow{|h_{n,new}|e^{j\phi_{n,new}}}$, $\phi_{n,new} = \angle\mathbf{v}_{n,new}$. As a result, the weight vector's new phase solution is denoted as

$$\varphi_{n,new} = (\phi_{n,new} + \vartheta_n)_{2\pi},\ n = 1, \cdots, N. \tag{28}$$

Eventually, $\mathbf{w}_{new} = [e^{j\varphi_{1,new}}, \cdots, e^{j\varphi_{N,new}}]^{\mathrm{T}}$ is the new collection of weight vectors. To summarize the preceding procedure, the new set of various weight vectors is created by mirror flipping the set of different retest groups. We summarize the process for calculating Equation (9) based on the mirror flip of the polygon in Algorithm 1 to make the preceding discussion clear. The number of groups and the vectors in the groups are fully random in the mirror flipping process, hence the final set of weight vectors is likewise completely random.

Algorithm 1 : Geometric Solution via Polygon Mirror Flip

Input: $\{h_0, h_1, \cdots, h_N\}, \{w_1, w_2, \cdots, w_N\}$
Initialize: $\vartheta_n = \angle h_n$, $\varphi_n = \angle w_n$, $\phi_n = (\varphi_n - \vartheta_n)$, $sum = 0$. $\mathbf{v} = [\mathbf{v}_1^{\mathrm{T}}, \ldots, \mathbf{v}_N^{\mathrm{T}}]^{\mathrm{T}}$, where $\mathbf{v}_n \triangleq [\Re(|h_n|e^{j\phi_n}), \Im(|h_n|e^{j\phi_n})]^{\mathrm{T}}$. Randomly set integer k, $k \in (0, n/2)$.
Set k random numbers, denoted as $n_1, \ldots, n_k, \sum_{k=1}^{k} n_k = N$
Randomly set permutation matrix $\mathbf{P}_{N\times N}$
$\mathbf{v}_{sort} = \mathbf{P}\mathbf{v}$
for $i = 1, 2, \cdots, k$ do
    if $sum <= N$ then
        $\mathbf{v}^{(k)} = \mathbf{v}_{sort}(sum : sum + n_k) = [\mathbf{v}_1^{(k)\,\mathrm{T}}, \ldots, \mathbf{v}_{L_k}^{(k)\,\mathrm{T}}]^{\mathrm{T}}$
        $sum = sum + n_k$
        $\mathbf{s}_k = \sum_{L_k=1}^{L_k} \mathbf{v}_{L_k}^{(k)}$
        $\mathbf{H}_{2\times 2}^{(k)} = \mathbf{I} - 2\mathbf{u}\mathbf{u}^T$, $\mathbf{u} = \dfrac{[-s_{k,I}, s_{k,R}]^{\mathrm{T}}}{\|\mathbf{s_k}\|}$
    end if
end for
Construct an overall mirror matrix $\mathbf{Y}$
$\mathbf{v}_{new} = \mathbf{P}^T\mathbf{Y}\mathbf{P}\mathbf{v}$
$\phi_{n,new} = \angle \mathbf{v}_{n,new}$, $\varphi_{n,new} = (\phi_{n,new} + \vartheta_n)_{2\pi}$
Output: $\{\varphi_{1,new}, \ldots, \varphi_{N,new}\}$

IV. Numerical Results

In this section, we will use the proposed method to construct a weight vector for transmitting data for simulation. The simulation results prove the effectiveness and rapidity of our proposed algorithm. We use a 15-element ULA and consider multi-path mmWave channels described in (3). Assume that the AoD of each path is uniformly distributed at $[0, \pi]$. For simplicity, we set $\sqrt{E_s} = 1$ and $|h_0| = 4$. To demonstrate the proposed algorithm's performance, we compare it to the polygonal construction method in the literature [12].

A. Constellation synthesis results for the proposed algorithm

We first consider the security of the algorithm when transmitting data. In this simulation, we focus on two Eves and a Bob just for sake of generality. The polygon construction method, which we described earlier, is used to develop the initial solutions. The polygon mirror flip method was used to generate the next set of solutions, and once the initial solution was established, additional solutions were continuously generated to propagate the symbols. We used 1000 time instants and different modulation approaches.

To begin, we ran simulations with QPSK modulation. Figure 2(a) shows the constellations that were received without any noise. Bob's composite constellation is shown by the red dots, while the green and blue dots represent the first and second Eve constellations, respectively. As shown

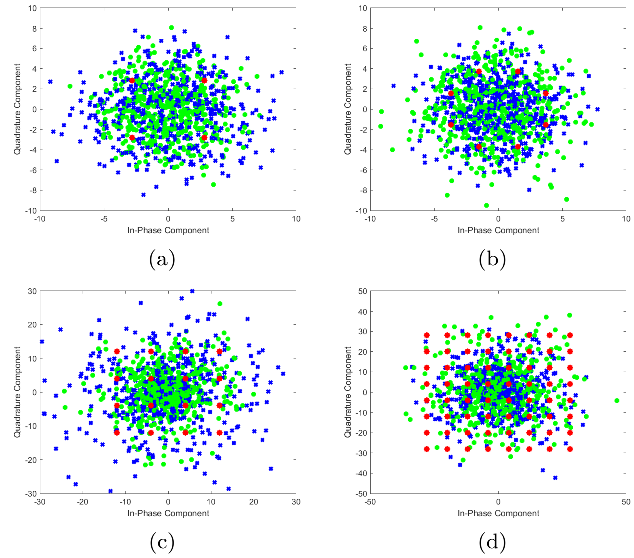


Fig. 2. Noiseless received constellations at Bob and Eves with different modulation methods. (The red color points represents Bob's composite constellation, the green and blue ones represent the constellation of the first Eve and the second Eve.) (a) QPSK modulation. (b) 8-PSK modulation. (c) 16-QAM modulation. (d) 64-QAM modulation.

in Figure 2(a), only four points were synthesized by Bob and the resulting constellation was not distorted, while the constellation generated by Eves was completely random, making it difficult for Eves to extract this information.

Following that, we added 8-PSK and QAM modulation to the simulations. Figures 2(b), 2(c), and 2(d) show the simulation results, which show that the method works well to distort the constellation of Eves and achieve secure data transfer even when different modulation schemes are used.

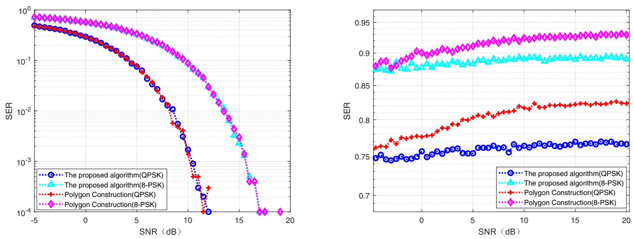
B. Security performance of the proposed algorithm

In this subsection, we will consider an Eve and study the security performance of the proposed algorithm. For comparison, we include the polygon construction method. To study the security performance of the proposed algorithm, we used SER simulation. The simulated SERs at Bob with different algorithms is shown in Figure 3(a) with signal-to-noise ratios ranging from -10dB to 30dB using QPSK and 8-PSK modulation, respectively. The SERs for the 8-PSK modulation in the proposed algorithm are slightly larger than those for the QPSK modulation due to the modulation mechanism, similar to the polygon construction method.

Figure 3(b) shows the simulated SERs for Eve, and we can see that, similar to the polygon construction approach, the proposed algorithm consistently maintains a high SER for each modulation method, showing that the suggested algorithm's safety performance is fairly good.

C. Computational performance of the proposed algorithm

In this subsection, we will discuss the computational performance of the proposed algorithm. Despite the fact



(a) (b)

Fig. 3. SER simulation results for Bob and Eve with QPSK and 8PSK modulation. (a) Bob. (b) Eve.

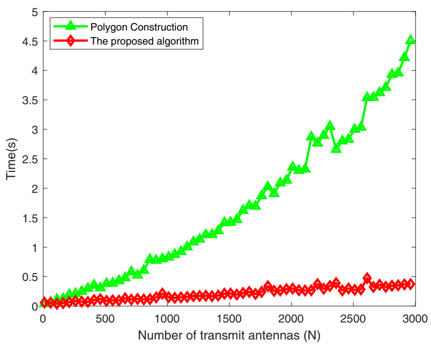


Fig. 4. Time comparison of different algorithms

that our proposed algorithm is based on the polygon construction method, it should take significantly less time to compute than the polygon construction method because it only contains basic operations.

In this simulation, we set the time instants to 200 and the number N to a range of 20 to 3000 in steps of 20, and we measured the time it took both algorithms to transfer the data. Figure 4 depicts the simulation findings received. The time spent on the Polygon Construction method is represented by the red line in the graph, while the time spent on the proposed approach is represented by the green line. The running time of the polygon creation approach steadily grows as N increases, much more than the time of the proposed algorithm, as shown in Figure 4. Furthermore, the proposed algorithm's time does not considerably raise as N increases, demonstrating the proposed algorithm's outstanding computing performance.

V. Conclusion

In this paper, the polygon mirror flip method is proposed as a new weight vector production method. Because the mirror flip operation only changes the phase of the vector and not its magnitude, the sum of the vector group is utilized as the mirror axis, allowing each mirror operation to yield a new phase solution. Furthermore, employing the polygon mirror flip method to transmit data reduces the risk of being eavesdropped greatly. It's worth mentioning that the proposed polygon mirror flip approach outperforms the polygon construction method in terms of computational performance and enables rapid weight vector synthesis even in the scenario of large-scale antenna array.

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