# Power Minimization in Artificial Noise Aided Generalized Spatial Modulation

Hong Niu, Xia Lei, Yue Xiao, Donglin Liu, You Li, and Hongyan Zhang

***Abstract*— Artificial noise (AN) has been proposed as an efficient way to improve the physical security of multiple input multiple output (MIMO) systems at the cost of power efficiency. In this letter, we first introduce AN to generalized spatial modulation (GSM) systems, which has never been reflected in the previous researches. Besides, a novel power minimization (PM) design for AN aided GSM is proposed, aiming at improving the power efficiency while maintaining the jamming effect of AN. We analyze the power optimization ratio of this PM aided AN (PM-AN) scheme. Moreover, we derive the theoretical bounds of the average bit error rate (BER) for the legitimate receiver and eavesdropper over fading channels. Simulation results validate our derived theoretical bounds and prove that the PM-AN scheme outperforms its conventional AN counterpart with higher reliability and higher security.**

***Index Terms*— Artificial noise (AN), generalized spatial modulation (GSM), power minimization (PM).**

## I. Introduction

SPATIAL modulation (SM) [1], [2], where both the index of the activated antenna and the amplitude phase modulation (APM) are utilized for conveying information, has been introduced as a novel low-complexity multiple-input multiple-output (MIMO) approach. Furthermore, toward a higher bandwidth efficiency, generalized spatial modulation (GSM) [3]–[5] relies on increased number of radio frequency (RF) chains, as a specific extension of SM. More explicitly, the information bits of GSM are conveyed by the index of the activated antenna combination and the APM symbols. Substantial studies have disclosed that both SM and GSM have potential opportunities to become the candidates for future wireless transmission [6]–[9].

Meanwhile, inspired by potential information leakage risk [10] in MIMO systems, substantial researchers utilized artificial noise (AN) [11], [12] as an efficient transmission approach to improve the physical-layer security. Specifically, [13] investigated how to guarantee a positive secrecy capacity with AN using limited feedback. The authors of [14] derived the secrecy rate of AN aided MIMO and proposed the optimal power allocation scheme by maximizing the secrecy rate. For both perfect and imperfect channel state information (CSI), the AN aided precoding schemes were designed in [15].

As a specific extension of MIMO systems, SM also faces the risk of information leakage. To alleviate this problem, several current researches have introduced AN to SM systems. Specially, the authors of [16] proposed secure unitary coded spatial modulation (UC-SM), which uses two different time slots to eliminate the effect of AN, but causes the reduction of spectral efficiency. Moreover, another artificial-noise-aided spatial modulation (AN-SM) system was investigated in [17]. In conventional SM [18], only one antenna is activated, thus only one active RF chain is required at the transmitter. In order to improve the security of SM, AN-SM [17] adds AN to all the transmit antennas, which implies that all the transmit antennas are required to be activated otherwise the interfere of AN cannot be eliminated. Due to the introduction of AN in the SM system, the number of active antennas increases, which is even larger than that of the GSM system. In addition, the AN aided space-time shift keying (AN-STSK) system was designed in [19] as an extension of AN-SM, but it also introduces extra RF chains. In order to further improve the security of pre-coding aided spatial modulation (PSM), secret PSM (SPSM) was considered in [20] and its bit error rate (BER) performance was analyzed in [21]. Compared with SM and GSM, PSM uses pre-coding technology to improve the system reliability at the cost of increased active antenna numbers and higher complexity at the transmitter. In general, the latest research in literature has not sufficiently considered the design of artificial noise aided GSM, which guarantees the system security with high spectral efficiency and has a lower RF chain hardware requirement at the transmitter than AN-SM and SPSM.

On the other hand, the conventional AN using complex Gaussian random matrix occupies a considerable ratio of power that could be allocated to the effective signals, which causes the reduction of power efficiency. The latest research has not considered to solve the power waste of AN by designing the random matrix.

Against this background, this letter has the following contributions. Firstly, we introduce an artificial noise aided GSM (AN-GSM) system, which maintains the same number of RF chains as conventional GSM and solves the problem of extra RF chain resource waste in AN-SM systems. Secondly, we propose a power minimization (PM) design to further optimize AN-GSM. The PM aided AN (PM-AN) scheme improves the power of effective signal and maintains a considerable jamming effect to eavesdroppers, which outperforms its conventional AN counterpart. Finally, the theoretical average BER bounds of the proposed PM-AN scheme are derived.

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The authors are with the National Key Laboratory of Science and Technology on Communications, University of Electronic Science and Technology of China, Chengdu 611731, China (e-mail: leixia@uestc.edu.cn; xiaoyue@uestc.edu.cn).

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The simulation results are displayed to validate our analytical bounds and the outstanding performance of the PM-AN scheme.

*Notation*: In the following, bold lower-case and upper-case letters denote vectors and matrices, respectively. $(\cdot)^H$, $(\cdot)^{-1}$ and $\mathrm{E}(\cdot)$ represent the conjugate transpose, matrix inverse and expectation, respectively. $\|\cdot\|$ and $\lfloor\cdot\rfloor$ indicate the norm and floor operations, respectively. $\begin{pmatrix}\cdot\\\cdot\end{pmatrix}$ and $\otimes$ stand for the binomial and Kronecker products, respectively. $\mathrm{I}_N$ and $\mathbb{C}$ are taken to mean the $N \times N$ identity matrix and the complex number field. $N\left(0,\sigma^2\right)$ represents the real Gaussian distribution with zero mean and $\sigma^2$ variance. Finally, the complex Gaussian distribution with zero mean and $\sigma^2$ variance is denoted by $CN\left(0,\sigma^2\right)$.

## II. System Model

Consider a point-to-point communication system, which employs $N_a$ active RF chains out of $N_t$ antennas at the transmitter (Alice) and $N_r$ $(N_r < N_a)$ antennas at the legitimate receiver (Bob). If Bob is equipped with $N_R\,(N_R \geqslant N_a)$ antennas, antenna selection (AS) schemes [22] can be used to select $N_r$ out of $N_R$ antennas and can achieve a higher diversity order. This system is wiretapped by the eavesdropper (Eve) with $N_e$ antennas. Besides, we assume that Bob is capable of obtaining the perfect knowledge of CSI and can ideally feedback it to Alice.

### A. Conventional GSM System Model

The information bits of the conventional GSM are conveyed by two kinds of modulation, which can be expressed as

$$\eta = \eta_l + \eta_s = \left\lfloor \log_2 \begin{pmatrix} N_t \\ N_a \end{pmatrix} \right\rfloor + N_a \log_2 M, \tag{1}$$

where the first $\eta_l$ bits determine the index set of active RF pattern $\mathbf{x}_{l_x} = [x_1, x_2, \cdots, x_{N_a}]^T$ $(\mathbf{x}_{l_x} \in \mathbf{X} = \{\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_\gamma\}, \gamma = 2^{\eta_l})$, and the rest $\eta_s$ bits are mapped to the set of $M$-ary APM symbols $\mathbf{s}^i = [s_1, s_2, \cdots, s_{N_a}]$ $(\mathbf{s}^i \in \mathbf{S} = \{\mathbf{s}^1, \mathbf{s}^2, \cdots \mathbf{s}^\rho\}, \rho = 2^{\eta_s})$. Therefore, the transmit vector in each channel use can be expressed as

$$\mathbf{s}_{l_x}^i = \sum_{l=1}^{N_a} \mathbf{e}_{x_l} s_l, \tag{2}$$

where $x_l$ is the index of the $l$-th active antenna, $\mathbf{e}_{x_l}$ refers to the $x_l$ columns of $N_t$-sized identity matrix and denotes that the $x_l$-th antenna is activated, $s_l$ represents the APM symbol conveyed on the $l$-th active antenna.

Thus, for a Rayleigh fading channel, the signals received by Bob $\mathbf{y}$ and Eve $\mathbf{z}$ are given as

$$\mathbf{y} = \mathbf{H}\mathbf{s}_{l_x}^i + \mathbf{u} = \mathbf{H}_{l_x}\mathbf{s}^i + \mathbf{u}, \tag{3}$$
$$\mathbf{z} = \mathbf{G}\mathbf{s}_{l_x}^i + \mathbf{v} = \mathbf{G}_{l_x}\mathbf{s}^i + \mathbf{v}, \tag{4}$$

where $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$ and $\mathbf{G} \in \mathbb{C}^{N_e \times N_t}$ denote the channel matrix of Alice-Bob and Alice-Eve, their entries obey complex Gaussian distribution $CN(0,1)$, respectively, $\mathbf{u} \in \mathbb{C}^{N_r \times 1}$ and $\mathbf{v} \in \mathbb{C}^{N_e \times 1}$ represent the complex white Gaussian noise vectors, whose independent and identically distributed elements follow zero mean and $\sigma_u^2$ and $\sigma_v^2$ variances, respectively, $\mathbf{H}_{l_x} = \mathbf{H}(:, \mathbf{x}_{l_x})$, $\mathbf{G}_{l_x} = \mathbf{G}(:, \mathbf{x}_{l_x})$ refers to the activated channel vector, respectively, $\mathbf{x}_{l_x} = [x_1, x_2, \cdots, x_{N_a}]^T$, where $x_i$ is the index of the $i$-th active antenna.

Followed from (3) and (4), the detection of Bob and Eve can be respectively formulated through the ML criterion as

$$\left\langle \hat{l}_x, \hat{i} \right\rangle = \arg \min_{\hat{\mathbf{s}}^i \in \mathbf{S}, \mathbf{x}_{l_x} \in \mathbf{X}} \left\| \mathbf{y} - \mathbf{H}_{l_x}\mathbf{s}^i \right\|^2, \tag{5}$$
$$\left\langle \hat{l}_x, \hat{i} \right\rangle = \arg \min_{\hat{\mathbf{s}}^i \in \mathbf{S}, \mathbf{x}_{l_x} \in \mathbf{X}} \left\| \mathbf{z} - \mathbf{G}_{l_x}\mathbf{s}^i \right\|^2. \tag{6}$$

### B. Artificial-Noise-Aided GSM System Model

It follows from Eq. (5) that Eve can decode the information bits on the assumption of having the knowledge of $\mathbf{G}$, which can be perfectly achieved by a capable eavesdropper. Thus, AN-GSM is proposed as a secure communication scheme by generating time-varying AN on active RF chains, which has no impact on Bob, but creates interference to Eve.

The null space can be obtained by the singular value decomposition of $\mathbf{H}_{l_x}$ as follows

$$\mathbf{H}_{l_x} = \mathbf{U} \begin{bmatrix} \mathbf{D} & 0 \end{bmatrix} \begin{bmatrix} \mathbf{V}_1 & \mathbf{V}_0 \end{bmatrix}^H, \tag{7}$$

where $\mathbf{V}_0 \in \mathbb{C}^{N_a \times (N_a - N_r)}$ denotes the null space of $\mathbf{H}_{l_x}$, i.e., $\mathbf{H}_{l_x}\mathbf{V}_0 = 0$. For keeping the same RF chains as conventional GSM, a zero matrix $\mathbf{V} \in \mathbb{C}^{N_t \times (N_a - N_r)}$ is primarily defined. Next, some elements are replaced through the following methods

$$\mathbf{V}(\mathbf{x}_{l_x}, :) = \mathbf{V}_0, \tag{8}$$

where $\mathbf{x}_{l_x} = [x_1, x_2, \cdots, x_{N_a}]^T$ is defined in section II. A, and $x_i$ is the index of the $i$-th active antenna. With the aid of (8), AN is only added to the index set of active antennas.

Finally, the transmit vector of AN-GSM is comprised of conventional GSM part and AN part

$$\tilde{\mathbf{s}}_{l_x}^i = \sqrt{\theta}\mathbf{s}_{l_x}^i + \mathbf{V}\mathbf{r}, \tag{9}$$

where $\theta$ is a power allocation coefficient, which represents the power ratio of effective signals, $\mathbf{r} \in \mathbb{C}^{(N_a - N_r) \times 1}$ denotes a random Gaussian vector, whose elements follow independent and identically distribution of zero mean and $\sigma_r^2 = \frac{(1-\theta)N_a}{N_a - N_r}$ variance.

Thus, the receive vector of Bob and Eve can be formulated as follows, respectively,

$$\mathbf{y} = \mathbf{H}\tilde{\mathbf{s}}_{l_x}^i + \mathbf{u} = \mathbf{H}\left(\sqrt{\theta}\mathbf{s}_{l_x}^i + \mathbf{V}\mathbf{r}\right) + \mathbf{u} = \sqrt{\theta}\mathbf{H}_{l_x}\mathbf{s}^i + \mathbf{u}, \tag{10}$$
$$\mathbf{z} = \mathbf{G}\left(\sqrt{\theta}\mathbf{s}_{l_x}^i + \mathbf{V}\mathbf{r}\right) + \mathbf{v} = \sqrt{\theta}\mathbf{G}_{l_x}\mathbf{s}_i + \mathbf{G}_{l_x}\mathbf{V}_0\mathbf{r} + \mathbf{v}. \tag{11}$$

Even if Eve have the perfect knowledge of $\mathbf{G}$, the ML detector based on (11) can only be given as

$$\left\langle \hat{l}_x, \hat{i} \right\rangle = \arg \min_{\hat{\mathbf{s}}^i \in \mathbf{S}, \mathbf{x}_{l_x} \in \mathbf{X}} \left\| \mathbf{z} - \sqrt{\theta}\mathbf{G}_{l_x}\mathbf{s}^i \right\|^2. \tag{12}$$

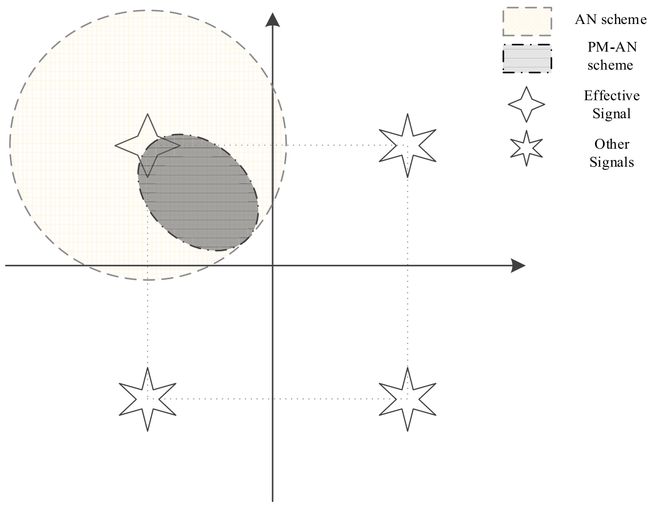


Fig. 1. Diagram of the difference between conventional AN and PM-AN.

### C. Proposed Power Minimization Scheme

For conventional AN schemes, $\mathbf{r}$ is arbitrarily determined as a Gaussian random vector, which results in unnecessary power waste. In this section, the PM-AN scheme is proposed through minimizing the total transmit power, which also guarantees the security of GSM systems on a considerable assumption that Eve does not know $\mathbf{H}$. Fig. 1 outlines the illustration of the difference between the conventional AN and the proposed PM-AN scheme. For a given effective signal $\mathbf{s}^i$ and a specific $\mathbf{V}_0$, the PM-AN scheme is first expressed as

$$\begin{aligned}&\min_{\mathbf{r}} \ \left\|\mathbf{s}^i+\mathbf{V}_0\mathbf{r}\right\|^2\\ &\text{s.t. } r_i\in\mathbb{C},\forall i=1,2,\cdots,(N_a-N_r),\end{aligned} \tag{13}$$

where $r_i$ represents the $i$-th elements of $\mathbf{r}$. In order to obtain the optimal solution of the above formula, we first should construct the objective function as follows

$$J(\mathbf{r})=\frac{1}{2}\left(\mathbf{s}^i+\mathbf{V}_0\mathbf{r}\right)^H\left(\mathbf{s}^i+\mathbf{V}_0\mathbf{r}\right). \tag{14}$$

Then we derive it to obtain the expression of gradient as

$$\nabla J(\mathbf{r})=\mathbf{r}+\mathbf{V}_0{}^H\mathbf{s}^i. \tag{15}$$

Furthermore, $\mathbf{r}$ can be achieved by making the gradient to zero as

$$\mathbf{r}=-\mathbf{V}_0{}^H\mathbf{s}^i. \tag{16}$$

Equipped with the PM-AN scheme, the average transmit power can be derived as

$$\mathrm{E}\left\{\left\|\mathbf{s}^i-\mathbf{V}_0\mathbf{V}_0^H\mathbf{s}^i\right\|^2\right\}=tr\left(\mathbf{I}-\mathbf{V}_0\mathbf{V}_0^H\right)\ =N_r. \tag{17}$$

Compared with conventional GSM, where $\mathrm{E}\left\{\left\|\mathbf{s}^i\right\|^2\right\}=N_a$, the PM-AN scheme reduces the ratio of $(N_a-N_r)/N_a$ for the transmit power. Therefore, the normalized transmit symbols can be expressed as

$$\tilde{\mathbf{s}}^i=\beta\left(\mathbf{I}-\mathbf{V}_0\mathbf{V}_0^H\right)\mathbf{s}^i, \tag{18}$$

where $\beta=\sqrt{\frac{N_a}{N_r}}$ denotes the power normalization factor. Finally, the receive vectors of Bob and Eve can be given as, respectively,

$$\mathbf{y}=\beta\mathbf{H}_{l_x}\mathbf{s}^i+\mathbf{u}, \tag{19}$$

$$\mathbf{z}=\beta\mathbf{G}_{l_x}\mathbf{s}^i-\mathbf{G}_{l_x}\mathbf{V}_0\mathbf{V}_0^H\mathbf{s}^i+\mathbf{v}. \tag{20}$$

## III. BER Performance Analysis

### A. BER Performance of Bob

In this section, the average BER for Bob in the proposed PM-AN scheme is upper bounded by the union bound criterion [23], which can be written as

$$P_b\leqslant\frac{1}{\eta 2^\eta}\sum_{l_x,i}\sum_{l_y,m}d\left(\mathbf{s}_{l_x}^i,\mathbf{s}_{l_y}^m\right)\mathrm{E}_{\mathbf{H}}\left\{P\left(\mathbf{s}_{l_x}^i\to\mathbf{s}_{l_y}^m\,|\mathbf{H}\right)\right\}, \tag{21}$$

where $d\left(\mathbf{s}_{l_x}^i,\mathbf{s}_{l_y}^m\right)$ denotes the Hamming distance between $\mathbf{s}_{l_x}^i$ and $\mathbf{s}_{l_y}^m$. Moreover, $\mathrm{E}_{\mathbf{H}}\left\{P\left(\mathbf{s}_{l_x}^i\to\mathbf{s}_{l_y}^m\,|\mathbf{H}\right)\right\}$ represents the average pairwise error probability (PEP) of transmitting $\mathbf{s}_{l_x}^i$ but decoding as $\mathbf{s}_{l_y}^m$ over $\mathbf{H}$.

The instantaneous PEP can be derived based on (19) as

$$\begin{aligned}&P\left(\mathbf{s}_{l_x}^i\to\mathbf{s}_{l_y}^m\,|\mathbf{H}\right)\\ &=P\left(\left\|\mathbf{y}-\beta\mathbf{H}_{l_x}\mathbf{s}^i\right\|^2>\left\|\mathbf{y}-\beta\mathbf{H}_{l_y}\mathbf{s}^m\right\|^2\right)\\ &=P\left(\Re\left[\mathbf{u}^H\mathbf{H}\boldsymbol{\Delta}\right]>\frac{1}{2}\beta\|\mathbf{H}\boldsymbol{\Delta}\|^2\right)=\mathrm{Q}\left(\sqrt{\frac{\beta^2\|\mathbf{H}\boldsymbol{\Delta}\|^2}{2\sigma_u^2}}\right),\end{aligned} \tag{22}$$

where $\boldsymbol{\Delta}=\mathbf{s}_{l_y}^m-\mathbf{s}_{l_x}^i$. The last step is obtained because the expression $\Re\left[\mathbf{u}^H\mathbf{H}\boldsymbol{\Delta}\right]$ obeys the real Gaussian distribution $N\left(0,\frac{\sigma_u^2}{2}\|\mathbf{H}\boldsymbol{\Delta}\|^2\right)$. In order to simplify the expectation of the instantaneous PEP, the upper bound of the average PEP over Rayleigh fading channel realizations is introduced [24, Eq. 25], which is formulated by

$$\mathrm{E}_{\mathbf{H}}\left\{P\left(\mathbf{s}_{l_x}^i\to\mathbf{s}_{l_y}^m\,|\mathbf{H}\right)\right\}\leqslant\frac{1}{2\left|\mathbf{I}_{N_rN_t}+\frac{\beta^2}{2\sqrt{2}\sigma_u^2}\boldsymbol{\Lambda}\right|}, \tag{23}$$

where $\boldsymbol{\Lambda}=\mathbf{I}_{N_r}\otimes\boldsymbol{\Delta}\boldsymbol{\Delta}^H$. It is shown that the Bob's theoretical BER performance with the PM-AN scheme is always better than that of the conventional GSM due to $\beta^2>1$.

Finally, Bob's average BER upper bound can be calculated by substituting (23) into (21).

### B. BER Performance of Eve

The average BER of Eve is similarly expressed as

$$P_e\leqslant\frac{1}{\eta 2^\eta}\times\sum_{l_x,i}\sum_{l_y,m}d\left(\mathbf{s}_{l_x}^i,\mathbf{s}_{l_y}^m\right)\mathrm{E}_{\mathbf{G}}\left\{P\left(\mathbf{s}_{l_x}^i\to\mathbf{s}_{l_y}^m\,|\mathbf{G}\right)\right\}. \tag{24}$$

And the instantaneous PEP can be unfolded as

$$\begin{aligned} & P\left(\mathbf{s}_{l_x}^i \to \mathbf{s}_{l_y}^m \,|\mathbf{G}\right) \\ & = P\left(\left\|\mathbf{z}-\beta\mathbf{G}\mathbf{s}_{l_x}^i\right\|^2 > \left\|\mathbf{z}-\beta\mathbf{G}\mathbf{s}_{l_y}^m\right\|^2\right) \\ & = P\left(\Re\left[\mathbf{v}^H\mathbf{p}\right] > \Re\left[\mathbf{p}^H\mathbf{q}\right] + \frac{\beta\mathbf{p}^H\mathbf{p}}{2}\right), \end{aligned} \tag{25}$$

where $\mathbf{p} = \mathbf{G}\boldsymbol{\Delta}$, $\mathbf{q} = \mathbf{G}_{l_x}\mathbf{V}_0\mathbf{V}_0^H\mathbf{s}^i$. The expression $\Re\left[\mathbf{v}^H\mathbf{p}\right]$ is a real Gaussian random variable, which obeys the distribution of $N\left(0, \sigma_v^2\|\mathbf{p}\|^2\right)$. Thus the instantaneous PEP can be further reduced to

$$P\left(\mathbf{s}_{l_x}^i \to \mathbf{s}_{l_y}^m \,|\mathbf{G}\right) = \mathrm{Q}\left(\frac{2\Re\left[\mathbf{p}^H\mathbf{q}\right] + \beta\mathbf{p}^H\mathbf{p}}{\sqrt{2\sigma_v^2\mathbf{p}^H\mathbf{p}}}\right). \tag{26}$$

It is difficult to get the distribution of the argument for the Q function, thus the close form expression of the average PEP is intractable. However, due to the strong jamming effect of the preserved AN, the asymptotic PEP (APEP) can be defined as the PEP of $\sigma_v^2 \to 0$ to approximate the average BER, which is formulated as follows

$$\begin{aligned} \text{APEP} & = \mu P\left(\mathbf{s}_{l_x}^i \to \mathbf{s}_{l_y}^m \,|\mathbf{G}\right) |\sigma_v^2 = 0 \\ & = \mu P\left(2\Re\left[\mathbf{p}^H\mathbf{q}\right] + \beta\mathbf{p}^H\mathbf{p} \leqslant 0\right), \end{aligned} \tag{27}$$

where $\mu$ represents the normalization factor as

$$\mu = \frac{1}{\sum\limits_{l_y,m} \mathrm{E}_{\mathbf{G}}\left\{P\left(2\Re\left[\mathbf{p}^H\mathbf{q}\right] + \beta\mathbf{p}^H\mathbf{p} \leqslant 0\right)\right\}}. \tag{28}$$

Finally, the analytical BER approximation can be obtained, which is close to the lower bound of Eve's average BER as

$$\begin{aligned} P_e \approx & \frac{1}{\eta 2^\eta} \sum_{l_x,i} \sum_{l_y,m} d\left(\mathbf{s}_{l_x}^i, \mathbf{s}_{l_y}^m\right) \\ & \mu\mathrm{E}_{\mathbf{G}}\left\{P\left(2\Re\left[\mathbf{p}^H\mathbf{q}\right] + \beta\mathbf{p}^H\mathbf{p} \leqslant 0\right)\right\}. \end{aligned} \tag{29}$$

## IV. Simulation Results

The following figures are drawn on the premise of BPSK modulation, ML detection criteria, and $\sigma_u^2 = \sigma_v^2 = N_a/\text{SNR}$.

Fig. 2 depicts the comparison between the analytical BER bounds and simulation results with the configuration of $N_t = 4, N_a = 3, N_r = 2$ and $N_e = 2$. As can be observed from Fig. 2, the analytical upper bound of Bob asymptotically approaches the simulation results with the increase of SNR. It is inapplicable in the low BER region due to the side effect of the union bound approach [23]. Moreover, with the aid of (29), the analytical bound of Eve draw an asymptotical bound that matches closely to the simulation results at all considered SNR region.

Fig. 3 plots the BER comparison between the GSM equipped with PM-AN and conventional GSM when the system configuration is $N_t = 4, N_a = 3, N_r = 2, N_e = 2$. It is shown that conventional GSM experiences potential risk of information leakage because Eve has the same BER performance as Bob. The PM-AN scheme outperforms conventional GSM counterpart by improving the BER performance of Bob by 2 dB, while significantly suppressing the detection of Eve. Fig. 3 proves that the PM-AN scheme offers higher reliability and higher security than its conventional GSM counterpart.

Fig. 4 provides the BER performance of the PM-AN in comparison to that of the AN with $N_t = 4, N_a = 3$,

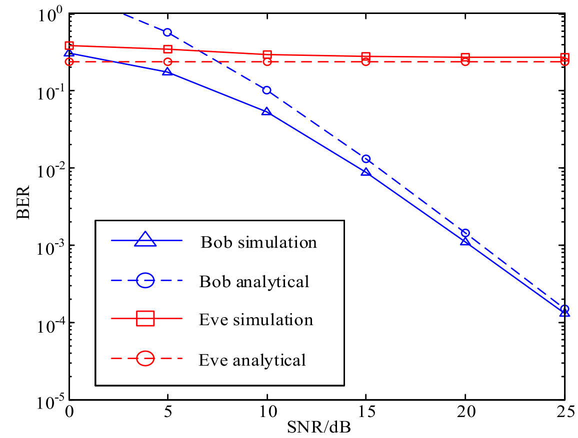


Fig. 2. BER simulation results and the analytical bounds of the proposed PM-AN scheme.

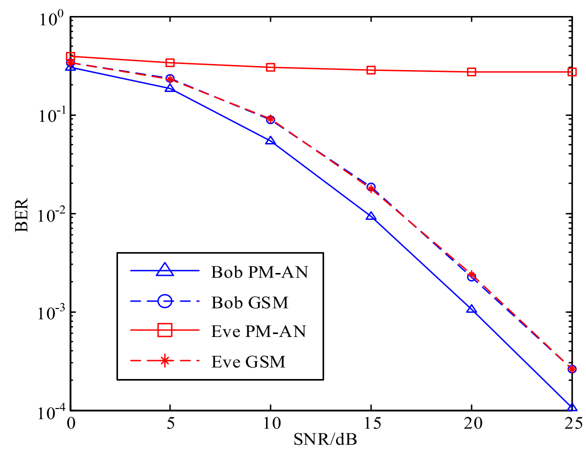


Fig. 3. Simulation results of GSM with PM-AN scheme and that of conventional GSM.

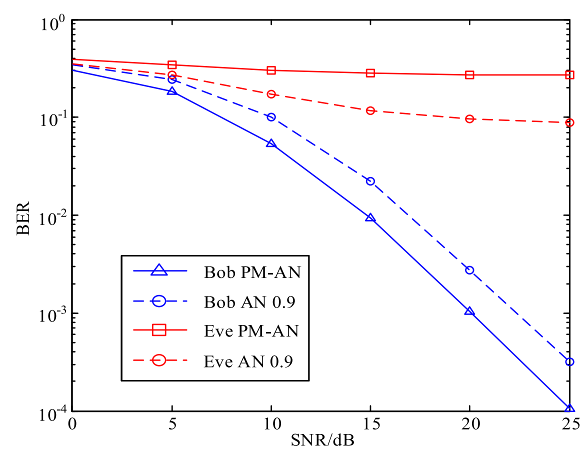


Fig. 4. Simulation results of the proposed PM-AN scheme and that of AN with $\theta = 0.9$.

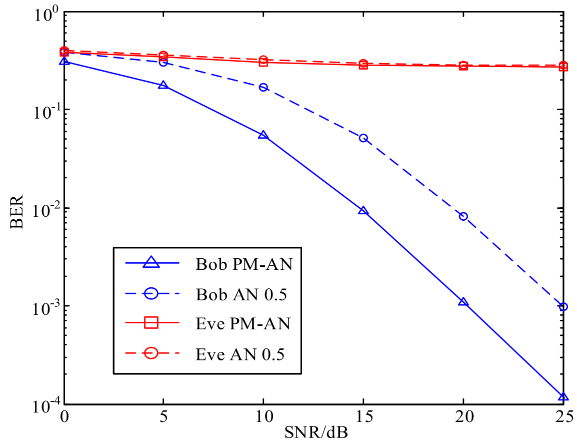


Fig. 5. Simulation results of the proposed PM-AN scheme and that of AN with $\theta = 0.5$.

$N_r = 2, N_e = 2$ and $\theta = 0.9$. It is followed from Fig. 4 that the PM-AN scheme offers a better trade-off by enhancing SNR gains around 3 dB at Bob and further suppressing the BER performance at Eve simultaneously. Fig. 4 proves that the PM-AN scheme outperforms its conventional AN counterpart with higher reliability and higher security.

Fig. 5 compares the BER performance of the PM-AN to that of the AN scheme when the configuration is $N_t = 4$, $N_a = 3, N_r = 2, N_e = 2$ and $\theta = 0.5$. It shows that, Eve's BER performance of the proposed PM-AN is well-matched in strength to that of the AN scheme with $\theta = 0.5$. Meanwhile, the BER performance of Bob with PM-AN obtains a significant improvement as around 5 dB than that with AN, which is benefited from the proposed PM-AN sufficiently solves the problem of power waste caused by conventional AN scheme.

## V. Conclusion and Future Work

A novel PM-AN design scheme was proposed for secure wireless GSM-MIMO transmission. Compared with conventional AN, PM-AN offers a better trade-off by significantly enhancing the BER performance of Bob and suppressing that of Eve simultaneously. Moreover, the analytical BER bounds of Bob and Eve for the proposed PM-AN scheme was also derived. Finally, simulation results were provided to validate our analytical bounds and demonstrated that the proposed PM-AN scheme aided GSM outperforms both the AN-GSM and conventional GSM counterparts. In our future work, precoding, optimal bit mapping and imperfect CSI will be further considered.

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