

Pairwise Error Probability Performance of SM-MIMO and Spatially Modulated Cooperative Communication Employing SDF Protocol



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Abstract: In this paper, we analyze the performance of spatially modulated (SM) multiple input multiple output (MIMO) system and spatially modulated MIMO cooperative system with multiple relays employing selective decode and forward (SDF) protocol. Here the analysis is done for pre-determined orthogonal channel for SM MIMO and SM MIMO cooperative system using M-PSK modulation and ML detection. Firstly Pairwise error probability (PEP) expression is derived and optimal, sub-optimal detection is done in a spatially modulated MIMO system. Further, the analysis of SDF spatially modulated MIMO cooperative system is extended to single relay and multiple relay configurations. PEP expression is also derived for SDF spatially modulated MIMO cooperative system. Simulation results for the SM MIMO system show optimal detection performs better than suboptimal detection and system performance improves as the number of antenna increases. The simulation results of PEP analysis in the SM MIMO cooperative system include the theoretical PEP, exact PEP and asymptotic PEP and Optimal power allocation (OPA) is also derived for the same. Optimal power allocation for theoretical PEP, exact PEP and asymptotic PEP outperforms the same at equal power allocation.

Index Terms: Spatial modulation, MIMO, Cooperative Communication

I. INTRODUCTION

Better performance and betterment of spectral efficiency of mobile communication is motivated by growing demand for improved QoS (quality of service) and high data rates across the wireless links. In next generation mobile communication superior spectral efficiency (SE) and high-data rates are valuable. To achieve this by sending data from several antennas is one solution in MIMO technology [1]. Receive spatial modulation (RSM) exploits abundance of antennas available on the receiver in the form of a local constellation diagram (CD) to enhance SE with minimum complications. The working principle behind RSM is that all antennas are triggered by the transmitter and in a multi antenna receiver,

using a pre-made linear pre-coder transmitted signal is beam formed from a single receive antenna [2]. In RSM, two units carried the information bits: Traditional PSK constellations and activated receive antennas indices (or index combinations) [3]. Recently proposed Multi-Input Multi-Output (MIMO) technology is proposed by Spatial Modulation (SM), where spatial resources are exploited in different ways from primary MIMO techniques [4] - [7]. The transmitted SM information bits are divided into two streams: one stream is used to activate single or multiple antenna (M_s), which is to transmit symbols mapped to another stream [8] - [13]. Spatial multiplexing gain and spatial diversity gain with low complexity consumption are offered by this technique, because at the transmitter a single or several radio frequency chains are needed [14], [15]. Throughout this paper, performance of cooperative MIMO space-time block coded (STBC) communication network with Single and various relays based on a selective decode-and-forward (DF) based technique is analyzed. We derived the closed form expression at the destination node of code block detection for the end to end PEP, while beginning with single relay based MIMO STBC system. The system with order of full diversity can be attained by cooperative MIMO (multi-input multi-output) STBC network [16], [17]. To reduce the unfavorable consequences of channel fading, power allocation (PA) techniques are proficient and BER is decreased and data rate is improved by this technique.

In fact, in terms of spatial multiplexing systems PA has been widely studied [18], [19]. In order to assist time-varying channels, it is more profitable for modifying the parameters of transmission, using SM with PA is a new MIMO technique. However, in SM-based schemes, only one transmitting antenna (TA) is active in each time slot, the PA approach may not be suitable for the SM system directly for spatial multiplexing based MIMO system.

Following are the contributions of this paper:

- PEP analysis based on a spatially modulated MIMO system using ML detection is derived.
- PEP analysis of spatially modulated MIMO system using ML detection is done for M-PSK modulation.
- PEP analysis of spatially modulated MIMO network using ML detection for M-PSK modulation is done optimal and suboptimal detection.
- Simulation has been done to spatially modulated MIMO system.

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- The PEP of spatially modulated MIMO cooperative communication using ML detection is derived.
- PEP of spatially modulated MIMO cooperative communication using ML detection is derived.
- Simulation has been done for spatially modulated MIMO cooperative system.

II. SYSTEM MODEL

There is an issue in practical realization of large MIMO Systems because it needs a high number of RF Chains. That is the reason, it increases the hardware complexity, size and cost. To overcome this issue, Spatially modulated MIMO System has been proposed. Spatially modulated MIMO System uses fewer number of transmitting RF chains than the transmit antennas. SM employs a multiple antenna at the source, but a single transmit RF chain.

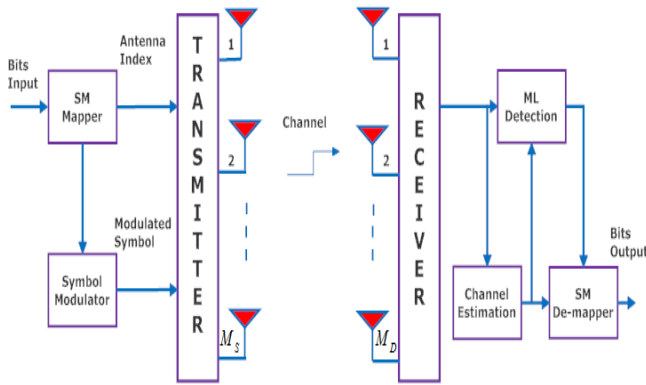


Fig. 1 Spatially Modulated MIMO System Using ML Detection

$$X = \begin{bmatrix} \mathbf{0}, \mathbf{0}, \dots, \mathbf{X}_p, \dots, \mathbf{0}, \mathbf{0} \end{bmatrix}^T \quad (1)$$

bth position

Where the transmitted vector is X and the digitally modulated symbol is X_p that is transmitted from the b^{th} antenna. In other words, the X_p symbol is contained in the b^{th} position. The choice of the activated antenna based on a group of m data bits. Where, $m = \log_2 M_s$. So $M_s = 2^m$ is the large number of antenna arrays. From the selected antenna, a symbol from a M -ary modulation alphabet V_M is sent. Therefore the accomplished rate in spatial modulation is $m + \log_2 M$ bits per channel use (bpcu). Mapping table of SM Signals of data bits for $m = 3, M_s = 8$ is shown in Table I of appendix.

III. PEP ANALYSIS OF SM-MIMO SYSTEM

A. PEP Performance Analysis

The pairwise error probability of spatially modulated MIMO system can be derived using the joint detection of antenna index and the digitally modulated symbol at the receiver. Where $X_{SM}(b, X_p)$ is the transmitted symbol and $X_{SM}(\hat{b}, X_{\hat{p}})$ is the detected symbol at the destination. So the PEP is given as [20],

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) = \Pr(\|Y - h_b X_p\|^2 \leq \|Y - h_{\hat{b}} X_{\hat{p}}\|^2) \quad (2)$$

PEP mathematical expression can be simplified as,

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) = \Pr(\|h_b X_p + W - h_{\hat{b}} X_{\hat{p}}\|^2 \leq \|h_b X_p + W - h_{\hat{b}} X_{\hat{p}}\|^2) \quad (3)$$

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) = \Pr(\|(h_b X_p(t) - h_{\hat{b}} X_{\hat{p}}) - W\|^2 \leq \|W\|^2) \quad (4)$$

By using the triangle inequality, the equation can be written as,

$$\|(h_b X_p - h_{\hat{b}} X_{\hat{p}})\|^2 - \|W\|^2 \leq \|(h_b X_p - h_{\hat{b}} X_{\hat{p}}) + W\|^2 \leq \|(h_b X_p - h_{\hat{b}} X_{\hat{p}})\|^2 + \|W\|^2 \quad (5)$$

By applying the above inequality, the PEP expression is given as,

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) = \Pr(\|(h_b X_p - h_{\hat{b}} X_{\hat{p}})\|^2 - \|W\|^2 \leq \|W\|^2) \quad (6)$$

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) = \Pr\left(\left\|\frac{(h_b X_p - h_{\hat{b}} X_{\hat{p}})}{2}\right\|^2 \leq \|W\|^2\right) \quad (7)$$

PEP expression can be expressed as,

$$\Pr(X_{SM}(b, X_p) \rightarrow X_{SM}(\hat{b}, X_{\hat{p}})) \leq Q\left(\frac{\gamma \|(h_b X_p - h_{\hat{b}} X_{\hat{p}})\|^2}{2}\right) \quad (8)$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{\alpha^2}{2}} d\alpha \quad (9)$$

B. Sub-optimal Detection

For spatially modulated reception, there is a sub-optimal detection that is maximum likelihood (ML) detection rule for antenna index (Spatially modulated bits) and digitally modulating symbol is taken for separate detection. At the receiver, the transmitted antenna index can be detected using ML criteria [13],

$$\hat{b} = \arg \max_q \|h_b^H Y\| \quad (10)$$

The transmitted signal can be detected as the detection process of MRC using ML criteria [13],

$$X_{\hat{p}} = \arg \min_p \|Y(t) - h_b X_p\|^2 = \arg \min_p \|h_b X_p\|^2 - 2 \operatorname{Re}\{h_b^H Y X_p^*\} \quad (11)$$

C. Optimal Detection

For spatially modulated reception, there is an optimal detection that is maximum likelihood (ML) detection rule for joint detection of antenna index (Spatially modulated bits) and digitally modulated symbol. Suboptimal detection is taken for separate detection. The optimal detection of spatially modulated MIMO system can be reproduced as [13],

$$\begin{aligned}
 (\hat{b}, X_{\hat{p}}) &= \arg \min_{b,p} \|Y - h_b X_p\|^2 \\
 &= \arg \min_{b,p} \|h_b X_p\|^2 - 2 \operatorname{Re}\{h_b^H Y X_p^*\} \quad (12)
 \end{aligned}$$

IV. SM-MIMO COOPERATIVE COMMUNICATION SYSTEM MODEL

In fig. 2, the performance and complexity of the network can be improved by using relay. In the first phase, spatially modulated signal is transmitted from source to the relay and source to destination respectively. If the signal is properly decoded, then it will be sent to the receiver. Otherwise, it will remain idle. But in the second phase, the bits are transmitted from relay to destination. Selective decode forward is used to decode the signal. A system model consisting of M_s source antennas, M_d destination antennas and L selection DF relay as shown in fig. 2. The communication process consists of two phases. In the first phase, an index is taken from the source antennas and bits are mapped from the data symbols M-PSK constellation diagram form $\log_2(MM_s)$. During the transmission, one source antenna ($b \in \{1:M_s\}$) is operating and data symbol X_p , $p \in \{1:M\}$, is transmitted at each time instant with energy E. Other source antennas are remains idle in this time instant.

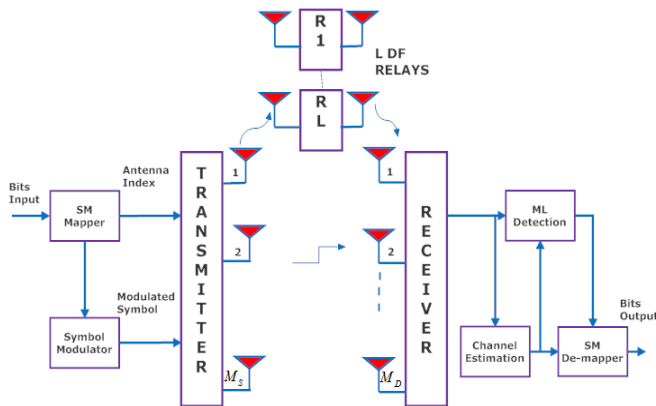


Fig.2 Spatially Modulated MIMO Cooperative Using SDF Protocol

The signal at q^{th} relay from the transmitter is written as [9],

$$Y_{S,R_q} = \sqrt{E}h_{q,b}X_p + W_{S,R_q} \quad (13)$$

Where P_s and $h_{q,j} \sim cN(0,1)$ can be expressed as the power source and channel coefficient between the b^{th} source antenna and q^{th} relay. W_{S,R_q} refers the additive white Gaussian noise (AWGN) at the relay input.

The signal at the receiver from the source is written as.

$$Y_{S,D} = \sqrt{E}h_b X_p + W_{S,D} \quad (14)$$

where $h_j \sim cN(0,1)$ denote the source power and coefficient between the b^{th} source antenna and destination. $W_{S,D}$ denotes the AWGN at the relay input.

The signal received at the receiving end from the q^{th} relay is written as,

$$Y_{R_q,D} = \sqrt{E}h_{b,q}g_q X_p + W_{R_q,D} \quad (15)$$

The channel state information (CSI) used by the optimal detector at the node D combinely estimates the transmitted symbol \hat{X}_p and antenna index \hat{b} that minimizes the subsequent expression [15],

$$\begin{aligned}
 [\hat{b}, X_{\hat{p}}] &= \arg \min_{b,p} \left(\|Y_{S,D} - \sqrt{E}h_b X_p\|^2 + \sum_{q=1}^{|C|} \|Y_{R_q,D} - \sqrt{E}h_{b,q}g_q X_p\|^2 \right) \quad (16)
 \end{aligned}$$

V. PEP ANALYSIS OF SM-MIMO COOPERATIVE COMMUNICATION

A. PEP Analysis

The average PEP and closed form mathematical representation of PEP for Spatially modulated MIMO system with multiple decode and forward can be calculated. PEP expressions are derived from the equation (17) to (23) as shown below in appendix. The equations describe the pairwise error probability with the distance between the origin and difference vector and distance between the origin and noise signal. In other words, the PEP depends on the position of noise signal of the difference signal. If noise signal is nearer to the origin, then there is no error and if it nearer to the difference vector then there is detection of the error.

B. PEP Analysis for L Relays

The probability of deciding that $\hat{k} = h_{b,q} X_{\hat{p}}$ is received, when $k = h_{b,q} X_p$ is the transmitted signal. The instantaneous probability of incorrectly detecting the signal as given in equation (24) shown in the appendix. So the average probability of incorrectly decoding the signal can be written as [3],[6].

$$P_{Avg} = E \left[Q \left(\sqrt{\frac{E|h_{b,q}X_p - h_{\hat{b},q}X_{\hat{p}}|^2}{2\eta_0}} \right) \right] \quad (25)$$

The probability, when all the relays are not linked and only direct link exists, is $(P_{Avg})^L$.

The average PEP can be written as,

$$PEP_D = (P_{Avg})^L \times E \left[Q \left(\sqrt{\frac{E \|h_b X_p - h_b X_{\hat{p}}\|^2}{2\eta_0}} \right) \right] \quad (26)$$

If q links out of L relay link detect the signal correctly, so the destination link combine the q indirect link combines with direct link can be estimated the estimated the transmitted signal. The probability of this can be given in equation (27) as shown below in appendix. By combining equation (26) and (27), provides the overall average PEP at the destination and shown as equation (28) is given in appendix.

$$PEP = PEP_D + PEP_R$$

VI. SIMULATION RESULTS

We consider the spatially modulated MIMO system employing maximum likelihood detection with M -PSK modulation scheme. Therefore, it has done PEP analysis for the SM MIMO system. PEP analysis of theoretical, optimal and sub-optimal detection have done from fig. 3 to fig. 6. In fig. 3, Pairwise error probability performance of spatially modulated MIMO versus signal to noise ratio, with $M_S = M_D = 8, M = 2$ (BPSK) has done. In fig. 4, PEP performance of spatially modulated MIMO versus signal to noise ratio, with $M_S = M_D = 4, M = 2$ and $M_S = M_D = 8, M = 2$ for BPSK has done and it has shown that if the number of source and destination antenna increases, the performance of the system will improve. In fig. 5, PEP performance of spatially modulated MIMO versus signal to noise ratio, with $M_S = 32, M_D = 5, M = 4$ for QPSK has done. Fig. 6, PEP performance comparison of spatially modulated MIMO versus signal to noise (SNR) ratio with $M_S = 8, M_D = 3, M = 4$ and $M_S = 16, M_D = 4, M = 4$ for QPSK and it can be seen in figure that as the number of antennas at the transmitter and receiver become greater, the system performance will improve. Further, we consider the spatially modulated MIMO cooperative system, the end to end PEP, simulated PEP and asymptotic PEP analysis have done. In Fig. 7, PEP performance of spatially modulated MIMO cooperative versus signal to noise (SNR) ratio has done.

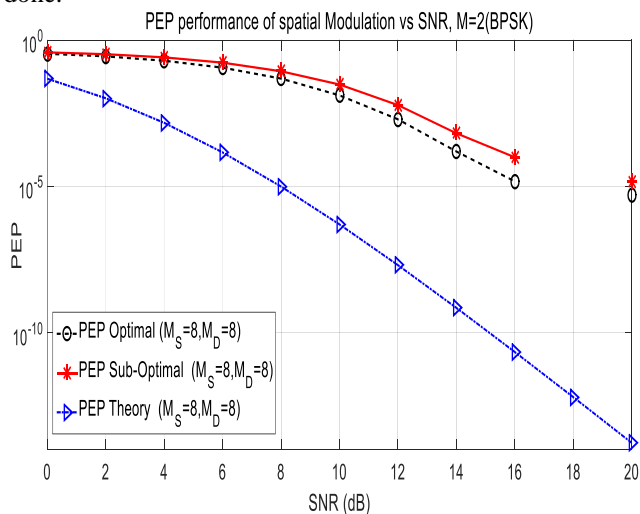


Fig. 3. Pairwise error probability performance of spatially modulated MIMO versus signal to noise ratio, with $M_S = M_D = 8, M = 2$ (BPSK).

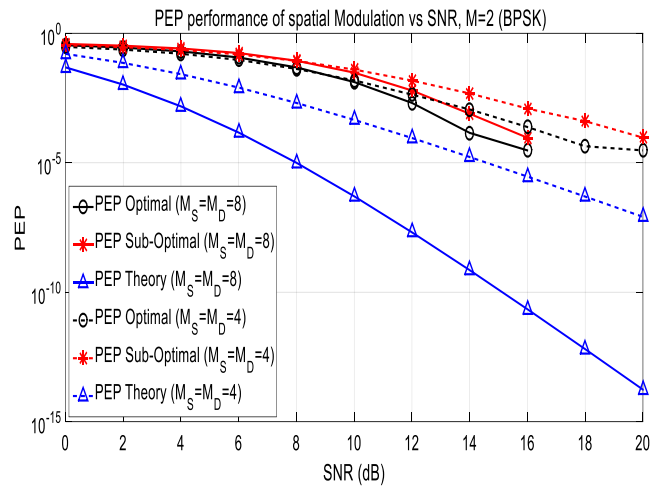


Fig. 4. Pairwise error probability performance of spatially modulated MIMO versus SNR ratio, with $M_S = M_D = 4, M = 2$ and $M_S = M_D = 8, M = 2$ for BPSK.

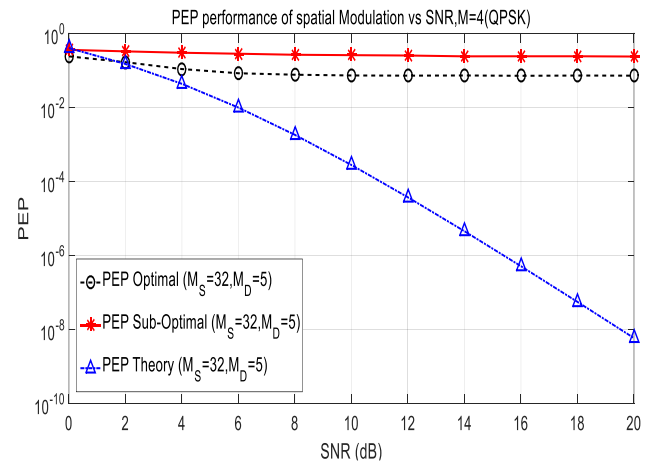


Fig. 5. PEP performance of spatially modulated MIMO versus signal to noise ratio, with $M_S = 32, M_D = 5, M = 4$ for QPSK.

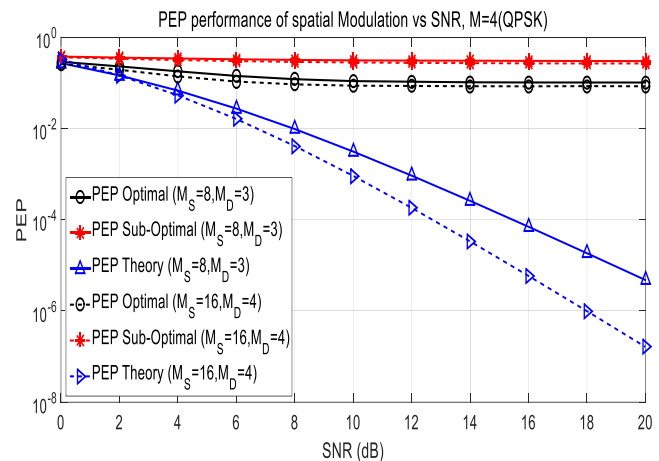


Fig. 6. PEP performance comparison of spatially modulated MIMO versus signal to noise (SNR) ratio with $M_S = 8, M_D = 3, M = 4$ and $M_S = 16, M_D = 4, M = 4$ for QPSK.

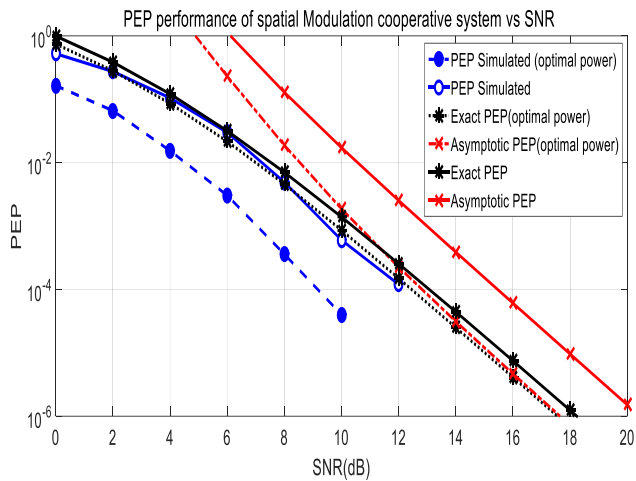


Fig. 7. PEP performance of spatially modulated MIMO cooperative versus signal to noise (SNR) ratio.

VII. CONCLUSION

This work presents the performance analysis of spatially modulated MIMO system and spatially modulated MIMO cooperative system system using ML detector. The PEP expression is derived for SM MIMO and SM MIMO cooperative system using ML detector. PEP analysis is done SM MIMO optimal and suboptimal detector. The PEP performance analysis is done for single relay and multiple relay for SM MIMO cooperative communication. Simulation of PEP analysis in SM MIMO cooperative systems employing the theoretical PEP, exact PEP and asymptotic PEP has been done. Performance of theoretical PEP, exact PEP and asymptotic PEP using optimal power allocation perform better than theoretical PEP, exact PEP and asymptotic PEP.

APPENDIX

TABLE I. MAPPING TABLE TO SM SIGNALS OF DATA BITS FOR $m = 3, M_s = 8$

Antenna Selection $m=3$	SM Transmitted Signal Vector, X	Status of Transmitting antennas ($M_s = 2^m$)							
		Ant1	Ant 2	Ant 3	Ant4	Ant 5	Ant 6	Ant 7	Ant 8
000	$[X_p, 0, 0, 0, 0, 0, 0, 0]^T$	$X_p \in V_M$	0	0	0	0	0	0	0
001	$[0, X_p, 0, 0, 0, 0, 0, 0]^T$	0	$X_p \in V_M$	0	0	0	0	0	0
010	$[0, 0, X_p, 0, 0, 0, 0, 0]^T$	0	0	$X_p \in V_M$	0	0	0	0	0
011	$[0, 0, 0, X_p, 0, 0, 0, 0]^T$	0	0	0	$X_p \in V_M$	0	0	0	0
100	$[0, 0, 0, 0, X_p, 0, 0, 0]^T$	0	0	0	0	$X_p \in V_M$	0	0	0
101	$[0, 0, 0, 0, 0, X_p, 0, 0]^T$	0	0	0	0	0	$X_p \in V_M$	0	0
110	$[0, 0, 0, 0, 0, 0, X_p, 0]^T$	0	0	0	0	0	0	$X_p \in V_M$	0
111	$[0, 0, 0, 0, 0, 0, 0, X_p]^T$	0	0	0	0	0	0	0	$X_p \in V_M$

The average PEP can be written as [6],

$$\Pr(k \rightarrow \hat{k}) = \Pr \left(\begin{aligned} & \left\| Y_{S,D} - \sqrt{E} h_b X_{\hat{p}} \right\|^2 + \sum_{\hat{p}=1}^{|C|} \left| Y_{R_q,D} - \sqrt{E} h_{b,q} g_q X_{\hat{p}} \right|^2 \\ & \leq \left\| Y_{S,D} - \sqrt{E} h_b X_p \right\|^2 + \sum_{q=1}^{|C|} \left\| Y_{R_q,D} - \sqrt{E} h_{b,q} g_q X_p \right\|^2 \end{aligned} \right) \tag{17}$$

$$\Pr(k \rightarrow \hat{k}) = \Pr \left(\begin{aligned} & \left\| \sqrt{E} h_b X_p + W_{S,D} - \sqrt{E} h_b X_{\hat{p}} \right\|^2 + \sum_{\hat{p}=1}^{|C|} \left\| \sqrt{E} h_{b,q} g_q X_p + W_{R_q,D} - \sqrt{E} h_{b,q} g_q X_{\hat{p}} \right\|^2 \\ & \leq \left\| \sqrt{E} h_b X_p + W_{S,D} - \sqrt{E} h_b X_p \right\|^2 + \sum_{q=1}^{|C|} \left\| \sqrt{E} h_{b,q} g_q X_p + W_{R_q,D} - \sqrt{E} h_{b,q} g_q X_p \right\|^2 \end{aligned} \right) \tag{18}$$



$$\Pr(k \rightarrow \hat{k}) = \Pr \left(\begin{aligned} & \left\| \sqrt{E}h_b X_p + W_{S,D} - \sqrt{E}h_{\hat{b}} X_{\hat{p}} \right\|^2 \\ & + \sum_{\hat{p}=1}^{|\mathcal{C}|} \left\| \sqrt{E}h_{b,q} g_q X_p + W_{R_q,D} - \sqrt{E}h_{\hat{b},q} g_q X_{\hat{p}} \right\|^2 \leq \|W_{S,D}\|^2 + \sum_{q=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \end{aligned} \right) \quad (19)$$

$$\left\| \sqrt{E}h_b X_p - \sqrt{E}h_{\hat{b}} X_{\hat{p}} \right\|^2 + \sum_{\hat{p}=1}^{|\mathcal{C}|} \left\| \sqrt{E}h_{b,q} g_q X_p - \sqrt{E}h_{\hat{b},q} g_q X_{\hat{p}} \right\|^2 - \left(\|W_{S,D}\|^2 + \sum_{\hat{p}=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \right) \leq \|W_{S,D}\|^2 + \sum_{\hat{p}=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \quad (20)$$

$$\Pr(k \rightarrow \hat{k}) \leq \Pr \left(\begin{aligned} & \left\| \sqrt{E}h_b X_p - \sqrt{E}h_{\hat{b}} X_{\hat{p}} \right\|^2 + \sum_{\hat{p}=1}^{|\mathcal{C}|} \left\| \sqrt{E}h_{b,q} g_q X_p - \sqrt{E}h_{\hat{b},q} g_q X_{\hat{p}} \right\|^2 \\ & - \left(\|W_{S,D}\|^2 + \sum_{q=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \right) \leq \left(\|W_{S,D}\|^2 + \sum_{q=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \right) \end{aligned} \right) \quad (21)$$

$$\Pr(k \rightarrow \hat{k}) \leq \Pr \left(\begin{aligned} & \left\| \frac{(\sqrt{E}h_b X_p - \sqrt{E}h_{\hat{b}} X_{\hat{p}})}{2} \right\|^2 \\ & + \sum_{\hat{p}=1}^{|\mathcal{C}|} \left\| \frac{(\sqrt{E}h_{b,q} g_q X_p - \sqrt{E}h_{\hat{b},q} g_q X_{\hat{p}})}{2} \right\|^2 \leq \left(\|W_{S,D}\|^2 + \sum_{q=1}^{|\mathcal{C}|} \|W_{R_q,D}\|^2 \right) \end{aligned} \right) \quad (22)$$

$$\Pr(k \rightarrow \hat{k}) \leq Q \left(\left\| \frac{(\sqrt{E}h_b X_p - \sqrt{E}h_{\hat{b}} X_{\hat{p}})}{2} \right\|^2 + \sum_{\hat{p}=1}^{|\mathcal{C}|} \left\| \frac{(\sqrt{E}h_{b,q} g_q X_p - \sqrt{E}h_{\hat{b},q} g_q X_{\hat{p}})}{2} \right\|^2 \right) \quad (23)$$

$$PEP = (P_{Avg})^L \times E \left[Q \left(\sqrt{\frac{E \|h_b X_p - h_{\hat{b}} X_{\hat{p}}\|^2}{2\eta_0}} \right) \right] + \quad (24)$$

$$\sum_{q=1}^L \binom{L}{q} (P_{Avg})^{L-q} (1 - P_{Avg})^q E \left[Q \left(\sqrt{\frac{\sum_{v=1}^q E \|g_v\|^2 \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0} + \frac{E \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0}} \right) \right]$$

$$PEP_R = \sum_{q=1}^L \binom{L}{q} (P_{Avg})^{L-q} (1 - P_{Avg})^q E \left[Q \left(\sqrt{\frac{\sum_{v=1}^q E \|g_v\|^2 \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0} + \frac{E \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0}} \right) \right] \quad (27)$$

$$PEP = (P_{Avg})^L \times E \left[Q \left(\sqrt{\frac{E \|h_b X_p - h_{\hat{b}} X_{\hat{p}}\|^2}{2\eta_0}} \right) \right] +$$

$$\sum_{q=1}^L \binom{L}{q} (P_{Avg})^{L-q} (1 - P_{Avg})^q E \left[Q \left(\sqrt{\frac{\sum_{v=1}^q E \|g_v\|^2 \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0} + \frac{E \|h_{b,q} X_p - h_{\hat{b},q} X_{\hat{p}}\|^2}{2\eta_0}} \right) \right]$$

(28)



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