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Performance assessment of space shift keying MIMO techniques for visible light communication

C.R. Bharathi

Department of ECE, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science & Technology, Avadi, Chennai, Tamil Nadu 600054, India

Corresponding Author Email: crbharathiveltech@gmail.com

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ABSTRACT

We compare various space shift keying multiple input multiple output (SSK-MIMO) techniques such as generalized space shift keying (GSSK), hamming code aided space shift keying (HSSK) and variable generalized space shift keying (VGSSK) for visible light communication (VLC) system. In addition, we analyze the bit error rate (BER) performance of these schemes for channels with different correlations. The BER expressions of these schemes are analytically approximated and used for the performance comparison. The suitability of VGSSK-MIMO for VLC is justified by its performance gain obtained over the other better performing SSK-MIMO systems. From the simulations, it is observed that the performance gain of 1 dB is achievable steadily under both high and less correlated channels for 3 bit/s/Hz by GSSK over HSSK.

1. INTRODUCTION

VLC overcomes the problem of limited modulation bandwidth by the application of multiple input multiple output (MIMO) techniques [1]. SM-MIMO is proposed to be simple and more energy-efficient among available MIMO techniques [2][3][6]. In optical SM (OSM), a particular light emitting diode (LED) gets activated during each time instant and transmits a modulated symbol through it, where other LEDs are silent [2]. SM-MIMO is a combination of space shift keying MIMO (SSK-MIMO) [7]–[9] and digital modulation. In optical SSK (OSSK), the information is conveyed by index modulation. This is equivalent to activating a single LED in each time interval. The encoding complexity of SSK-MIMO gets reduced at the cost of less spectral efficiency. The spectral efficiency enhancement [8] was done by generalizing the operation of SSK and called generalized space shift keying (GSSK). GSSK is reported to be suitable for large scale MIMO for its simplest encoding [10]. Two generalized versions of SSK were reported in [11] and [12] called hamming code aided SSK (HSSK) and variable generalized SSK (VGSSK) respectively.

The existing MIMO techniques were studied for radio frequency (RF) communications [7]-[13]. Their suitability for VLC has not been validated. This work compares the available SSK-MIMO schemes for VLC system. The rest of the paper is organized as follows: In Section II, we describe the system model of VLC. Section III elaborates the operation of conventional SM-MIMO and various SSK-MIMO techniques. Then, the approximate BER expressions of various SSKMIMO techniques are developed to study their performances for channels with different correlations. The performances of different SSK-MIMO techniques are compared and discussed

Fig. 1. Illustration of SM-MIMO transmission with four LEDs (top block in SM mapper represents symbol mapper and bottom block represents index mapper). through analytical simulations for different correlated channels in Section IV. Finally, we conclude the paper with Section V.

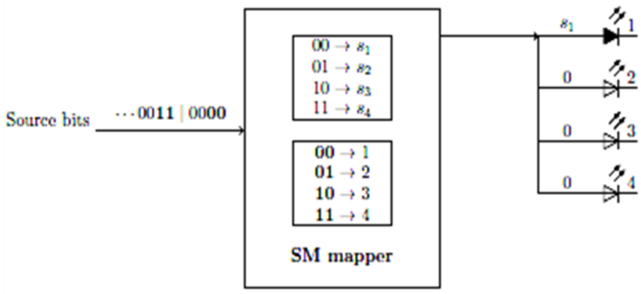

Figure 1. SM-MIMO transmission process

2. SYSTEM MODEL

The channel model of the conventional MIMO system can be presented as in [2],

$$y = Hs + n; \tag{1}$$

where y represents Nr-length receive vector, Nr is the number of photodetectors, s denotes Nt-length transmit vector where N_t indicates the number of LEDs, H denotes Nr x Nt channel matrix whose entries are determined by

$$h=\begin{cases} \frac{(m+1)A}{2\pi d^2} cos^k(\emptyset)cos(\varphi), & 0 \le \varphi \le \varphi_{\frac{1}{2}} \\ 0 \quad , & \varphi > \varphi_{\frac{1}{2}} \end{cases} \tag{2}$$

where Ø and ψ are the angles subtended between particular LED and photodetector with respect to the transmitter and receiver plane's normal axes respectively, d is the distance between them.

3. SSK-MIMO TECHNIQUES

Let us start with the operation of SM-MIMO. Consider 4 bit/s/Hz transmission for the illustration of SM operation with four LEDs as shown in Fig. 1. The SM transmitter consists of mapper and light sources i.e. LEDs. The SM mapper contains two blocks namely, index mapper and symbol mapper.

Table 1. GSSK mapping with four LEDs and two active LEDs

Source Bits	Transmit Vector	Active LED Indices
00	$[1, 1, 0, 0]^T$	$\{1, 2\}$
01	$[1, 0, 1, 0]^T$	$\{1, 3\}$
10	$[1, 0, 0, 1]^T$	$\{1, 4\}$
11	$[0, 1, 1, 0]^T$	$\{2, 3\}$

Table 2. HSSK and VGSSK mapping with four LEDs

Source Bits	Transmit Vector		Active LED indices	
	HSSK	VGSSK	HSSK	VGSSK
000	$[0, 0, 0, 1]^T$	$[0, 0, 0, 1]^T$	$\{4\}$	$\{4\}$
001	$[0, 0, 1, 0]^T$	$[0, 0, 1, 0]^T$	$\{3\}$	$\{3\}$
010	$[0, 1, 0, 0]^T$	$[0, 1, 0, 0]^T$	$\{2\}$	$\{2\}$
011	$[0, 1, 1, 1]^T$	$[0, 1, 1, 0]^T$	$\{2, 3, 4\}$	$\{2, 3\}$
100	$[1, 0, 0, 0]^T$	$[1, 0, 0, 0]^T$	$\{1\}$	$\{1\}$
101	$[1, 0, 1, 1]^T$	$[1, 0, 1, 0]^T$	$\{1, 3, 4\}$	$\{1, 3\}$
110	$[1, 1, 0, 1]^T$	$[1, 1, 0, 0]^T$	$\{1, 2, 4\}$	$\{1, 2\}$
111	$[1, 1, 1, 0]^T$	$[1, 1, 1, 0]^T$	$\{1, 2, 3\}$	$\{1, 2, 3\}$

Table 3. Comparison of spectral efficiency

MIMO	Spectral Efficiency (bit/s/Hz)
SSK	2
GSSK	2
HSSK	3 for $d_{\min} = 2$ 1 for $d_{\min} = 3$ 1 for $d_{\min} = 4$
VGSSK	3

For 4 bits transmission, there are 24 possible binary combinations, out of which randomly one will present at the input of SM mapper for each symbol interval. Let us assume ‘0000’ be the symbol to be transmitted. This symbol is split to have two independent symbols differentiated as normal and bold. SM requires two bits to activate one of the four LEDs using index mapper. The first symbol, i.e. bold symbol “00” is used to choose a particular LED index. The corresponding indexed LED gets activated which is shown by shaded LED in Fig. 1. Followed by this, the second symbol [12], i.e. normal symbol “00” is modulated by digital modulation preferably unipolar M-ary pulse amplitude modulation (M-PAM) using symbol mapper. The modulated symbol is then transmitted through the activated LED whereas the other LEDs are silent. The spectral efficiency of unipolar M-PAM is given as $\log_2 M$ [14]. Mathematically, the transmit signal can be represented as a vector s = [s1; 0; 0; 0]^T. The spectral efficiency of SM-MIMO is given as $\log_2 N_t + \log_{2M}$ [2].

Alternatively, the second box of SM mapper in Fig. 1 called SSK-MIMO [7]-[9] jointly with digital modulation provide SM mapping. The spectral efficiency of SSK-MIMO is given as $\log_2$ Nt [7]. In order to improve its spectral efficiency, the generalized space shift keying MIMO is discussed in [13]. The spectral efficiency of GSSK-MIMO is given as [$\log_2(\binom{N_t}{N_a})$] where Na denotes the number of active LEDs. In GSSKMIMO, Na LEDs will be active during each symbol interval. The GSSK-MIMO mapping is given in Table 1. It should be noted that the given combinations are not unique. Similarly, HSSK and VGSSK MIMO mapping are presented in Table 2. Their respective spectral efficiencies are RHSSK _ $\log_2 N(N_t; d_{min})$ and RVGSSK = N_t -1, where $N(N_t; d_{min})$ represents the number of codewords generated of length Nt maintaining the minimum hamming distance d_{min} of the codebook. The construction of the HSSK mapping table requires the knowledge of hamming code generation for fixed d_{min}. This can be easily achievable for lower values of d_{min}, whereas advisable to use the online tool as mentioned in [11] for higher values of d_{min}. Similarly, the construction of the Table 3 compares the achievable spectral efficiency of SSK, GSSK, HSSK and VGSSK for the given system parameters $N_t = 4$ and $N_a = 2$. HSSK (for $d_{min} = 2$) and VGSSK achieve maximum spectral efficiency of 3 bit/s/Hz for the given parameters. The average bit error probability (ABEP) expression of SMMIMO can be obtained from [2]. It is given as

$$ABEP \leq \frac{1}{N_t log_2(N_t)} \sum_{b=1}^{N_t} \sum_{a \neq b=1}^{N_t} d_{a,b}. Q\left(\frac{\sqrt{\gamma_0{}^2||h_a - h_b||_2^2}}{2a}\right) \quad (3)$$

where N = MNt, M denotes the constellation size of pulse modulation used, da;b denotes the hamming distance between the bit combinations of a and b, 0 represents average optical signal-to-noise ratio (OSNR).Q- function. The ABEP of SSK can be obtained by keeping M = 1 in (3) and expressed as

$$ABEP \leq \frac{1}{N_t log_2(N_t)} \sum_{b=1}^{N_t} \sum_{a \neq b=1}^{N_t} d_{a,b}. Q\left(\sqrt{\frac{\gamma_0^2||h_a - h_b||_2^2}{4}}\right) \quad (4)$$

where ha represents the ath column of H and hb represents the bth column of H. Similarly, the ABEP of GSSK, HSSK and V GSSK techniques are developed as below:

$$ABEP \leq \frac{1}{N_1 log_2(N_1)} \sum_s \sum_r d_{r,s}. Q\left(\sqrt{\frac{\gamma_0^2||h_r - h_s||_2^2}{4N_a^2}}\right) \quad (5)$$

$$ABEP \leq \frac{1}{N_2 log_2(N_2)} \sum_s \sum_r d_{r,s}. Q\left(\sqrt{\frac{\gamma_0^2||h_r - h_s||_2^2}{4P_0^2}}\right) \quad (6)$$

$$ABEP \leq \frac{1}{N_3 log_2(N_2)} \sum_s \sum_r d_{r,s}. Q\left(\sqrt{\frac{\gamma_0^2||h_r - h_s||_2^2}{4P_0^2}}\right) \quad (7)$$

where N1 = $2^{b\log 2\ (Nt\ /\ Na)c}$, N2 = $N(N_t; d_{min})$, N3 = 2^{Nt-1}, hr = $\sum h_r$ (for instance, r = f2; 3; 4g gives $h_{\{2;3;4\}}$ = h2 + h3+h4) where r is a set of all active LED indices combinations used for mapping as given in Table II, Po = E[ksk1] denotes the average optical power of HSSK and ^ Po represents the average optical power of VGSSK.

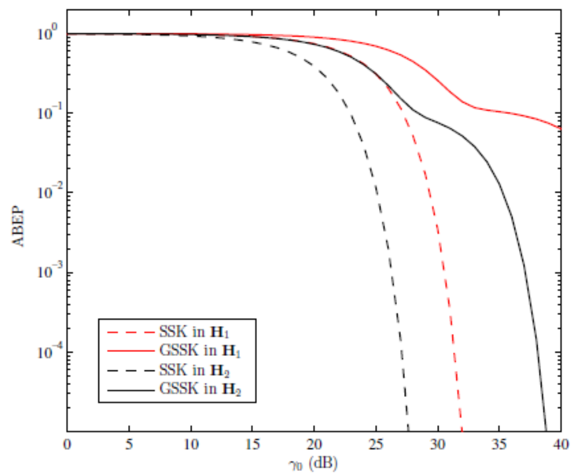

Figure 2. Performance comparison of SSK and GSSK for 2 bit/s/Hz under two different channels H1 and H2

4. RESULTS AND DISCUSSIONS

We follow the values of required parameters for simulation from [2]. Using (2), the channel matrix H1 and H2 are obtained and normalized which provides

$$\mathbf{H_1} = \begin{bmatrix} 0.2500 & 0.2389 & 0.2389 & 0.2284 \\ 0.2389 & 0.2500 & 0.2284 & 0.2389 \\ 0.2389 & 0.2284 & 0.2500 & 0.2389 \\ 0.2284 & 0.2389 & 0.2389 & 0.2500 \end{bmatrix} \quad (8)$$

and

$$\mathbf{H_2} = \begin{bmatrix} 0.2500 & 0.2190 & 0.2190 & 0.1922 \\ 0.2190 & 0.2500 & 0.1922 & 0.2190 \\ 0.2190 & 0.1922 & 0.2500 & 0.2190 \\ 0.1922 & 0.2190 & 0.2190 & 0.2500 \end{bmatrix}. \quad (9)$$

H1 is highly correlated channel as its condition number is large whereas H2 offers less correlation. Fig. 2 shows the performance comparison of SSK and GSSK for spectral efficiency of 2 bit/s/Hz under channels of high and low correlation. The above curves are obtained using the developed upper bounds which will be good approximations to simulations at high SNRs. It is observed that GSSK suffers from high correlation, but comparatively less degradation for SSK. This happens only for low data rate systems where spectral efficiency will be low. A simple numerical calculation gives the values of spectral efficiency as 3 bit/s/Hz and 6 bit/s/Hz for SSK and GSSK with system parameters Nt = 8 and Na = 4, respectively. To achieve a value of 6 bit/s/Hz, SSK-MIMO requires Nt = 64 which leads to the drawbacks such as increased levels of correlation and cost. It is immediately concluded that GSSK is favorable for any scale of MIMO systems. While comparing GSSK with both HSSK (for dmin = 2) and VGSSK, we find that there will be a spectral efficiency loss of 1 bit/s/Hz, i.e. the HSSK and VGSSK offers spectral efficiency of 7 bit/s/Hz.

Therefore, we focus our attention mostly on HSSK and VGSSK for VLC systems. Fig. 3 shows the performance comparison of SM, HSSK and VGSSK for 3 bit/s/Hz under the channels mentioned by H1 and H2. It is interesting to see that SM outperforms both HSSK and VGSSK. This also happens only for low data rate system, i.e. system with less spectral efficiency. For higher spectral efficiency, the constellation size will be large, even for same MIMO order. The large value contributes increase in average optical signal power. In order to maintain the average optical power of MIMO to be unity, the signal vector has to be scaled by the value of average optical power which reduces the intensity levels. These levels suffer more under high correlation and even in less correlation where the power loss presents. Further, we conclude that HSSK and VGSSK are suitable for high spectral efficiency systems. It is also observed that the performance gain of 1 dB is seen for VGSSK over HSSK under both the channels. Finally, we conclude that the suitability of VGSSK is justified for indoor optical wireless communications under different correlated channels.

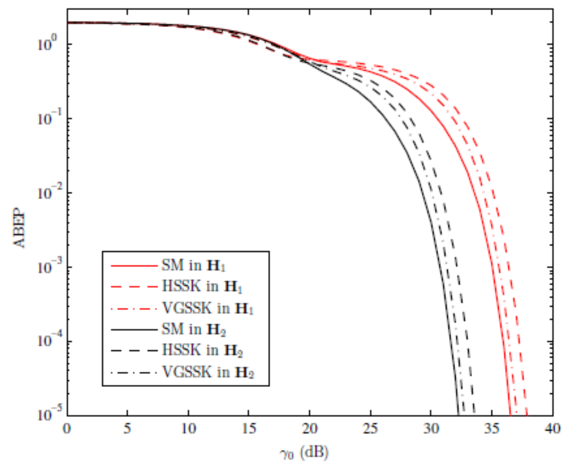

Figure 3. Performance comparison of SM, HSSK and VGSSK for 3 bit/s/Hz under H1 and H2

5. CONCLUSION

In this paper, the various SSK-MIMO techniques are studied and analyzed in VLC system. The performance gain of 1 dB is observed for VGSSK over HSSK steadily. It is concluded that VGSSK-MIMO provides the advantages such as simple encoding, high spectral efficiency, reasonable performance gain and cost effective which guarantees its suitability for large scale MIMO-VLC systems.

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