Joint Spatial Diversity and Network Coding in Satellite Communications

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Abstract. In this paper, we focus on the transmission reliability in satellite communications. In current algorithms, traditional Spatial Diversity (SD) was investigated to resist wireless channel fading. However, intermittent connections between satellites lead to the higher system outage probability. To solve this problem, we propose a novel joint SD and Systematic Random Linear Network Coding (SRLNC) transmission scheme, namely SD-SRLNC. For time-varying satellite channels, we assume that all the source-satellite links are ON/OFF channels, and then model the satellite transmission between ON and OFF states by using the two-state Markov chain. Following this, we discuss the procedure of SD-SRLNC, and provide a theoretical analysis on its effectiveness of resisting the fading in satellite channel. Furthermore, the expressions of outage probability and Bit Error Rate (BER) for the proposed scheme are derived respectively. Simulation results show that the proposed SD-SRLNC can improve the BER performance and reduce the outage probability compared with other existing transmission schemes.

Keywords: Satellite communication · Spatial diversity · Network coding · BER · Outage probability

1 Introduction

The presence of wireless channel fading raises more and more practical difficulties on transmission reliability in satellite communications [1–3]. As well known, Spatial Diversity (SD) has been proved as an effective way to combat the transmission failures in wireless fading channels [4–6]. Additionally, Network Coding (NC) has attracted much attention to mitigate the effect of wireless fading channel caused by its advantage in improving the network reliability and its application in the cooperative diversity communication. The author in [7] employed the XOR network coding in two-way relay satellite communication for the asymmetric data transmission. In [8], the authors applied Random Linear Network Coding (RLNC) to the multi-beam satellite communication scenario to provide enhanced and robust load-balancing to unequal load demands between beams. Therefore, the existing NC schemes proposed in the satellite communication mostly considered the XOR network coding and RLNC.

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Recently, a novel network coding named Systematic Network Coding (SNC) using XORs was introduced in [9] to provide the closer performance of completion time and the added advantage of requiring fewer and simpler operations during the decoding process compared with the RLNC scheme. But, when using XORs, a direct link between the source and the destination must be existed. The author in [10] proposed a SNC using RLNC scheme, namely Systematic Random Line Network Coding (SRLNC), where the source could transmit data just via relay, and denoted the proposed approach reduced the packet loss compared with the traditional RLNC scheme. With SNC using RLNC, the author demonstrated the less computation time in encoding & decoding in [11] and showed higher decoding probability than traditional RLNC in [12]. Distinguished from [10–12], SNC using RLNC was applied to satellite communication scenarios to jointly optimize throughput and packet drop rate in [13].

In order to make further improvement of system performance, several works have focused on studying how to introduce NC along with SD into the wireless communication to reduce the effect of fading and increase the transmission reliability [14–16]. In [14], the XOR network coding was applied to the distributed wireless network and better diversity performance was obtained. In [15], a protocol named network coding cooperative MAC was introduced to obtain the better network throughput and delay by employing RLNC in the distributed cooperative network. The author in [16] presented several important contributions to the improvement of overall performance of combining analog network coding with SD in wireless relay networks. As a result, the combinational scheme of SD and NC has been applied widely for wireless channel transmission to improve system performance effectively. Therefore, as above mentioned, the existing joint schemes mainly considered the combination of SD and XORs, SD and RLNC, even SD and analog network coding, few have introduced SRLNC into the SD up till the present. And also, most of them mainly focused on the terrestrial communications, few papers on the satellite communications [13], where the wireless link is intermittent, the error probability is higher, and the transmission outage is more possible compared with terrestrial communications.

In light of above problems, we propose a novel joint SD and SRLNC (SD-SRLNC) scheme based on the ON/OFF satellite channels by taking comprehensively into account the advantages of SD and SRLNC. In the following, we assume that the destination can receive data from two sources simultaneously. All links between sources and satellite are modeled as ON/OFF channels, the link between satellite and ground terminal is assumed reliable. Based on the proposed satellite communication model, we discuss the procedure of data transmission for SD-SRLNC, and provide a theoretical analysis on its effectiveness of resisting the fading in satellite channel. Also, the expressions of outage probability and BER are derived. Simulation results show that SD-SRLNC has much better outage probability performance than the traditional SD scheme and the SD-RLNC scheme, but does not outperform SD-RLNC with respect to BER. Through the paper, we can help the readers decide which type of NC should be employed to be jointed with SD according to the performance they need optimize.

The rest of the paper is organized as follows. Section 2 introduces the system model and the transmission procedure of the SD-SRLNC scheme. In Sect. 3, the system outage probability and BER of the proposed scheme are derived by analyzing the model feature. The simulation results are given in Sect. 4.

2 System Model

In this section, we describe the system model and state the primary procedure of the SD-SRLNC scheme in the satellite communication.

As shown in Fig. 1, we consider a cooperative satellite model consisting of four parts: two source areas A and B, a satellite relay R and a destination D. In this model, sources only can transmit their information to D via R. We let the set $\{S_1, S_2, \ldots S_{|s|}\}$ and $\{S_{-1}, S_{-2}, \ldots S_{-|s|}\}$ respectively denote the sources included in A and B areas. The data that is going to be transmitted are composed by N packets, expressed by the set $P_1, P_2, \ldots P_N$. Each source and relay use 4-QAM modulation. Also, we assume that the two areas have the same transmission process.

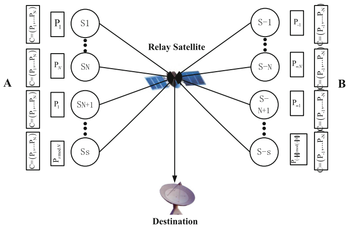

Fig. 1. The model of SD-SRLNC

In addition, the links between sources and satellite are assumed to suffer from shadowed-Rican fading, and modeled as ON/OFF channels, meanwhile the link between satellite and ground terminal is reliable. During the ON states, the relay satellite receives packets from the sources correctly and during the OFF states, packets are lost. Let E_G and E_B be the expected durations in seconds of the good and bad states respectively. For a mean transmission rate of R packets per second, the mean durations in packets of the good D_G and bad D_B states are derived and given by $D_G = R \cdot E_G, D_B = R \cdot E_B$ respectively [17]. The probabilities are expressed as $P_G = D_G/(D_G + D_B)$ $P_B = D_B/(D_G + D_B)$. In this paper we assume uncorrelated channels but with identical channel statistics.

Following above assumptions and known conditions, we take just the transmission in one area as an example to state the primary procedure of the SD-SRLNC scheme. The transmission can be divided into two substeps: (1) each source from S_1 to S_N sends R a different uncoded packet P_1 to P_N, then sources $S_{N+1}, S_{N+2}, \ldots S_{|S|}$ correspondingly send $P_1, P_2, \ldots P_{|s| \text{mod} N}$; (2) the sources send coded packets to R that are generated from N native packets using RLNC. The R handles these packets and transmits them to D.

As for the traditional SD, each source sends an uncoded packet to R. The SD-RLNC scheme employs RLNC to generate a single coded packet from N native packets, and uses SD to send the coded packets to R.

3 Performance Analysis of SD-SRLNC

In this section, we analyze and derive the system outage probability and BER of the SD-SRLNC scheme, and also compare the performance of the proposed scheme with the existing schemes including the traditional SD and SD-RLNC.

3.1 The Outage Probability

The Outage Probability of SD-SRLNC. Firstly, we derive the expression of outage probability in the A area through analyzing the transmission process of SD-SRLNC, and then according to the feature of the communication model, we obtain the system outage probability. We focus on the transmission of N different packets. Let the set of packets to be transmitted be $P = \{P_1, P_2, \ldots P_N\}$. Let n_{Pj} denote the number of sources sending the packet P_j with $1 \leq j \leq N$.

As the description in Sect. 2, the SD-SRLNC scheme transmission is divided into two stages. If both of the two stages occur outage, the whole transmission will be fail. So the outage probability of this scheme at the area A is expressed as,

$$P_{out1}^{SNC} = P_{out1}^{SD} \cdot P_{out1}^{NC} \tag{1}$$

The system outage probability is given by,

$$P_{out}^{SNC} = 1 - \left(\left(1 - P_{out1}^{SNC}\right) \cdot \left(1 - P_{out1}^{SNC}\right)\right) \tag{2}$$

where P_{out1}^{SD} detonates the outage probability when the sources send uncoded packets at the first stage, and P_{out1}^{NC} is the outage probability when sending coded packets at the second stage.

In the following, we introduce the expressions of P_{out1}^{SD} and P_{out1}^{NC}. At the first stage, sources employ SD scheme to send their uncoded packets to R, and a system outage occurs when any of the N packets is not received. The outage probability of SD in area A is given by,

$$P_{out1}^{SD}(N, |S|) = 1 - \sum_{i=N}^{|S|} P_G^i P_B^{|S|-i} T_{i,N} \tag{3}$$

where i denotes the number of links between sources and satellite in good sate and $T_{i,N}$ computes the number of ways of getting N different packets taking into account the cases where repeated versions of the same packet would be received. To compute $T_{i,N}$, we should first get the integer solutions of the following expression,

$$x_{P1} + \ldots + x_{PN} = i, 1 \le x_{Pj} \le n_{Pj}, j = 1, \ldots N \tag{4}$$

The equation can be solved through standard algorithms [16]. Let $x^*_{l,Pj}, \ldots, x^*_{l,PN}$ be one of the N_s solutions of (5), then we can obtain $T_{i,N}$ given by,

$$T_{i,N} = \sum_{l=1}^{N_s} \left(\prod_{j=1}^{N} \binom{n_{Pj}}{x^*_{l,Pj}} \right) \tag{5}$$

Plugging (5) into (3), we obtain the expression for P^{SD}_{out1}.

At the second stage, the sources transmit coded packets which are generated from the N native packets to R. We use L to denote the length in bits of a native packet, and the payload of each packet is split into blocks of $m^{'}$ bits. The $k-th$ coded block of a coded packet is given by,

$$C_K = \sum_{j=1}^{N} c_j b_{jk}, \forall k = \left\{1, \ldots, L\Big/m^{'}\right\} \tag{6}$$

where b_{jk} denotes the $k-th$ block of $j-th$ packet, with $1 \le k \le L\big/m^{'}$, and c_j denotes encoding coefficients chosen from F_q, with $q = 2^m$.The encoding coefficients $c_1, \ldots, c_N$ are added in the header of the packet. At the relay, at least N coded packets must be received to retrieve the original packets. The parameter m is the size of the finite field and should be big enough to ensure that the probability of generating two linearly dependent (l.d.) coded packets is negligible. The outage occurs when less than N coded packets are received at the relay in the A area,

$$P^{NC}_{out1}(N, |s|) = 1 - \sum_{i=N}^{|s|} P^i_G P^{|s|-i}_B \binom{|s|}{i} \tag{7}$$

For a given $i \ge N$, the term $P^i_G P^{|s|-i}_B$ denotes the probability of having i links between sources and satellite in good state and $\binom{|s|}{i}$ computes the number of distinct i link subsets from the $|s|$ links between sources and satellite.

Plugging (3), (7) into (1) and combining (2), we can obtain the system outage probability for the SD-SRLNC scheme.

The Outage Probability of Traditional SD. From the analysis in part above, we know the outage probability for area A by using traditional SD. Now that the two areas have the same transmission, the system outage probability with traditional scheme is shown as,

$$P^{SD}_{out} = 1 - \left(\left(1 - P^{SD}_{out1}\right) \cdot \left(1 - P^{SD}_{out1}\right)\right) \tag{8}$$

Plugging (3) into (8), we have,

$$P_{out}^{SD} = 1 - \sum_{i=N}^{|s|} P_G^i P_B^{|s|-i} T_{i,N} \cdot \sum_{i=N}^{|s|} P_G^i P_B^{|s|-i} T_{i,N} \tag{9}$$

The Outage Probability of SD-RLNC. The main idea of SD-RLNC is that each source sends a single coded packet. We have known the outage probability for area A from above, so the system outage probability by using SD and RLNC is computed as,

$$P_{out}^{NC} = 1 - \left(\left(1 - P_{out1}^{NC}\right) \cdot \left(1 - P_{out1}^{NC}\right)\right) \tag{10}$$

Plugging (7) into (10), we have,

$$P_{out}^{NC} = 1 - \sum_{i=N}^{|s|} P_G^i P_B^{|s|-i} \binom{|s|}{i} \cdot \sum_{i=N}^{|s|} P_G^i P_B^{|s|-i} \binom{|s|}{i} \tag{11}$$

3.2 The BER Performance

The BER Performance of SD-SRLNC. A coded packet is composed of $l_0 = h + L_n + Ng$, where h represents the number of bits allocates for the packet's header, L_n denotes the number of bits for the linear combination of all N data packets, and $g = \log_2 q$ is the number of bits used to represent the randomly chosen coding coefficients for each data packet. In the SD-SRLNC scheme, according to the definition of BER we provide the computational formula of the system using SRLNC in area A,

$$P_{AR}^{SNC} = \frac{P_{AR}^{SD} \times L_n + P_{AR}^{NC} \times |s| \times (h + L_n + \log_2 q)}{L_n + |s| \times (h + L_n + \log_2 q)} \tag{12}$$

$$P_{BR}^{SNC} = \frac{P_{BR}^{SD} \times L_n + P_{BR}^{NC} \times |s| \times (h + L_n + \log_2 q)}{L_n + |s| \times (h + L_n + \log_2 q)} \tag{13}$$

The system BER for SD-SRLNC scheme is expressed as,

$$\begin{aligned} P_e^{SNC} = {} & (1 - P_{RD}^{SNC})(P_{AR}^{SNC}(1 - P_{BR}^{SNC} + (1 - P_{AR}^{SNC})P_{BR}^{SNC} + P_{BR}^{SNC}P_{AR}^{SNC}) + \\ & P_{RD}^{SNC}(1 - (P_{AR}^{SNC}(1 - P_{BR}^{SNC}) + (1 - P_{AR}^{SNC})P_{BR}^{SNC} + P_{BR}^{SNC}P_{AR}^{SNC})) \end{aligned} \tag{14}$$

where $P_{RD}^{SNC} = P_{RD}^{NC} = P_{RD}$ denotes the BER of link $R \rightarrow D$ with SD-SRLNC, P_{AR}^{SD}, P_{BR}^{SD} respectively denotes the BER using traditional SD scheme in area A and B, P_{AR}^{NC} and P_{BR}^{NC} respectively denote the BER from A and B areas to the relay in the case of SD-RLNC.

In the following, we introduce the expression of P_{AR}^{SD}, P_{BR}^{SD} and P_{AR}^{NC}, P_{BR}^{NC}. Throughout the paper, the links between satellite and ground are assumed to suffer from shadowed-Rican fading. Adopting the shadowed Rican model, Nakagami-m_0

random variables with average power Ω, where m_0 describes the severity of shadowing varying over the range $m_0 \geq 0$. Let h_{xy} denote the coefficient of channel fading, and r_{xy} denotes the average SNR from node x to node y. The Probability Density Function (PDF) of is shown as (8), where $x \in \{A, B, R\}$, $y \in \{R, D\}$,

$$f_{r_{xy}}(r_{xy}) = \alpha \sum_{l=0}^{c} \binom{c}{l} \beta^{c-1} \left(F\left(r_{xy}, l, d, \bar{r}_{xy}\right) + \varepsilon\delta F\left(r_{xy}, l, d+1, \bar{r}_{xy}\right) \right) \tag{15}$$

where

$$\begin{aligned} F(r_{xy}, l, d, \bar{r}_{xy}) = & \frac{(\beta-\delta)^{\frac{l-d}{2}}}{\bar{r}_{xy}^{\frac{d-l}{2}} \Gamma(d-l)} r_{xy}^{\frac{l-d}{2}-1} e^{\frac{\beta-\delta}{2\bar{r}_{xy}} r_{xy}} \\ & \times \mathrm{M}_{\frac{d+l}{2}, \frac{d-l-1}{2}} \left(\frac{\beta-\delta}{\bar{r}_{xy}} r_{xy} \right) \end{aligned} \tag{16}$$

$$\bar{r}_{xy} = \frac{E_b}{N_0} E\left[\left| h_{xy} \right|^2 \right] \tag{17}$$

$$\begin{cases} \beta = (0.5/b) \\ c = \left(d - N_0^+\right) \\ \varepsilon = m_0 - d \\ \delta = 0.5\Omega/(2b^2 + b\Omega) \\ \alpha = 0.5(2bm_0/(2bm_0 + \Omega))m_0/b \end{cases} \tag{18}$$

where N_0 denotes the antenna numbers equipped at the relay and destination, $d = \max\{1, \lfloor m_0 \rfloor\}$, $\lfloor m_0 \rfloor$ denotes the largest integer not greater than m_0; $\left(d - N_0^+\right)$ indicates that if $(d - N_0) \leq 0$, then use $d - N_0 = 0$; $\max\{1, \lfloor m_0 \rfloor\}$ chooses the greatest of the two positive integers; $\Gamma(\cdot)$ denotes the Gamma function [17], and $M_{u,v}(\cdot)$ represents the Whittaker function [17].

We assume that at the two areas each link between source and satellite has the same BER P_{A1R}, P_{B1R} expressed by (15) during the good state, and during the bad state, the BER is equal to 1.

According to [1],

$$\begin{aligned} P_{A1R} = P_{B1R} = \alpha \sum_{l=0}^{c} \binom{c}{l} \beta^{c-1} \times \\ \left[T(1, l, d, \bar{r}_{A1R}) + \varepsilon\delta T(1, l, d+1, \bar{r}_{A1R}) \right] \end{aligned} \tag{19}$$

$$P_{RD} = \alpha \sum_{l=0}^{c} \binom{c}{l} \beta^{c-1} \times \left[T(1, l, d, \bar{r}_{RD}) + \varepsilon\delta T(1, l, d+1, \bar{r}_{RD}) \right] \tag{20}$$

where

$$T(1,l,d,\bar{r}_{xy}) = \frac{\Gamma(d-l+1/2)}{2\sqrt{\pi}\times(1/2)^{d-l}\times\bar{r}_{xy}\times\Gamma(d-l+1)}\times \\ {}_3F_2\left(d,d-l,d-l+\frac{1}{2};d-l+1,d-l;-\frac{(\beta-\delta)}{1/2\bar{r}_{xy}}\right) \tag{21}$$

where ${}_3F_2(\cdot,\cdot,\cdot;\cdot,\cdot;\cdot)$ represents the generalized Hypergeometric function. The expression of BER from A to R is the following,

$$P_{AR}^{SD} = P_L \times \frac{L\times P_{A1R} + (N-L)}{N} \tag{22}$$

$$P_L = \sum_{i=L}^{|s|} P_G^L P_B^{|s|-L} T_{i,L}, 0 \le i \le L, 0 \le L \le N \tag{23}$$

The first term in (22) represents the number of methods to send L packets to relay successfully, the second term denotes the BER of sending L packets one time.

Similarly to A, the BER of B is calculated as

$$P_{BR}^{SD} = P_L \times \frac{L\times P_{B1R} + (N-L)}{N} \tag{24}$$

The P_{AR}^{NC}, P_{BR}^{NC} respectively denote the BER from A or B area to the relay in the case of SD-RLNC, and are expressed as,

$$P_{AR}^{NC} = \sum_{i=0}^{|s|} C_{|s|}^i P_G^i P_B^{|s|-i} P_{A1R} \tag{25}$$

$$P_{BR}^{NC} = \sum_{i=0}^{|s|} C_{|s|}^i P_G^i P_B^{|s|-i} P_{B1R} \tag{26}$$

The BER Performance of Traditional SD. With the traditional SD, at the relay, the satellite obtains the data from A and B, then recodes and sends them to D using RLNC. The error occurs at the destination when either of the two data is transmitted incorrectly or the relay sends incorrect data, so the system BER is expressed as,

$$P_e^{SD} = \left(1-P_{RD}^{SD}\right)\left(P_{AR}^{SD}\left(1-P_{BR}^{SD}\right)+\left(1-P_{AR}^{SD}\right)P_{BR}^{SD}+P_{AR}^{SD}P_{BR}^{SD}\right)+ \\ P_{RD}^{SD}\left(1-\left(P_{AR}^{SD}\left(1-P_{BR}^{SD}\right)+\left(1-P_{AR}^{SD}\right)P_{BR}^{SD}+P_{AR}^{SD}P_{BR}^{SD}\right)\right) \tag{27}$$

where $P_{RD}^{SD} = P_{RD}$ that computed by (20) denotes the BER of transmitting data from relay to destination, and P_{AR}^{SD},P_{BR}^{SD} that expressed in (22) and (24) respectively means the BER from A or B to the relay.

Plugging (20), (22) and (24) into (27), we can obtain the system BER of SD.

The BER Performance of SD-RLNC The SD-RLNC scheme employs RLNC to deal with the signal at each source and the encoded packets will be sent to the relay. Under the condition that each area at less N packets are received at the relay, then the relay decodes the packets using RLNC, finally sends packets to the destination. The expression of BER of SD-RLNC is given by,

$$\begin{aligned} P_e^{NC} = &\left(1 - P_{RD}^{NC}\right)\left(P_{AR}^{NC}\left(1 - P_{BR}^{NC}\right) + \left(1 - P_{AR}^{NC}\right)P_{BR}^{NC} + P_{BR}^{NC}P_{AR}^{NC}\right) + \\ &P_{RD}^{NC}\left(1 - \left(P_{AR}^{NC}\left(1 - P_{BR}^{NC}\right) + \left(1 - P_{AR}^{NC}\right)P_{BR}^{NC} + P_{BR}^{NC}P_{AR}^{NC}\right)\right) \end{aligned} \tag{28}$$

where $P_{RD}^{NC} = P_{RD}\, P_{AR}^{NC}$ and P_{BR}^{NC} shown in (25) and (26) respectively denote the BER from A or B area to the relay in the case of SD-RLNC. Plugging (20), (25) and (26) into (28), we can obtain the BER of SD-RLNC system.

4 Simulation Results

In this section, we verify the performance of our proposed scheme and compare it with that of the traditional SD, the SD-RLNC. Throughout the simulation, the number of antenna equipped at the relay and destination is $N_0 = 1$; the number of transmitted packets $N = 2$; the number of data bits in a packet $L = 1600$; the number of header bits $h = 80$ and the number of sources in one area is from 2 to 10. Moreover, the field size is set $q = 2^8$, $E_G = 1200, E_B = 600$ and the transmission rate R = 10 kbps, transmission rate is very low since the uplink for this scenario is typically used for sending command message. The channel is assumed to suffer from the average shadowing (AS) Rican fading unless mentioned otherwise.

In Fig. 2, we compare the system outage probability of three schemes. We can observe clearly under the condition of $|s| = 2$, the outage probability is almost identical of the three schemes. As the increase of the number of sources, the outage probability decreases for all of these schemes. In addition, it is obviously indicated that the performance of SD-SRLNC is much better than that of another two schemes as sources increase. The SD-RLNC outperforms than SD, from which we conclude combining SD and NC should be employed widely in satellite communication to reduce outage probability and improve the satellite communication reliability.

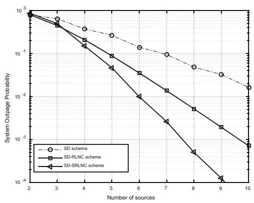

Fig. 2. The outage probability of SD, SD-SRLNC and SD-RLNC

The BER performance of these three schemes are simulated and compared in Fig. 3. It can be obtained that our proposed scheme behaves much better than that of SD, but does not outperform than SD-RLNC. The reason for the better performance of SD-RLNC scheme is that RLNC avoids duplicated versions of the same packets are received, and RLNC provides fair protection of the packets. Each coded packet stores information from *N* original packets, then if one source-satellite link is in bad state, it equally affects to all the *N* packets and not to a single packet. The SD-SRLNC and SD may provide duplicated versions. The Fig. 2 indicates that our proposed SD-SRLNC reduces the outage probability by sacrificing the BER performance. We can determine which combination scheme should be employed in satellite communication depending on the different optimized goal.

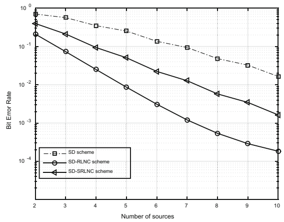

Fig. 3. The BER of SD, SD-SRLNC and SD-RLNC

In Fig. 4, we compare the BER performance for three schemes in the case of frequent heavy shadowing (FHS), average shadowing (AS) and infrequent light shadowing (ILS). The simulated paratemers under these shadowing enviroments are shown in Table 1. From Fig. 4, we can observe that the BER performance in AS and ILS environments is much better than that in the FHS environment. Also, the BER performance of SD-RLNC in the AS environment approximates to that in the ILS when the number of sources is 2 to 5. As the increasing of number of sources, the distinction is obvious. When using SRLNC, the BER performance of AS and ILS is always closer.

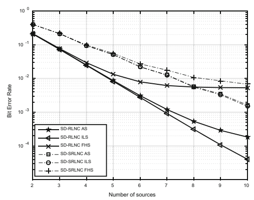

Fig. 4. The BER for SD-SRLNC in different shadowing environment

Table 1. Different shadowing environment parameter

Shadowing	b	m_0	Ω
Frequent heavy shadowing (FHS)	0.063	0.739	8.97×10^{-4}
Average shadowing (AS)	0.126	10.1	0.835
Infrequent light shadowing (ILS)	0.158	19.4	1.29

The E_G and E_B is the expected durations in seconds of the good and bad states respectively. In Fig. 5, we investigate the effect of the variation on the performance in terms of the outage probability for the aforementioned schemes. We can obtain the better system performance with the variation of E_G from 600 to 1200. Additionally, the figure indicates that lower outage probability is obtained when $E_G > E_B$ than that of $E_G = E_B$.

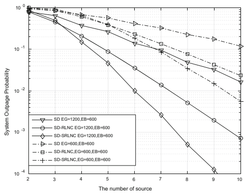

Fig. 5. The outage probability with different E_G and E_B

5 Conclusion

In this paper, considering the issue on transmission failures due to the deep fading produced by the randomness of the surrounding environment, we have analyzed the existed traditional schemes and proposed the SD-SRLNC scheme in the scene of multiple sources-single relay-single destination. In addition, we derive the outage probability and BER expressions of these schemes. Simulation results show that the proposed scheme outperforms SD-RLNC scheme and traditional SD in terms of outage probability, and the performance will be promoted as the increase of the numbers of sources. However, the SD-RLNC scheme provides the best BER performance. The simulation results will be helpful to make the decision for choosing the appropriate scheme according to different requirements in satellite communications.

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