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ABER analysis of RIS-aided SSK schemes over Ricean fading channels

RIS-destekli SSK şemalarının Ricean sönümlenmeli kanallardaki ABER analizi

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Abstract

Reconfigurable intelligent surface (RIS) is a promising technology to meet the needs of next-generation wireless communication techniques that enhance the quality of service by effectively adjusting the phases of the signals through a reflective surface. On the other side, space shift keying (SSK), as one of the typical index modulation (IM) techniques, provides data transmission by using only the information of the active transmitting antenna index instead of applying traditional modulation methods. In this study, two of the RIS-assisted SSK schemes are studied to take potential benefits of both RIS and SSK techniques, and the average bit error rate (ABER) performance is investigated over Ricean fading channels. The activated transmitter antenna for each transmission instant is detected by utilizing the maximum likelihood (ML) detection algorithm at the receiver side. The ABER performance of the proposed RIS-based systems in proportion to the increasing number of reflecting elements and Ricean-*K* factor is presented by both theoretical derivations and computer simulations. The obtained results show that the Ricean-*K* parameter and the number of reflective elements on the RIS have an undeniable effect on the system performance.

Keywords: Wireless communication, Error performance analysis, Reconfigurable intelligent surface (RIS), Index modulation (IM), Space shift keying (SSK).

Öz

Uyarlanabilir akıllı yüzey (RIS), yeni nesil kablosuz iletişim tekniklerinin gereksinimlerini karşılamak üzere yansıtıcı bir yüzey üzerinden sinyallerin fazını etkin bir şekilde düzenleyerek hizmet kalitesini artıran umut verici bir teknolojidir. Öte yandan, tipik indis modülasyon (IM) tekniklerinden biri olan uzay kaydırmalı anahtarlama (SSK), veri iletimi için klasik modülasyon yöntemlerini uygulamak yerine sadece aktif verici anten indisi bilgisini kullanmaktadır. Bu çalışmada, hem RIS hem de SSK tekniklerinin potansiyel avantajlarından yararlanmak için RIS-destekli SSK şemalarından ikisi incelenmekte ve Ricean sönümlenmeli kanallar üzerindeki ortalama bit hata oranı (ABER) performansı değerlendirilmektedir. Her iletim anı için aktif edilen verici anten, alıcı tarafta en büyük olabilirlik (ML) sezimi algoritması kullanılarak belirlenmiştir. Önerilen RIS-tabanlı sistemlerin artan yansıtıcı eleman sayısı ve Ricean-*K* faktörüne göre ABER performansı, hem teorik türetimler hem de bilgisayar simülasyonları aracılığıyla sunulmuştur. Elde edilen sonuçlar, Ricean-*K* parametresinin ve RIS üzerindeki yansıtıcı eleman sayısının sistem performansı üzerinde yadsınamaz bir etkiye sahip olduğunu ortaya koymaktadır.

Anahtar kelimeler: Kablosuz iletişim, Hata performansı analizi, Uyarlanabilir akıllı yüzey (RIS), İndis modülasyonu (IM), Uzay kaydırmalı anahtarlama (SSK).

1 Introduction

The demand of ultra-high performance communication devices is increasing day by day depending on the advancement of technology. Unfortunately, the conventional communication techniques are inadequate to attain the objectives of the next generation wireless networks, such as ultra-fast data transfer at extremely high frequency bands. This inability of existing communication methods necessitates novel transceiver designs and innovative transmission and modulation techniques. Regarding this, both academic and industrial studies are focused on providing high spectral and energy efficiency for future wireless communication systems.

Accordingly, reconfigurable intelligent surface (RIS) is proposed as a high-potential technology that can satisfy the requirements of 6^{th} generation (6G) wireless communication networks and beyond. An RIS can be simply integrated into the existing wireless communication systems with the ability of effectively controlling and/or manipulating the wireless channel through the phase adjustment, which provides considerable enhancement in overall system performance [1]. Specifically, it reveals the ability of using wireless channels in the most efficient way by making changes in the amplitude and/or phase of the radio signals [2].

Multiple-input multiple-output (MIMO) systems, which conventionally configure a separate RF chain for each antenna, are also proposed as a key physical layer solution to increase spectral efficiency [3]. However, a larger number of RF chain increases the cost of both the RF circuit and wireless cellular networks [4]. Additionally, hundreds or even thousands of antennas are simultaneously being activated in massive MIMO systems, and that causes a significant increment in the energy consumed by the RF chain [5]. Besides, a larger number of selected/activated antennas increases the power required by processing

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activities [6]. Hence, to overcome that power consumption, finding new solutions with limited RF chain and active antenna number becomes an emerging challenge for the future wireless communication systems.

At this point, index modulation (IM) techniques, in which data bits are transmitted using IM bits as well as modulation bits [7], are promising. More specifically, spatial modulation (SM) and its simplified version, spatial shift keying (SSK), convey information via activating only one transmitter antenna during each transmission slot. Thus, the transceiver requires only one RF chain at the transmitter side for each transmission instant [8]. Hereby, the communication is completed without inter-channel interference and receiver complexity.

Recently, the researchers investigate the potential of RIS assisted IM schemes, which retain the advantages of both IM and RIS. The first RIS-SSK/SM schemes were introduced only about two years ago [8], which shows that further investigations are required to gain a clear understanding about their full potential. An energy-efficient RIS-based SSK scheme was introduced in [9] considering Rayleigh fading channels to provide reliable transmission and avoid synchronization and interference problems by exploiting the SSK at the transmitter side. Another RIS-aided SSK scheme that grants knowledge of the active antenna index at the RIS and achieves passive beamforming, was also proposed in [10].

In wireless communications, the combination of constructive and destructive effects stemming from randomly delayed, reflected, scattered and refracted signal components cause multipath fading. Depending on the nature of the propagation environment, there are different models describing the statistical behavior of this effect. For instance, Rayleigh model is usually preferred for preliminary studies to provide the basis for further theoretical research, since it leads to neat and easy closed-form expressions. Rayleigh is generalized by including a deterministic component providing arbitrary mean values for the complex-valued variables, and called Ricean fading model, which is generally used to model propagation path gains consisting of one strong line-of-sight (LOS) component and many other random weak components [11].

In this paper, two of the RIS-assisted SSK MISO transmission schemes are investigated in terms of error probability over Ricean fading channels. Performance analyses are realized by theoretical calculations using maximum likelihood (ML) detection and verified by computer simulations. The obtained results show that including an RIS can provide considerably superior results for traditional SSK schemes depending on the system model.

2 Material and methods

2.1 Channel model

Ricean can be defined as the probability distribution of the magnitude of a non-zero mean circularly symmetric bivariate normal random variable. Following that, a Ricean distributed variable, R, with a noncentrality parameter, $|v|$, and a scale parameter, σ, can be denoted by $R\sim Rice(|v|,\sigma)$, and has the following probability density function [12]:

$$f(r\mid v,\sigma)=\frac{r}{\sigma^2}\exp\left(-\frac{(r^2+v^2)}{2\sigma^2}\right)I_0\left(\frac{rv}{\sigma^2}\right), \tag{1}$$

where I_0 is being the modified Bessel function of the first kind with order zero.

Then, the mean value is calculated from the expectation of R, and given as:

$$\mu_R=E\{R\}=\sigma\sqrt{(\pi/2)}L_{1/2}\left(\frac{-v^2}{2\sigma^2}\right), \tag{2}$$

while the variance of R can be written by

$$\sigma_R^2=2\sigma^2+v^2-\frac{\pi}{2}\sigma^2L_{1/2}\left(\frac{-v^2}{2\sigma^2}\right). \tag{3}$$

Here, defining $K=v^2/2\sigma^2$ as the Ricean parameter, $L_{1/2}(-K)$ represents the Laguerre polynomial, which can be calculated by utilizing the confluent hypergeometric function of the first kind as $L_{1/2}(-K)={}_1F_1(-1/2;1;-K)$ [13].

Now, considering the abovementioned points, the Ricean fading channels can be modeled as follows [14]:

$$h=\Delta h_{det}+\Theta h_{rand}, \tag{4}$$

where h_{det} is a deterministic component related to the LOS path, while h_{rand} is a random component representing the fading of the scattered paths. Here, it should be given that $\Delta=\sqrt{K/(K+1)}$, $\Theta=\sqrt{1/(K+1)}$, and thus, $K=\Delta^2/\Theta^2$. Regarding that, the mean and variance values of a Ricean distributed variable are also written as follows, respectively:

$$\mu_R=\frac{\sqrt{\pi}L_{1/2}(-K)}{2\sqrt{K+1}}, \tag{5}$$

$$\sigma_R^2=1-\frac{\pi L_{1/2}^2(-K)}{4(K+1)}. \tag{6}$$

It is worth noting here that the Ricean fading model turns into the Rayleigh fading model when $K=0$.

2.2 System model

In this section, the system models of the proposed schemes, namely intelligent and power-sensing RIS-SSK, are presented. The proposed schemes are built on a dual hop scenario in which a base station applying SSK with N_t transmitter antennas and communicating with a single-antenna receiver through an RIS with N reflecting elements on it. The reflection phases of the incoming signals are adjusted by using a communication software so as to maximize the signal-to-noise ratio (SNR) at the receiver side.

2.2.1 Intelligent transmission scheme for RIS-SSK

The transmission model of the intelligent RIS-assisted SSK wireless communication system, which operates similar to that given in [9], is illustrated in Fig. 1. Unlike [9], here, the receiver is assumed to be unaware of the selected reflection phase, which is more practical. Thus, the received unmodulated baseband signal can be written as follows:

$$y = \sqrt{E}\left(\sum_{i=1}^{N} h_{t,i} e^{j\phi_i} g_i\right) + n = \sqrt{E}\left(\sum_{i=1}^{N} \alpha_{t,i}\beta_i e^{j(\phi_i - \theta_{t,i} - \varphi_i)}\right) + n. \quad (7)$$

where $t \in \{1,\ldots,N_t\}$ is the index of the activated transmitter antenna for data transmission, while $h_{t,i} = \alpha_{t,i}e^{-j\theta_{t,i}}$ and $g_i = \beta_i e^{-j\varphi_i}$ are the channel fading gain between the t^{th} transmit antenna and the reflecting elements, and between the reflecting elements and the receiver antenna, respectively. Additionally, E is the transmitted signal energy and ϕ_i is the adjusted phase for the i^{th} reflector of the RIS. Besides that, $n \sim \mathbb{CN}(0, N_0)$ represents the additive white Gaussian noise (AWGN) with a total noise power of N_0, while $\mathbb{CN}(\mu, \sigma^2)$ denoting a complex Gaussian random variable with mean μ and variance σ^2.

Here, it should be noted that the value of the received SNR can be maximized by eliminating the channel phases with the help of the RIS that has the knowledge of the channel phases, as $\phi_i = \theta_{t,i} + \varphi_i$ [9]. Hence, the received signal at the destination can be rewritten as:

$$y = \sqrt{E}\left(\sum_{i=1}^{N} \alpha_{t,i}\beta_i\right) + n. \quad (8)$$

It is worth noting here that the RIS needs to know not only the channel phases, but also the activated transmitter antenna index, which defines the best-case scenario that might be possible when the BS is in the near field of the RIS [9]. Thus, perfect channel state information is assumed to be provied for the RIS via a communication software possibly supported by machine-learning algorithms [15]. On the other hand, a multi-antenna receiver is not a practical scenario for the proposed scheme discussing optimal phase adjustment, since the reflectors can be set at just one specific phase for each reflection.

2.2.2 Power-sensing transmission scheme for RIS- SSK

The transmission model of the power-sensing RIS-assisted SSK wireless communication system is illustrated in Fig. 2. The key strategy of this concept is granting the knowledge of the activated transmitter antenna index at the RIS with the help of the embedded sensors throughout the RIS. Here, the transmitter antennas convey the data with different power levels on the condition of a fixed average power, and then the sensors located on the RIS sense the power and adjust the reflection angle for that transmission instant via a communication software.

Accordingly, the received signal can be written by:

$$y = \sqrt{P_t}\left(\sum_{i=1}^{N} h_{t,i} e^{j\phi_{t,i}} g_i\right) + n, \quad (9)$$

where $P_t = k_t E$ is the power of the t^{th} transmitter antenna with a power constant of $k_t = (2t-1)/N_t$. Remembering that the received SNR should be maximized by utilizing the same method used for the intelligent scheme, i.e., eliminating the channel phases, the received signal can be rewritten as follows:

$$y = \sqrt{P_t}\left(\sum_{i=1}^{N} \alpha_{t,i}\beta_i\right) + n. \quad (10)$$

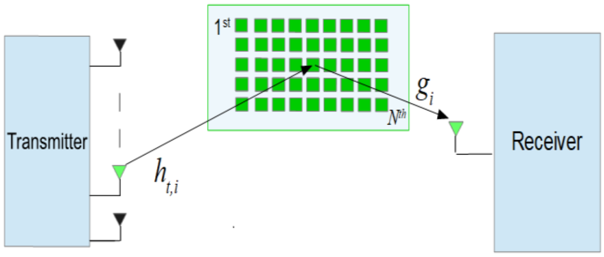

Fig. 1. Transmission scheme of the intelligent RIS-SSK.

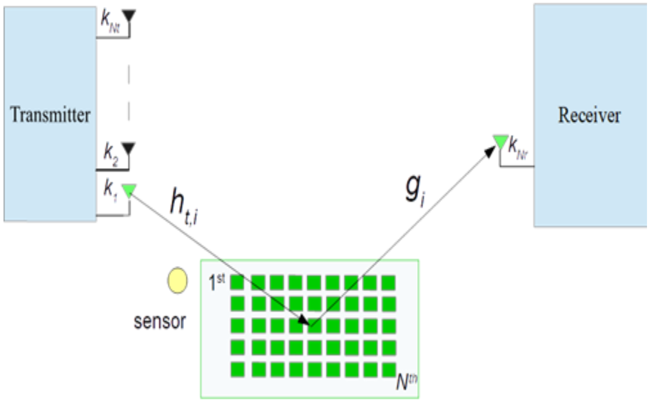

Fig. 2. Transmission scheme of the power-sensing RIS-SSK.

2.3 Performance analysis

In this section, analytical derivations of the ABER over Ricean fading channels are presented for both intelligent and power-sensing transmission cases of RIS-aided SSK.

2.3.1 Performance of the intelligent RIS-SSK scheme

In order to determine the index of the activated transmitter antenna at the receiver side, an optimal ML detector is designed for the intelligent RIS-aided SSK scheme as follows:

$$\hat{t} = \arg\min_{t}\left\{\left|y-\sqrt{E}\left(\sum_{i=1}^{N}\alpha_{t,i}\beta_i\right)\right|^2\right\}. \tag{11}$$

Assuming that the unmodulated carrier signal generated by the source is conveyed to the RIS with transmitter antenna *t* to be reflected to the receiver antenna, however, it has been detected erroneously at the receiver side that the signal was transmitted through the transmitter antenna $\hat{t}$, the conditional pairwise error probability (CPEP) can be calculated from:

$$\begin{aligned}&\Pr\{t\to\hat{t}\mid h,g,\phi\}\\ &=\Pr\left\{\left|y-\sqrt{E}\left(\sum_{i=1}^{N}\alpha_{t,i}\beta_i\right)\right|^2>\left|y-\sqrt{E}\left(\sum_{i=1}^{N}\alpha_{\hat{t},i}\beta_i\right)\right|^2\right\}\\ &=\Pr\left\{\begin{aligned}&-E\left|\left(\sum_{i=1}^{N}\left(\alpha_{t,i}-\alpha_{\hat{t},i}\right)\beta_i\right)\right|^2\\ &-2\Re\left\{\sqrt{E}\left(\sum_{i=1}^{N}\left(\alpha_{t,i}-\alpha_{\hat{t},i}\right)\beta_i\right)n^*\right\}>0\end{aligned}\right\}\\ &=\Pr\{D>0\},\end{aligned} \tag{12}$$

where $\Pr\{\cdot\}$ defines the probability of an event and $(\cdot)^*$ represents the complex conjugate, while $\Re\{A\}$ representing the real part of a complex-valued A. From (12), it can be written that

$$\Pr\{t\to\hat{t}\mid h,g,\phi\} = P\{D>0\}, \tag{13}$$

where D is a complex Gaussian random variable that can be given by:

$$D=\left\{\begin{aligned}&-E\left|\left(\sum_{i=1}^{N}(\alpha_{t,i}-\alpha_{\hat{t},i})\beta_i\right)\right|^2\\ &-2\Re\left\{\sqrt{E}\left(\sum_{i=1}^{N}(\alpha_{t,i}-\alpha_{\hat{t},i})\beta_i\right)n^*\right\}\end{aligned}\right\}. \tag{14}$$

Here, it can be easily realized that the mean and variance of $D\sim\mathbb{CN}\left(\mu_D,{\sigma_D}^2\right)$ can be defined as follows:

$$\mu_D = -E\left|\left(\textstyle\sum_{i=1}^{N}(\alpha_{t,i}-\alpha_{\hat{t}i})\beta_i\right)\right|^2,\quad \sigma_D^2=-2\mu_D N_0. \tag{15}$$

Considering that, we can rewrite the CPEP given in (12) by using the well-known Q-function as follows [3]:

$$\begin{aligned}&\Pr\{t\to\hat{t}\mid h,g,\phi\}\\ &=Q\left(\sqrt{\frac{E}{2N_0}\left|\left(\sum_{i=1}^{N}\left(\alpha_{t,i}-\alpha_{\hat{t},i}\right)\beta_i\right)\right|^2}\right)=Q\left(\sqrt{\frac{E}{2N_0}|\Xi|^2}\right).\end{aligned} \tag{16}$$

Defining $\Lambda=|\Xi|^2$ and considering (16), it can be said that Ξ follows a zero mean Gaussian distribution for reasonably high N values according to Central Limit Theorem (CLT). Now, realizing that $\alpha_{t,i}$ and β_i in (16) are independent Ricean distributed random variables, the variance of Ξ can be calculated as:

$$\sigma_\Xi^2 = 2N\left(1-\frac{\pi}{4(K+1)}L_{1/2}^2(-K)\right). \tag{17}$$

In order to find the average pairwise error probability (APEP), the following should be calculated:

$$\overline{\Pr}\{t\to\hat{t}\mid h,g,\phi\} = \frac{1}{\pi}\int_0^\infty Q\left(\sqrt{\frac{E\Lambda}{2N_0}}\right)f_\Lambda(\Lambda)\,d\Lambda, \tag{18}$$

where $f_\Lambda(\Lambda)$ defines the probability density function of Λ. Here, utilizing the CLT by considering (16), it is easy to realize that Λ is a central chi-square random variable with one degree of freedom. Hence, for sake of simplicity, the APEP can be calculated by using the moment-generating function (MGF) of central chi-square distribution [9], which is denoted here by $M_\Lambda(\cdot)$, as follows:

$$\begin{aligned}\overline{\Pr}\{t\to\hat{t}\mid h,g,\phi\} &= \frac{1}{\pi}\int_0^{\pi/2} M_\Lambda\left(\frac{-E}{4N_0\sin^2\vartheta}\right)d\vartheta\\ &=\frac{1}{\pi}\int_0^{\pi/2}\frac{d\vartheta}{\sqrt{1+\dfrac{NE}{N_0\sin^2\vartheta}\left(1-\dfrac{\pi}{4(K+1)}L_{1/2}^2(-K)\right)}}.\end{aligned} \tag{19}$$

Considering that the value of $\sin^2\vartheta$ in (19) can be 1 at maximum, a closed-form equation can be written for an upper bounded ABER calculation as follows:

$$\overline{\Pr}\{t\to\hat{t}\mid h,g,\phi\}\approx\frac{1}{2}\left[1+\frac{NE}{N_0}\left(1-\frac{\pi L_{1/2}^2(-K)}{4(K+1)}\right)\right]^{-\frac{1}{2}}. \tag{20}$$

2.3.2 Performance of the power-sensing RIS-SSK scheme

Considering (10), an optimal ML detector, which detects the index of the activated transmitter antenna can be designed for the power-sensing RIS-SSK scheme as follows:

$$\hat{t} = \arg\min_{t} \left\{ \left| y - \sqrt{P_t}\left(\sum_{1}^{N} \alpha_{t,i}\beta_i \right) \right|^2 \right\}. \quad (21)$$

Assume that the unmodulated carrier signal generated by source is conveyed to the RIS to be reflected to destination with transmitter antenna t; however, it has been detected erroneously that the signal was conveyed from the transmitter antenna $\hat{t}$ at the destination, the CPEP can be calculated by:

$$\begin{aligned} &\Pr\{t \to \hat{t} \mid h, g, \phi\} \\ &= \Pr\left\{ \left| y - \sqrt{P_t}\left(\sum_{i=1}^{N} \alpha_{t,i}\beta_i \right) \right|^2 > \left| y - \sqrt{P_t}\left(\sum_{i=1}^{N} \alpha_{\hat{t},i}\beta_i \right) \right|^2 \right\} \\ &= \Pr\left\{ \begin{aligned} &-E\left| \sum_{i=1}^{N} \beta_i \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right) \right|^2 \\ &-2\Re\left\{ \sqrt{E}\left(\sum_{i=1}^{N} \beta_i \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right) n^* \right) \right\} > 0 \end{aligned} \right\} \\ &= \Pr\{F > 0\}, \end{aligned} \quad (22)$$

where $F \sim \mathbb{CN}\left(\mu_F, \sigma_F^2\right)$ is a complex Gaussian random variable that can be written as:

$$F = \left\{ \begin{aligned} &-E\left| \sum_{i=1}^{N} \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right)\beta_i \right|^2 \\ &-2\Re\left\{ \sqrt{E}\left(\sum_{i=1}^{N} \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right)\beta_i \right) n^* \right\} \end{aligned} \right\}. \quad (23)$$

.

Here the mean and variance of F can be given respectively by:

$$\mu_F = -E\left| \sum_{i=1}^{N} \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right)\beta_i \right|^2, \; \sigma_F^2 = -2\mu_F N_0 \quad (24)$$

Considering that, we can rewrite the CPEP given in (22) by using the Q-function as follows:

$$\begin{aligned} &\Pr\{t \to \hat{t} \mid h, g, \phi\} \\ &= Q\left(\sqrt{ \frac{E}{2N_0} \left| \sum_{i=1}^{N} \left(\sqrt{k_t}\alpha_{t,i} - \sqrt{k_{\hat{t}}}\alpha_{\hat{t},i} \right)\beta_i \right|^2 } \right) = Q\left(\sqrt{ \frac{E}{2N_0} |\Theta|^2 } \right). \end{aligned} \quad (25)$$

Defining $\Upsilon = |\Theta|^2$ and considering CLT, it is known that $\Theta \sim \mathbb{CN}\left(\mu_\Theta, \sigma_\Theta^2\right)$ for reasonably high N values according to (25). Now, realizing that $\alpha_{t,i}$ and β_i in (25) are independent Ricean distributed random variables, the mean and variance values of Θ can be given as follows, respectively:

$$\mu_\Theta = N\left(\frac{\pi}{4(K+1)} L_{1/2}^2(-K) \right)\left(\sqrt{k_t} - \sqrt{k_{\hat{t}}} \right), \quad (26)$$

$$\begin{aligned} \sigma_\Theta^2 = \; &2N\left(1 - \frac{\pi}{4(K+1)} L_{1/2}^2(-K) \right) \\ &\times \left(\left(k_t + k_{\hat{t}} \right) + \frac{\pi\left(\sqrt{k_t} - \sqrt{k_{\hat{t}}} \right)^2}{4(K+1)} L_{1/2}^2(-K) \right). \end{aligned} \quad (27)$$

In order to find the APEP, (25) can be averaged through the following statement:

$$\overline{\Pr}\{t \to \hat{t} \mid h, g, \phi\} = \frac{1}{\pi}\int_0^\infty Q\left(\sqrt{\frac{E\Upsilon}{2N_0}} \right) f_\Upsilon(\Upsilon)\, d\Upsilon, \quad (28)$$

where $f_\Upsilon(\Upsilon)$ is the probability density function of Υ, which is a non-central chi-square random variable with one degree of freedom. Hence, the APEP can be computed by using the MGF of Υ [9], which is denoted here by $M_\Upsilon(\cdot)$, as follows:

$$\begin{aligned} &\overline{\Pr}\{t \to \hat{t} \mid h, g, \phi\} = \frac{1}{\pi}\int_0^{\pi/2} M_\Upsilon\left(\frac{-E}{4N_0 \sin^2\vartheta} \right) d\vartheta \\ &= \frac{1}{\pi}\int_0^{\pi/2} \left(1 + 2\sigma_\Theta^2 \times \frac{E}{4N_0 \sin^2\vartheta} \right)^{-\frac{1}{2}} \\ &\times \exp\left(\frac{ -\dfrac{E N^2 \pi^2 \left(\sqrt{k_t} - \sqrt{k_{\hat{t}}} \right)^2}{64 N_0 (K+1)^2 \sin^2\vartheta} \times L_{1/2}^4(-K) }{ 1 + 2\sigma_\Theta^2 \times \dfrac{E}{4N_0 \sin^2\vartheta} } \right) d\vartheta. \end{aligned} \quad (29)$$

Considering that the value of $\sin^2\vartheta$ in (29) can be 1 at maximum, a closed-form equation can be written for an upper bounded ABER calculation of the power-sensing scheme as:

$$\begin{aligned} \overline{\Pr}\{t \to \hat{t} \mid h, g, \phi\} \approx \frac{1}{2}\left(1 + \frac{E\sigma_\Theta^2}{2N_0} \right)^{-\frac{1}{2}} \\ \times \exp\left(\frac{ -E N^2 \pi^2 \left(\sqrt{k_t} - \sqrt{k_{\hat{t}}} \right)^2 L_{1/2}^4(-K) }{ 32(K+1)^2 \left(2N_0 + E\sigma_\Theta^2 \right) } \right). \end{aligned} \quad (30)$$

3 Findings and discussion

In this section, extensive computer simulation results are provided to investigate the ABER performance of the proposed schemes, namely intelligent and power-sensing RIS-SSK, by using ML detection algorithm. The presented results are obtained by Monte Carlo simulations, and verified by analytical derivations. During the simulations, at least 10^5 symbols have been sent for each SNR value, which is defined as E/N_0, while $N_t = 2$ without loss of generality.

In Fig. 3, the ABER performance of both the intelligent and power-sensing RIS-aided SSK is presented for a fixed number of transmitter antenna, $N_t = 2$, and a fixed Ricean-K parameter, $K = 10$ dB, and compared to the traditional SSK scheme in [16]. Clearly, the power-sensing RIS-aided SSK achieves the best results. For instance, power-sensing transmission requires approximately 45 dB less SNR than the intelligent RIS-aided SSK to provide that ABER= 10^{-2} for $N = 64$, and it is even less than that for $N = 128$. Additionally, doubling N ensures a much lower ABER with the power-sensing RIS-aided SSK for a fixed value of SNR. For instance, utilizing 128 reflectors instead of 64 provides 6 dB gain in SNR for the power-sensing scheme, while it is only 3 dB for the intelligent case.

Considering (8) and (10), it can be said that this is an expected result, since the power-sensing scheme utilizes not only the spatial information like the intelligent one but also the amplitude information. Clearly, cancelling all the channel phases in the intelligent scheme reduces the distinctness of the channels, which means limiting the performance of the SSK. Another important remark related to Fig. 3 can be that the CLT approach, which is utilized during the analytical derivations, is proved to be significantly accurate, as the analytical and simulation results match perfectly.

In Fig. 4, the ABER performance of the intelligent RIS aided SSK scheme is investigated for various values of K. It is observed that decreasing the value of the Ricean factor from $K = 10$ dB to $K = 3$ dB ensures 5 dB gain in SNR. As can be seen from this figure, Ricean fading has more destructive effects on the system performance of the intelligent RIS-aided SSK compared to Rayleigh fading.

Contrary to this, it is seen from Fig. 5 that the power-sensing RIS-SSK performs better over Ricean fading channels, and it provides 3 dB gain in SNR when the Ricean parameter increases from 3 to 10 dB. Additionally, considering both Figs. 4 and 5, it is obvious that the exact ABER values are in compliance with their upper bounds, which are derived in (20) and (30) for the intelligent and power-sensing schemes, respectively.

Noting that the LOS component increases SNR value but reduces spatial diversity, it can be seen from (4) that increasing K parameter makes the LOS component more effective. Therefore, increasing K has a destructive effect on the performance of the intelligent scheme, since it needs a rich scattering environment to achieve a good performance, which highly depends on the distinctness of the channels. On the other hand, the power sensing scheme utilizes not only the spatial information but also the amplitude information, and thus, increasing K enhances its ABER performance.

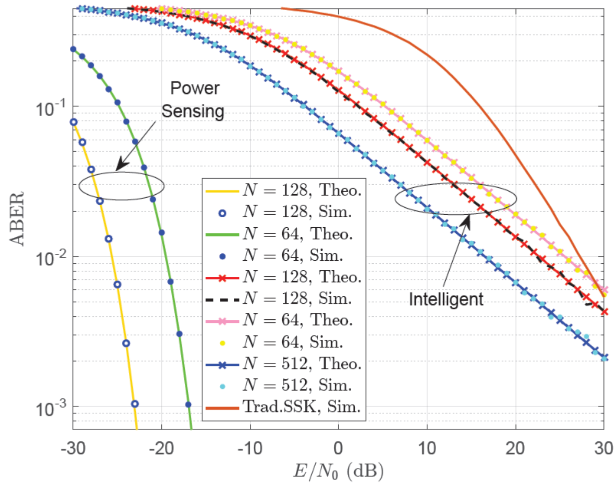

Fig. 3. ABER performance of the proposed RIS-assisted SSK schemes with increasing N for $N_t = 2$ and $K = 10$ dB.

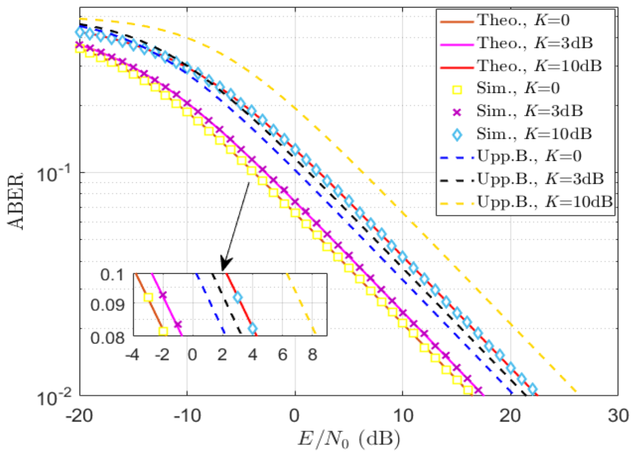

Fig. 4. ABER performance of the intelligent RIS-aided SSK scheme for $N_t = 2$ and $N = 128$ with increasing Ricean factor K.

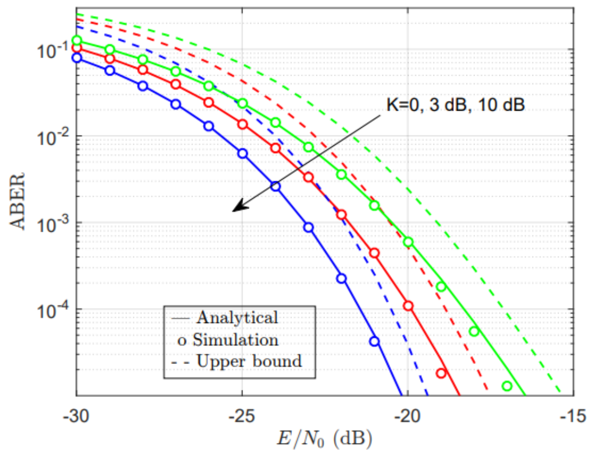

Fig. 5. ABER performance of the power-sensing RIS-aided SSK scheme for $N_t = 2$ and $N = 128$ with increasing Ricean factor K (green: K=0, red: K=3 dB, blue: K=10 dB).

4 Conclusion

The ABER performance of intelligent and power-sensing RIS-assisted SSK schemes are investigated over Ricean fading channels in this study. The obtained results show that utilizing an RIS in SSK by generating an intelligent transmission environment can provide better quality of service, since the intelligent RIS-aided SSK, especially with high number of reflecting elements, achieves a better performance compared to the traditional SSK without an RIS. Furthermore, the power-sensing approach provides extremely superior results for the intelligent RIS-aided SSK scheme. It is observed that channel characteristics have model-specific effects on the service quality of RIS aided schemes. Clearly, further investigations are required to gain a clear understanding about the full potential of the RIS assisted schemes for future communication systems in more challenging channel environments.

Conflict of interest

The authors declare that there is no conflict of interest

Similarity rate: %20

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