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Original Scientific Paper

NOMA COOPERATIVE RELAYING SYSTEMS OVER RICIAN-SHADOWED FADING CHANNELS

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ABSTRACT

Non-orthogonal multiple Access (NOMA) is an efficient 5G technology that enables network spectral efficiency increase and network access latency. In order to additionally improve the reliability of transmission and increase the achievable rate of NOMA system, combined utilization of NOMA and cooperative relay transmission (CRS) could appear as effective remedy. In this work, we will carry out performance analysis of NOMA based CRS over Rician-Shadowed fading channels. The closed-form expression for the exact average achievable rate is presented in the form of Meijer G functions infinite-series. Numerical results are presented in order to manifest the credibility of the presented method.

Keywords: Average achievable rate, CRS, Rician-Shadowed fading, NOMA.

INTRODUCTION

Non-orthogonal multiple access (NOMA) has emerged as an effective technology for increasing spectral efficiency of 5G downlink networks and while increasing networks access latency (Wei et al., 2017). Opposite to regular orthogonal multiple access (OMA) the main concept of NOMA is to explore the power domain in order to provide multiple access to users with distinct power levels, while using at the reception the principle of successive interference cancellation (SIC) after decoding the highest quality signal, in order to decode the remaining signals. For the purpose of further improvement of the reliability of NOMA transmission and increase the achievable NOMA rate, combined utilization of NOMA and cooperative relay transmission (CRS) could be used. CRS NOMA system realizations and their performances have been often discussed in literature recently: Jiao et al. (2017); Duan et al. (2018); Liang et al. (2016); Men & Ge (2016); Kim & Lee (2015); Ding et al. (2015); Wan et al. (2018); Jha & Kumar (2018); Jha et al. (2018); Panic & Jayakody (2019).

In 5G signal propagation theory most observed is case when transmitted signal with the strong LOS (line-of-sight) component propagates together along different non-LOS paths, so various LOS shadow fading effects occur due to total or partial blockage of the LOS by corresponding obstacles that appear or move on a direction between the transmitter and receiver. As the result of this blockage, the amplitude of the LOS component behaves a random process, so signal propagation can be accurately modeled with shadowed Rician fading model Simon & Alouini (2005). This model serves as good representation for 4 different shadowing scenarios: light shadowing scenario, heavy shadowing scenario, overall shadowing scenario and average shadowing scenario. Also this model could correctly represent random fluctuations at the reception caused by fading and shadowing that occur separately Simon & Alouini (2005).

In Kim & Lee (2015) performance analysis of the CRS NOMA over both Rayleigh fading channels and Hoyt fading channels were carried out, but only asymptotic expression are provided for the achievable rate criterion. In Jiao et al. (2017) performance analysis of CRS NOMA over Rician fading channels were carried out, but only expressions for approximating the achievable rate based on the Gauss-Chebyshev method Hildebrand (1987) have been introduced. Identical approximation method has been used in Jha & Kumar (2018); Jha et al. (2018) to deliver achievable rate of an Opportunistic CRS NOMA over Rician fading channels for the case of available CSI (Channel State Information). In Panic & Jayakody (2019) closed form expressions have been provided for the achievable average rate of the NOMA based CRS over Hoyt fading channels. However, to the best of the authors knowledge, there is no work reported in literature, where closed form expressions have been provided for the achievable average rate of NOMA based CRS over Rician-Shadowed fading channels.

In this work we will carry out the performance analysis of NOMA based CRS over Rician-Shadowed fading channels and deliver rapidly converging infinite series expression for the average achievable rate in the form of of Meijer G functions. Numerical results will be delivered and analyzed in the function of Rician-Shadowed fading severity parameters.

SYSTEM MODEL

We are observing cooperative relaying system composed of a source node (S), a relay node (R) with decode-and-forward (DF) performed in in half-duplex (HD) mode, and a destination node (D), where is assumed that all the links, i.e., S-D, S-R, and R-D are ready for transmission. The Rician Shadowed modeled fading

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channel coefficients of S-D, S-R, and R-D links are denoted with h_{SD}, h_{SR}, and h_{RD}, while Ω_{SD}, Ω_{SR}, and Ω_{RD}, denote corresponding average powers, respectively. As it is assumed that the path loss of the S-D link is higher the path loss of the S-R link, we are observing the case when stands $\Omega_{SD} < \Omega_{SR}$. The system model of NOMA-based CRS is showed in Fig. 1. The advantage of such architecture comes from the ability that system is capable of receiving distinct signals in distinct time slots at the destination, so it can outperform the traditional CRS system throughput performances, as illustrated in Kim & Lee (2015). Namely, NOMA-based CRS transmits two signals in two slots, so it easily outperforms traditional CRS concept that only transmits one signal during time.

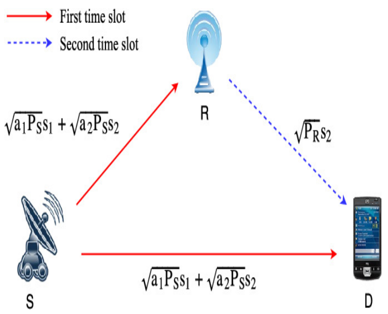

Figure 1. NOMA-based CRS scheme.

The source transmits in the first time slot the superposition of two distinct symbols: s_1 and s_2, to both R and D. Allow us represent i-th transmittion symbol with s_i, whose normalized power is $E(|s_i|^2) = 1$, while let P_t denote the total transmit power, a_i the power allocation coefficient, where stands $a_1 + a_2 = 1$, and $a_1 > a_2$, due to $\Omega_{SD} < \Omega_{SR}$. At the destination only symbol s_1 is decoded, while symbol s_2 is observed as noise, so R acquires symbol s_2 using SIC. In the second time slot, R only transmits to D the decoded symbol s_2 with total power P_t, assuming that R have perfectly decoded symbol s_2 at first time slot. Therefore, the received signals r_{sr} and r_{sd} in the first time slot, and the received signal in the second time slot, r_{rd}, can be represented as:

$$\begin{aligned}
t &= \sqrt{a_1 P_t} s_1 + \sqrt{a_2 P_t} s_2,\\
r_{sr} &= h_{sr} t + n_{sr},\\
r_{sd} &= h_{sd} t + n_{sd},\\
r_{rd} &= h_{rd} P_t s_2 + n_{rd},
\end{aligned} \tag{1}$$

where n_{SR}, n_{RD} and n_{SD} denote the additive white Gaussian noise (AWGN) of zero mean and variance σ^2. Consequently, signal-to-interference plus noise ratios (SINRs) of symbols s_1 and s_2 at the relay can be represented as:

$$\begin{aligned}
\gamma_{sr}^1 &= \frac{|h_{sr}|^2 a_1 P_t}{|h_{sr}|^2 a_2 P_t + \sigma^2},\\
\gamma_{sr}^2 &= \frac{|h_{sr}|^2 a_2 P_t}{\sigma^2},\\
\gamma_{sd} &= \frac{|h_{sd}|^2 a_1 P_t}{|h_{sd}|^2 a_2 P_t + \sigma^2},\\
\gamma_{rd} &= \frac{|h_{rd}|^2 P_t}{\sigma^2}.
\end{aligned} \tag{2}$$

Achievable rate analysis

Here we will consider the average achievable rate of signals s_1 and s_2. Let $\lambda_{SD} = |h_{SD}|^2$, $\lambda_{SR} = |h_{SR}|^2$, $\lambda_{RD} = |h_{RD}|^2$, and $\rho = P_t/\sigma^2$, where ρ denotes the transmit SNR. Since both signals, s_1 and s_2, should be successfully decoded at both relay and the destination then corresponding rates of these two signals should be lower than the rates of both links, and therefore achievable rate can be observed as the minimum of the rates of two different links. Based on above-mentioned the achievable rates C_{s_1} and C_{s_2} of signals s_1 and s_2 could be respectively expressed as:

$$\begin{aligned}
C_{s1} &= \frac{1}{2}\min\{\log_2(1+\gamma_{sd}), \log_2(1+\gamma_{sr}^1)\}\\
&= \frac{1}{2}\left(\log_2(1+\min\{\lambda_{sd},\lambda_{sr}\}\rho) - \log_2(1+\min\{\lambda_{sd},\lambda_{sr}\}\rho a_2)\right);\\
C_{s2} &= \frac{1}{2}\min\{\log_2(1+\gamma_{rd}), \log_2(1+\gamma_{sr}^2)\}\\
&= \frac{1}{2}\log_2(1+\min\{a_2\lambda_{sr},\lambda_{rd}\}\rho),
\end{aligned} \tag{3}$$

There arises a necessity to observe scenario when obstacles block the LOS link in between relay nodes and LOS signal fluctuations are affected by shadowing effect. Various studies have demonstrated that the Rician-Shadowed fading model provides a good match to 5G channel estimations in a various propagation cases, and spreads wide scope of fading conditions from strong LOS fading model to heavy shadowed NLOS model, and in that way Rician-Shadowed offers a possibility to characterize fading environments which are more intense than those characterized by the Rician fading model. PDF of Rician-shadowed distributed SNR can be presented as Panic et al. (2013):

$$\begin{aligned}
f_{\lambda_i}(\lambda_i) &= \frac{m_i^{m_i}(1+\kappa_i)}{(\kappa_i+m_i)^{m_i}\bar{x}_i}\exp\left(-\frac{(1+\kappa_i)\lambda_i}{\bar{x}_i}\right)\\
&\times {}_1F_1\left(m_i, 1, \frac{\kappa_i(1+\kappa_i)\lambda_i}{\bar{x}_i(m_i+\kappa_i)}\right),
\end{aligned} \tag{4}$$

where ${}_1F_1(x)$ represents the confluent hypergeometric function of first kind Gradshteyn & Ryzhik (2007), parameter $2b_i$ denotes the average power of scatter component, while parameter m_i expresses fading severity magnitude. Further, parameter κ_i defines the ratio of powers, $\kappa_i = \frac{\Omega_i}{2b_i}$, Ω_i stands for the average power of LOS component, while $\bar{x}_i$, $\bar{x}_i = E[X_i]$, represents average channel SNR value. Rician-Shadowed link parameter values for corresponding shadowing mode are provided in Abdi et al. (2003) as: heavy shadowing ($m_i = m_j = 0.739$, $b_i = b_j = 0.063$, $\kappa_i = \kappa_j = 0.00711$, $\bar{x}_i = \bar{x}_j = 8.97\times10^{-4}$), average shadowing ($m_i = m_j = 10.1$, $b_i = b_j = 0.126$, $\kappa_i = \kappa_j = 4.0828$, $\bar{x}_i = \bar{x}_j = 0.835$), overall shadowing ($m_i = m_j = 5.21$, $b_i = b_j = 0.251$, $\kappa_i = \kappa_j = 0.55387$, $\bar{x}_i = \bar{x}_j = 0.278$) and light shadowing ($m_i = m_j = 19.4$, $b_i = b_j = 0.158$, $\kappa_i = \kappa_j = 2.64241$, $\bar{x}_i = \bar{x}_j = 1.29$). Following Popovic et al. (2011), we can express the cumulative distribution function (CDF) of $z = min\{\lambda_i, \lambda_j\}, (i, j) \in (SD, SR, RD)$ as:

$$\begin{aligned} &F_z(z) = 1 - P(\lambda_i > z)P(\lambda_j > z) = \\ &1 - (1 - P(\lambda_i < z))(1 - P(\lambda_j < z)) = \\ &= F_{\lambda_i}(z) + F_{\lambda_j}(z) - F_{\lambda_i}(z)F_{\lambda_j}(z) = \\ &1 - \sum_{p=0}^{\infty} \sum_{l=0}^{p} \frac{m_i\kappa_i^p(1+\kappa_i)^l\Gamma(m_i+p)z^l}{(\kappa_i+m_i)^{m_i}\bar{x}_i{}^l\Gamma(m_i)(p!)^2 l!} \quad \exp\left(-\frac{(1+\kappa_i)z}{\bar{x}_i}\right) \\ &\times \sum_{q=0}^{\infty} \sum_{s=0}^{q} \frac{m_j\kappa_j^q(1+\kappa_j)^s\Gamma(m_j+q)z^s}{(\kappa_j+m_j)^{m_j}\bar{x}_j{}^l\Gamma(m_j)(q!)^2 s!} \quad \exp\left(-\frac{(1+\kappa_j)z}{\bar{x}_j}\right), \end{aligned} \tag{5}$$

where $\gamma(a, x)$, denotes lower incomplete Gamma function Gradshteyn & Ryzhik (2007).

Now, in order to escape from the usage of the Gauss-Chebyshev approximation, that is heavily conditioned on the order of approximation, and in order to acquire closed form solution for achievable rate expressions over Rician-Shadowed fading channels, we must define expression for C_{s_1}:

$$C_{s1} = \frac{1}{2}\int_0^{\infty} \left(\log_2(1 + z_1\rho) - \log_2(1 + z_1 a_2\rho)\right) f_z(z)dz, \tag{6}$$

and derive closed-form expressions based on the PDF expression of $z = min\{\lambda_i, \lambda_j\}, (i, j) \in (SD, SR, RD)$, that is expressed according to (5) as:

$$f_z(z) = f_{\lambda_i}(z) + f_{\lambda_j}(z) - f_{\lambda_i}(z)F_{\lambda_i}(z) - f_{\lambda_j}(z)F_{\lambda_i}(z). \tag{7}$$

By replacing (4) and (5) in (7), and carrying out some basic mathematical manipulations, namely by presenting lower incomplete gamma function, $\gamma(a, x)$, in the form of hypergeometric function ${}_1F_1(a, b, x)$, by using (§8.351.2) from Gradshteyn & Ryzhik (2007) and capitalizing on series representation, given with (9.210/1) from Gradshteyn & Ryzhik (2007), and beyond by noticing that logarithmic function can be represented through Meijer G function by using (11) from Gradshteyn & Ryzhik (1990): $\ln(1 + x) = G_{1,2}^{2,2}\left(\begin{matrix}1, 1\\0, 0\end{matrix}\middle| x\right)$, and finally by using the expression, (27) from Gradshteyn & Ryzhik (1990):

$$\begin{aligned} &\int_0^{\infty} x^{-\alpha}\exp(-\omega x)\, G_{p,q}^{m,n}\left(\begin{matrix}a_p\\b_q\end{matrix}\middle|\eta x\right)dx = \\ &\omega^{\alpha-1}G_{p+1,q}^{m,n+1}\left(\begin{matrix}\alpha, a_p\\b_q\end{matrix}\middle|\frac{\eta}{\omega}\right), \end{aligned} \tag{8}$$

expressions for achievable rates can now be expressed in the form of $I_1(\rho)$ and $I_1(\rho a_2)$, through Meijer G function infinite series sums as:

$$C_{s1} = I_1(\rho) - I_1(\rho a_2), \tag{9}$$

where only 15-25 terms should be summed in both infinite sum to attain accuracy at 4^{th} significant digit. In similar manner C_{s2} can be presented through rapidly-converging Meijer G function infinite series sums, beginning from

$$C_{s2} = \frac{1}{2}\int_0^{\infty} \left(\log_2(1 + y\rho)\, f_y(y)dy,\right. \tag{10}$$

by using the fact that variable y can be expressed as y=min($a_2\lambda_{sr}, \lambda_{rd}$), when acquiring its CDF and PDF.

In presented expressions for C_{s2} and $I_1(\rho)$, given with Eq.(11), factor $(a)_n$ stands for the Pochhammer symbol, defined in ((6.1.22) from Gradshteyn & Ryzhik (2007).

$$\begin{aligned} C_{s1} = &\frac{1}{2ln2}\sum_{q=0}^{\infty}\sum_{p=0}^{\infty}\sum_{l=0}^{p} \frac{m_i m_j\kappa_j^q\kappa_i^p\Gamma(m_i+p)\Gamma(m_j+q)(1+\kappa_i)^l(1+\kappa_j)^{q+1}\bar{x}_i{}^{q+1}\bar{x}_j{}^l}{(\kappa_i+m_i)^{m_i}(\kappa_j+m_j)^{m_j}\Gamma(m_i)\Gamma(q)(p!)^2(q!)^2 l!((1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i)^{q+l+1}} \\ &\times\left(\rho G_{1,3}^{3,2}\left(\begin{matrix}-q-l, 1, 1\\1, 0\end{matrix}\middle|\frac{\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right) - a\rho G_{1,3}^{3,2}\left(\begin{matrix}-q-l, 1, 1\\1, 0\end{matrix}\middle|\frac{a\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right)\right) + \\ &\frac{1}{2ln2}\sum_{q=0}^{\infty}\sum_{p=0}^{\infty}\sum_{s=0}^{q} \frac{m_i m_j\kappa_j^q\kappa_i^p\Gamma(m_i+p)\Gamma(m_j+q)(1+\kappa_i)^s(1+\kappa_j)^{p+1}\bar{x}_i{}^{p+1}\bar{x}_j{}^s}{(\kappa_i+m_i)^{m_i}(\kappa_j+m_j)^{m_j}\Gamma(m_i)\Gamma(q)(p!)^2(q!)^2 s!((1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i)^{p+s+1}} \\ &\times\left(\rho G_{1,3}^{3,2}\left(\begin{matrix}-p-s, 1, 1\\1, 0\end{matrix}\middle|\frac{\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right) - a\rho G_{1,3}^{3,2}\left(\begin{matrix}-p-s, 1, 1\\1, 0\end{matrix}\middle|\frac{a\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right)\right); \end{aligned} \tag{11}$$

$$\begin{aligned} C_{s2} = &\frac{1}{2ln2}\sum_{q=0}^{\infty}\sum_{p=0}^{\infty}\sum_{l=0}^{p} \frac{m_i m_j\kappa_j^q\kappa_i^p\Gamma(m_i+p)\Gamma(m_j+q)(1+\kappa_i)^l(1+\kappa_j)^{q+1}\bar{x}_i{}^{q+1}\bar{x}_j{}^l a^{q+1}}{(\kappa_i+m_i)^{m_i}(\kappa_j+m_j)^{m_j}\Gamma(m_i)\Gamma(q)(p!)^2(q!)^2 l!((1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i a)^{q+l+1}}\left(\rho G_{1,3}^{3,2}\left(\begin{matrix}-q-l, 1, 1\\1, 0\end{matrix}\middle|\frac{a\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right)\right) + \\ &\frac{1}{2ln2}\sum_{q=0}^{\infty}\sum_{p=0}^{\infty}\sum_{s=0}^{q} \frac{m_i m_j\kappa_j^q\kappa_i^p\Gamma(m_i+p)\Gamma(m_j+q)(1+\kappa_i)^s(1+\kappa_j)^{p+1}\bar{x}_i{}^{p+1}\bar{x}_j{}^s a^{p+1}}{(\kappa_i+m_i)^{m_i}(\kappa_j+m_j)^{m_j}\Gamma(m_i)\Gamma(q)(p!)^2(q!)^2 s!((1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i a)^{p+s+1}}\left(\rho G_{1,3}^{3,2}\left(\begin{matrix}-p-s, 1, 1\\1, 0\end{matrix}\middle|\frac{a\rho\bar{x}_i\bar{x}_j}{(1+\kappa_i)\bar{x}_j+(1+\kappa_j)\bar{x}_i}\right)\right); \end{aligned}$$

NUMERICAL RESULTS

Rician-Shadowed fading severity over corresponding relay links can be defined through set of parameters (m_i, b_i, κ_i, $\bar{x}_i$) $i \in (RS, SD, RD)$, while as explained in Panic & Jayakody (2019) a represents the power allocation coefficient. Parameter $\bar{x}_i$, $i \in (RS, SD, RD)$, denotes the average power gains of links S-D, S-R, R-D, mostly mirroring the impact of relay node lengths. Since is assumed that the S-R and R-D distances are generally smaller than the S-D distance, then links S-R and R-D should have larger average power gains than S-D link, which corresponds to values of $\bar{x}_{SD} < \bar{x}_{SR} \leq \bar{x}_{RD}$.

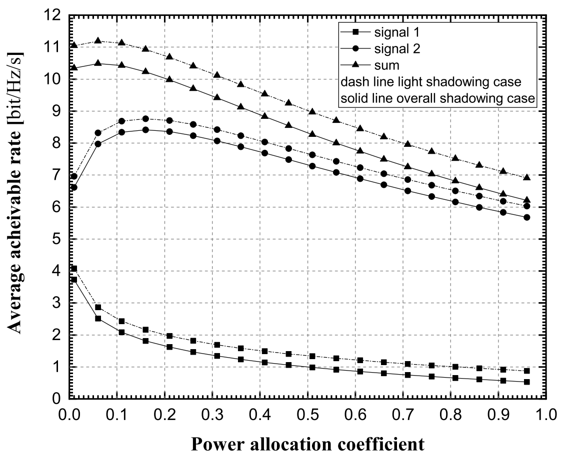

Figure 2. Achievable rates for the CRS NOMA over Rician-Shadowed fading channels.

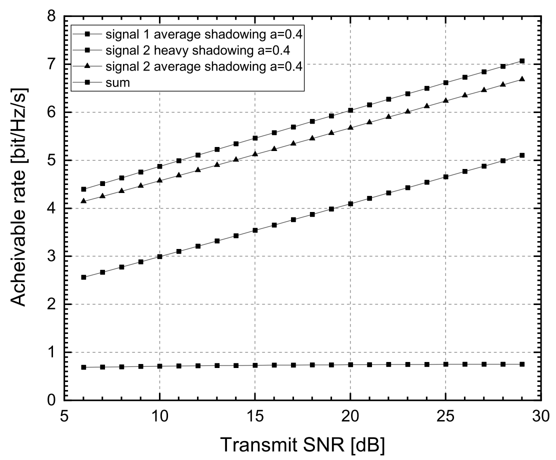

Figure 3. Achievable rates for the CRS NOMA over Rician-Shadowed fading channels.

At Fig. 2 the achievable rate performances of s_1, s_2 are presented along with the equivalent sum rate of the CRS NOMA in the function of the power allocation coefficient a. We have predefined SNR value to SNR=20 dB, $\bar{x}_{SD} = 2$, $\bar{x}_{RS} = \bar{x}_{RD} = 10$, and Rician-Shadowed channel conditions of light shadowing and overall shadowing. As expected, when a parameter increases, signal s_2 reaches more power so its achievable rate consequently increases, while simultaneously corresponding achievable rate of signal s_1 will decrease. Sum rate of two signals will first increase and then will further decrease with the growth of a parameter values. It can be seen that for smaller a values the achievable rate of signal s_2 is mostly influenced by link S-R, since $a_2\lambda_{SR} < \lambda_{RD}$. Because of SIC, signal s_2 would have no interference in S-R link, so increase in a would lead to increase the achievable rate of signal s_2, and consequently to increase in total sum rate. Afterwards, when a increases, $a\lambda_{SR}$ becomes than λ_{RD}, so the rate of link R-D will becomes the uppermost reason, which would cause that achievable rate of signal s_2 finally could not recompense for the decrease of s_1 achievable rate, so total rate would also notably decrease. We can observe from figure that there lays an optimal power allocation coefficient that can be used to maximise the sum rate.

Fig. 3 presents the achievable rates of the NOMA-based CRS against the transmit SNR, for Rician-Shadowed channel conditions of heavy shadowing and average shadowing where we set $a = 0.4$, $\bar{x}_{SD} = 2$, $\bar{x}_{RS} = 10$, and $\bar{x}_{RD} = 15$. As expected it is obvious that better results are received for average shadowing condition case.

CONCLUSION

In this work, we have carried out performance analysis of NOMA based CRS over Rician-Shadowed fading channels and presented the exact analytical expressions of the achievable rates. Expression have been provided in the form of Meijer G function infinite-series sums that rapidly converge.Numerical results have been delivered and analyzed in the function of Rician-Shadowed fading severity parameters.

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