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Performance Analysis of Two-Way Relaying Transceiver Hardware Impairments Over Student-T Fading channel

Er. Sunil Kumar[1], Dr. Tripatjot Singh Panag[2]
[1,2]Electronics and Communication, Punjab Technical University, Jalandhar, Punjab, India

Abstract: In today's world, with the ameliorations in communication technology, it has become vital in everyday life. As the reachability of wired network for communication is limited, wireless network has to plays a gigantic role in communication. For superior quality, efficiency and reliability of wireless communication network, the work presented in the thesis has been carried out by using two-way relaying transceiver hardware of different qualities to observe impact of quality of hardware, on a reliable and efficient wireless communication network. The channel model used is the Student-T channel which is replica of well planned, equally density modelled channel. Simulation were carried out to obtain the Symbol Error Rate (SER) and Outage Probability (OP) over a Student-T fading channel and simulated results have been compared with SER and OP parameters over Rayleigh channel. The signal to noise and distortion ratios were precisely evaluated for both the transmitting nodes and were used to compute the outage probabilities, as well as the symbol error rate (SER), precisely. It is observed from simulated results that hardware impairments in physical transceivers have a fatal consequence on wireless communication systems. A comparison of the graphs for outage probability while using a Student –T channel and a Rayleigh channel revels that in both the cases, increase in hardware impairment caused due to low quality hardware increases the probability of outage. For the same level of impairments, the outage probability for Student –T channel is generally less than for the Rayleigh channel.

Keywords: Two-way relay transceiver, Hardware Impairment, Symbol error rate, Outage probability, Student-T channel.

I. INTRODUCTION

Relays can fetch significant performance improvements to wireless networks in a profitable technique; for eg. coverage gains, uniform quality of service and spatial diversity gains [1]. In the typical half duplex technique, the transmission amid a source and a destination occupies two time slots, consequently the throughput of an actual system in bits per channel use is shortened by a factor of two. Two-way relaying licences two nodes to interconnect in two time slots with the aid of a relay node and can be used to sort out this problem. The two nodes transmit information parallelly in the 1^{st} time slot to the relay, and the relay guides the information to the certain destinations in the 2^{nd} time slot. Most research supports in the field of relaying presume that the transceiver hardware of the relay node is ideal. Albeit in practice, the transceiver hardware of wireless equipment's is continually wedged by impairments; for eg. phase noise, IQ imbalance and amplifier amplitude-amplitude non-linearity's [2]-[4]. Impairments forms a vital capacity upper limit that cannot be overawed by increasing the transmit power; thus, they have a very considerable impact predominantly in high rate schemes.

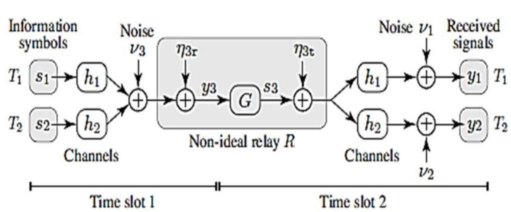

Fig. 1: Block diagram of two-way AF relaying with a non-ideal relay with $\boldsymbol{\eta_{3t}}, \boldsymbol{\eta_{3r}}$.

In the interim relays must be of low-cost equipment their transceiver hardware is more prone to impairments as they are of inferior quality. In vindictiveness of the impact of impairments for relaying, there are very rare relevant works and these only studied their impact on one-way relaying. In this context [5] – [7] are references studied how transceiver impairments impact OP and SER i.e. outage probability and symbol error rate respectively in one-way relaying [8]. Enthused by the above conversation henceforth systematically assess the effect of relay transceiver impairments in a two-way relaying arrangement, by enchanting the AF i.e. amplify and forward protocol. More accurate, expressions for the signal to noise and distortion ratio

(SNDR) on both transmitting nodes, as well as closed form expressions for the asymptotic and precised OP and SER [9], [10]. This permits a precise cataloguing of the effect of transceiver hardware impairments on both metrics. Our asymptotic examination brings engineering ideas in what way the optimum communication performance varies with the level of impairments. This research work stretches the performance analysis on the effect of hardware impairments in two-way relaying arrangement over Student-T channel [5], [14].

II. IMPLEMENTATION

A two-way AF relaying arrangement including two transmitting nodes T1 & T2, a relay node R. Communication occurs in two time slots, here, in the first time slot T_1 & T_2, transmit the information symbols s_1 and s_2 respectively, to R. The relay receives a superimposition of the symbols and broadcasts an amplified version of it to T_1 & T_2 in the second-time slot. A block diagram is stated in Fig. 1. In short, the expected receiver of s_i will be signified as T_{ri} where, $ri \triangleq \frac{2}{i}$ for $i = 1, 2$. The subscripts $1, 2, 3$ to states to terms related with T_1, T_2, & R respectively. The signal received at R in the first time slot is specified by

$$y_3 = h_1 s_1 + h_2 s_2 + \eta_{3r} + \nu_3 \tag{1}$$

Where, $s_i \sim CN(0, Pi)$, for $i = 1, 2$ is a symbol information from a zero mean gaussian circularly symmetric complex distribution by power P_i. In gathering, $\nu_i \sim CN(0, N_i)$ implies the additive gaussian complex noise at T_1, T_2 and R for $i = 1, 2, 3$.

The channel coefficient for the link $Ti \rightarrow R$ or vice-versa $R \rightarrow Ti$ is epitomized by h_i for $i = 1, 2$. Each of them is exhibited as independent *Rayleigh fading distributed* with normal gain $\Omega_i = Eh_i\{|h_i|^2\}$, which signifies that $h_i \sim CN(0, \Omega_i)$. As such, $\rho_i \triangleq |hi|^2$, the probability density function and cumulative density function of the channel gains respectively specified by [14], [18]

$$f_{\rho i}(x) = \frac{1}{\Omega_i} e^{-\frac{z}{\Omega_i}}, \; F_i(x) = 1 - e^{-\frac{z}{\Omega_i}}, \qquad x \geq 0 \tag{2}$$

In the 2^{nd} timeslot, the transmitted signal s_3 by R is fundamentally an improved form of its received signal y_3 or $s_3 = G_{y3}$. Presume that all nodes have seamless instant knowledge of the fading channels h_1, h_2. Therefore, R can put on variable gain relaying [14], [18],

$$G \triangleq \sqrt{\frac{P_3}{\rho_1 P_1 + \rho_2 P_2 (1 + \kappa_{3r}^2) + N_3}} \tag{3}$$

Where, P_3 is the avg. transmit power of the node relay. Note that the level of impairments κ_{3r} in eq. (1.5) may not be flawlessly acknowledged. Such a potential misalliance will weaken the system performance and can be straightforwardly amalgamated in the consequent analysis. Henceforth, can direct the signals received at T_1 & T_2, as [14], [18]

$$y_i = h_i \left(G_{y3} + \eta_{3t}\right) + \nu_i = G h_1 h_2 s_{ri} + G h_{2i} s_i + G h_i (\eta_{3r} + \nu_3) + h_i \eta_{3t} + \nu_i \tag{4}$$

for $i = 1, 2$ where, in the transmitting hardware of the relay, $\eta_{3t} \sim CN(0, \kappa_{3t}^2 P_3)$ is model distortion noise. Note that (4) shortens $y_i = G h_1 h_2 s_{ri} + G h_{2i} s_i + G h_{iv3} + \nu_i$ for an ideal hardware; this special case was considered in eq. (1) & (2). The node T_i needs to citation s_{ri} from y_i. As it identifies its own transmitted symbol s_i, it can effortlessly eradicate the consistent self-interference term $G h_i^2 s_i$. Then, the actual SNDR at T_i for acknowledgment of the symbol is s_{ri}, is represented as [14], [18]

$$SNDR_i = \frac{\rho_1 \rho_2 P_{ri}}{\rho_i \left(N_3 + \kappa_{3r}^2 (\rho_1 P_1 + \rho_2 P_2)\right) + \frac{\rho_i \kappa_{3t}^2 P_3 + N_i}{G^2}} \tag{5}$$

By replacing (3) into (5) we obtain,

$$SNDR_i = \frac{\rho_1\rho_2}{\rho_i^2 \frac{P_i}{P_{ri}} C\rho_1\rho_2 + \rho_{ri} b_i + \rho_i (a_i + \frac{P_i}{P_{ri}} b_i) \frac{N_3 N_i}{P_{ri} P_3}} \tag{6}$$

Where, $a_i \triangleq \frac{N_3}{P_{ri}}(1 + \kappa_{3t}^2)$, $b_i \triangleq \frac{N_i}{P_3}(1 + \kappa_{3r}^2)$, and $c \triangleq \kappa_{3t}^2 + \kappa_{3r}^2 + \kappa_{3t}^2\kappa_{3r}^2$ for $i = 1, 2$. [3].

A. Performance Analysis

B. Exact Outage Probability Analysis

The outcome at T_i is signified by $P_{out,i}(x)$ and is the probability of falling $SNDR_i$ underneath a definite threshold attributable to channel fading x, of acceptable communication quality; i.e. [14], [18]

$$P_{out,i}(x) \triangleq P_r\{SNDR_i \leq x\} \tag{7}$$

At T_i, the outage probability, when accomplishing s_{ri}, is specified by $P_{out,i}(x) = 1$ for $x \geq \frac{1}{c}$ and for $0 \leq x < \frac{1}{c}$ where, $K_1(\cdot)$ represents the 2^{nd} kind first order adapted Bessel function. [14], [18]

$$P_r\{SNDR_i > x|\rho_i\} = \begin{cases} 1 - F_{\rho_{ri}}\left(\frac{x\left(\rho_i^2 \frac{P_i}{P_{r_i}} c + \rho_i\left(a_i + \frac{P_i}{P_{r_i}} b_i + \frac{N_i N_3}{P_{r_i} P_3}\right)\right)}{\rho_i(1-cx)b_i}\right), & if\ x < \frac{1}{c}, \\ 0, & if\ x \geq \frac{1}{c} \end{cases} \tag{8}$$

C. Asymptotic Outage Probability Analysis

With the aim to attain some engineering ideas into a vital consequence of impairments, we now elaborate on the high-power command. We assume, in this case, without significant loss of generality, that $P_1 = P_2 = \tau P_3$ rise large (with $\tau > 0$), which results in relaying gain G in (5) congregates to

$$G^\infty = \sqrt{\frac{1}{\tau(\rho_1 + \rho_2)(1 + k_{3r}^2)}} \tag{9}$$

and remainders to be finite and positive. Thereby, the $SNDR$ in (7) becomes comparable to

$$SNDR_i^\infty = \frac{\rho_1\rho_2}{\rho_i^2 c + \rho_1\rho_2 c} = \frac{\rho_{r_i}}{(\rho_1 + \rho_2)c} \tag{10}$$

Result 1: The outage probability at T_i become eq. (10), at high-power regime where, $P_1 = P_2 = \tau P_3 \rightarrow \infty$ & $\tau > 0$,

$$P_{out,i}^\infty(x) = \begin{cases} \frac{\Omega_i c x}{\Omega_{r_i} + cx(\Omega_i - \Omega_{r_i})}, & if\ x < \frac{1}{c} \\ 1, & if\ x \geq \frac{1}{c} \end{cases} \tag{11}$$

D. Exact and Asymptotic Symbol Error Rate Analysis

It now shifts our courteousness to the SER. The avg. SER at T_i can be indicated by the generic formula in eq. (11) to this end, it first rises that for many modulation arrangements like BPSK, M-ary PAM, BFSK through orthogonal signalling.

$$SER_i = \mathbb{E}SNDR_i\{\alpha Q(\sqrt{2\beta SNDR_i})\} \qquad i = 1, 2 \tag{12}$$

Where, $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-t^2/2}\,dt$ is the Gaussian Q-function and α, β are modulation precised constants. Using integration, (12) can be converged into the arithmetically more apposite form

$$SER_i = \frac{\alpha\sqrt{\beta}}{2\sqrt{\pi}}\int_0^\infty \frac{e^{-\beta x}}{\sqrt{x}} FSNDR_i(x)dx \tag{13}$$

Where, the CDF of $SNDR_i$ is $FSNDR_i(x) = P_{out,i}(x)$ by cataloguing. Combining Proposal 1 and (3.14), it does not seem like that the consequential integral can be evaluated in closed-form; even if, the SER can be accomplished from (3.14) by arithmetic integration which is much more operative than Monte Carlo conclusions. It henceforth takes the high-power regime as precise in above Section and accomplish the following conclusion.

Result 2: Presume the high-power regime for which $P_1 = P_2 = \tau P_3 \rightarrow \infty$. For identical avg. channel gains $\Omega_1 = \Omega_2$, the $SERs$ at T_1 and T_2 are alike and equivalent to

$$SER_1^\infty = SER_2^\infty = \frac{\alpha c}{2\beta\sqrt{\pi}}\gamma\left(\frac{3}{2}\frac{\beta}{c}\right) + \frac{\alpha}{2} erfc\left(\sqrt{\frac{\beta}{c}}\right) \tag{14}$$

Where, $\gamma(p,x) = \int_0^x t^{p-1} e^{-t} dt$ is partial gamma function and $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}\ dt$ is complementary error function.

E. Student-T fading Channel

The Student-T distribution in its shape looks identical to Cauchy or Gaussian distributions, in some cases it tends to gaussian distribution and in some cases, it tends to Cauchy distribution. Even though its density function is not sprightly castoff in wireless communication. The t distribution should not be castoff with small samples from populations that are not almost normal. Assume that Z for the standard normal distribution, V for the chi-squared distribution with n degree of freedom where, $n \in (0,\infty)$ and moreover Z and V are independent random variable [17].

$$T = \frac{Z}{\sqrt{V/n}} \tag{15}$$

has the Student-T distribution with degree of freedom n .

Assume that T has the t distribution with degrees of freedom n. Then, T has a continuous distribution on R with probability density function f stated by

$$f(t) = \frac{\Gamma\left[n + \frac{1}{2}\right]}{\sqrt{n\pi}\,\Gamma\left(\frac{n}{2}\right)}\left(1 + \frac{t^2}{n}\right)^{-(n+1)/2} \quad t \in R \tag{16}$$

III. SIMULATED RESULTS

A. Outage Probability

In this chapter, simulated outcomes have been presented a set to validate our previous theoretical conclusions. In Fig. 2 equates the simulated OP (Outage Probability) at transmitter 1 T_1 over Rayleigh channel [3].

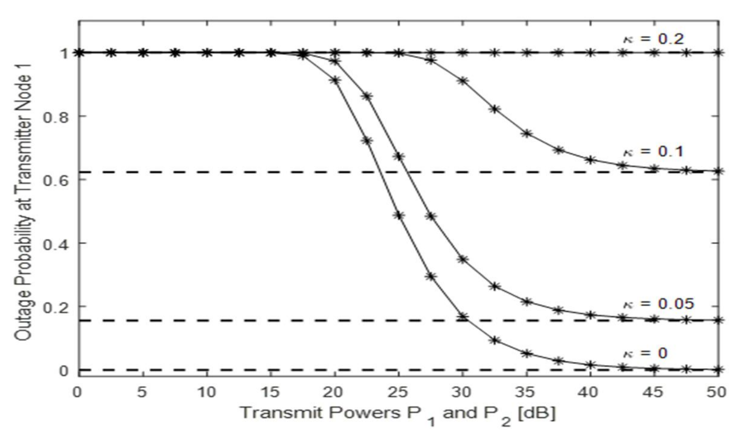

Fig. 2: Outage probability (OP) for Rayleigh Channel at node T_1 against the transmit power [3].

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At high level of impairments that is at $k = 0.2$, the scheme is recurrently in outage and no communication can be braced regardless of transmit power control level and the channel it may be Rayleigh or Student-T fading channel. At sensible level of impairments, the OP (Outage Probability) reaches to a non-zero saturation value in the high-power command, that is precisely expected in below results. These postures are significant contrast in case of ideal hardware $k = 0$, where the OP (Outage Probability) goes abruptly to zero for both channels Rayleigh as well as Student-T as shown in below simulated Fig. 2 and Fig. 3.

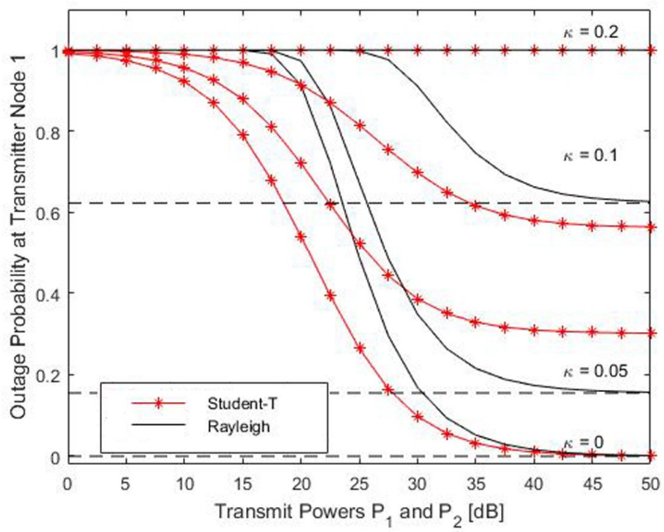

Fig. 3: Outage Probability for Student-T Vs Rayleigh Channel at Tx node 1 against the transmit power

In above Fig. 3 validates and compares OP (Outage Probability) over Rayleigh channel and Student-T channel for transmitter antenna 1 that is T_1 with transmitting power P_1. Simulated graph exhibits that outcomes withstand same for high level of impairments i.e. at $k = 0.2$, the system is constantly in outage and no communication can be braced regardless of the channels Rayleigh or Student-T. In the same way, for low impairments reaches to zero imitates OP (Outage Probability) also reaches to zero. Above Fig. 3 exhibits, at low transmitting powers Student-T channel response is better than Rayleigh channel response.
Whilst at impairment quality $k = 0.05$ at transmit power >30 dB, outage probability over Rayleigh channel is superior than Student-T channel.

Table 1:Comparison of outage Probability

Transmitting Power P (dB)	Outage Probability					
	Student-T Channel			Rayleigh Channel		
	$\mathcal{K}$=0	$\mathcal{K}$=0.05	$\mathcal{K}$=0.1	$\mathcal{K}$=0	$\mathcal{K}$=0.05	$\mathcal{K}$=0.1
15	0.8	0.92	0.98	1	1	1
20	0.7	0.7	0.95	0.99	0.96	1
25	0.27	0.59	0.9	0.57	0.6	1
30	0.17	0.41	0.7	0.2	0.41	0.98
35	0.03	0.32	0.61	0.037	0.23	0.77
40	0	0.3	0.59	0	0.21	0.66

However, for transmit power < 30 dB outage probability over Student-T channel is lesser than Rayleigh channel, which means at impairment quality $k = 0.05$ for transmit power < 30 dB communication is better over Student-T Channel than Rayleigh channel. But when OP is evaluated at impairment quality $k = 0.1$ and $k = 0$, its better in case of Student-T channel irrespective of transmit power & transmitting node. Which means communication over Student-T channel is much more reliable. While it is observed from the above simulated plots that for both channels i.e. Student-T and Rayleigh, with the increase in

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Transmitting power, irrespective of the value of k, the outage probability (OP) declines, which means network becomes more reliable as with the increase in Tx power, better is the SNR, and thereby, lower the Outage probability (OP) is, in turn.

B. Analysing & Simulated Results for SER

In Fig. 4, SER with BPSK modulation, examine different impairment combinations for which $k_{3_t} + k_{3_r} = 0.2$ is fixed to be remain constant over Rayleigh channel.

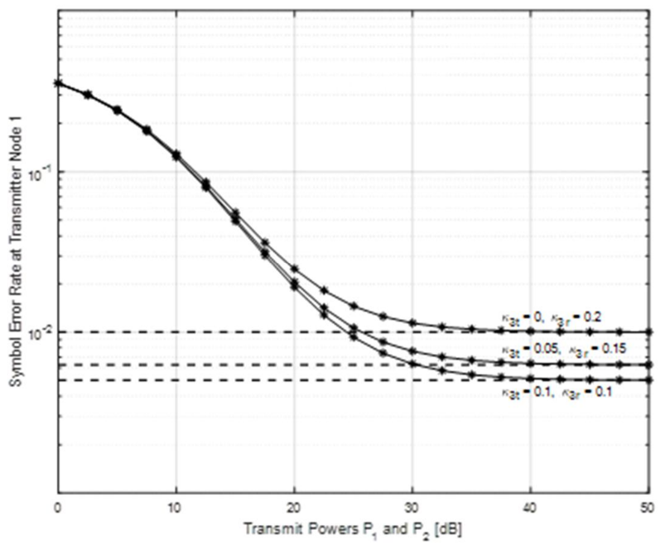

Fig. 4: Symbol error rate (SER) against the transmit power $\boldsymbol{P_1}$over Rayleigh channel [3].

The exact curves are attained by numerical evaluation, while the high-power SER bounds stem. As expected, the best optimal for minimalizing the SER is to have the same hardware quality ($k_{3_t} = k_{3_r}$= 0.1) at the transmit and receive side of the relay. Such an optimal asymptotically lessens the SER by a factor of 2, when compared with case where $k_{3_t} = 0$, $k_{3_r} = 0.2$. Usually, in other words when a relay node with low quality hardware on transmitter side and a high-quality hardware on the receiver side should be evaded. In below Fig. 5, SER with BPSK modulation observed over Student-T channel and is compared with Rayleigh channel by creating thee different impairment combinations by such that $k_{3_t} + k_{3_r} = 0.2$ stands constant.

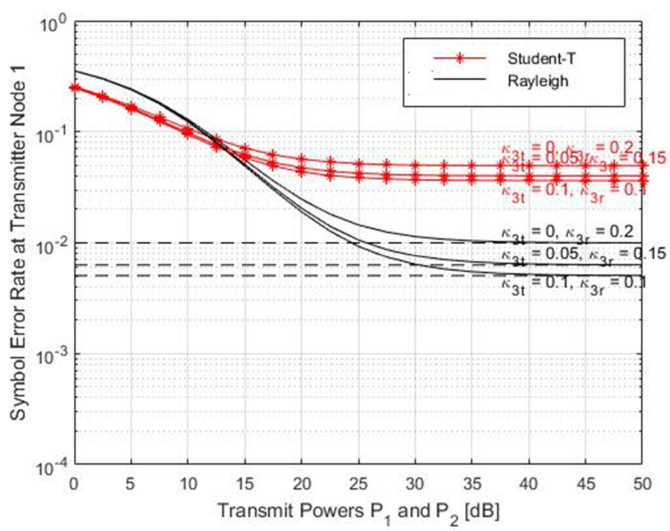

Fig 5: Symbol error rate (SER) against the transmit power over Student-T Vs Rayleigh channel.

1) Case 1: $\boldsymbol{k_{3_t} = 0, k_{3_r} = 0.2}$

When $k_{3_t} = 0, k_{3_r} = 0.2$, means hardware impairment at one end is of poorest quality and at other end it is of highest quality then over Student-T channel results follows the same way as that of over Rayleigh channel but for transmit power < 12.5 dB, SER is slightly better in case of Student-T channel. However, for transmit power > 12.5 dB, SER over Rayleigh channel outperforms Student-T channel significantly.

2) Case 2: $\boldsymbol{k_{3_t} = 0.05, k_{3_r} = 0.15}$

In this case, SER is marginly better than previous case as hardware impairment quality is enhanced at reciever end whilst at transmitting end hardware used is of slightly of inferior quality than that was used in earlier case. When it is equated channel wise equation remains the same for transmit power < 12.5 dB Student-T channel still responded marginally better than rayleigh channel. Howbeit, for transmit power > 12.5 dB SER over Rayliegh channel is far better than Student-T channel.

3) Case 3: $\boldsymbol{k_{3_t} = 0.1, k_{3_r} = 0.1}$

When hardware castoff at both ends are of equivalent quality, outcomes are superior from all cases over both rayleigh as well as Student-T channel. However, channel wise comparison remains same as it was in earlier cases. It is observed in all the above three cases for SER simulated plot that for both channels i.e. Student-T and Rayleigh, irrespective of the value of k and Tx node 1 & 2, the Symbol Error Rate (SER) dips with the increase in Transmit power, which means network becomes more reliable and efficient as with the increase in Transmit power, healthier is the SNR, and thus, lower the Symbol Error Rate (SER) is, in turn.

IV. CONCLUSION

In this thesis work, performance of transceiver hardware impairments on two-way relaying arrangement over Rayleigh channel and Student-T channel have been analysed and were compared by considering parameters like outage symbol error rate i.e. SER and outage probability i.e. OP. Simulated results concluded that the hardware of the relay node at transmitting and receiving obliged to be of same quality in order to minimize both SER and OP. when both channels i.e. Rayleigh and Student-T channel are compared, for OP (Outage Probability) response over Student-T channel is mostly better than that of Rayleigh channel, whilst for SER response over Rayleigh channel at most of time surpasses to that of over Student-T channel. It is also concluded that with the increase in Transmit power, SER and OP improves, irrespective of the channels, value of k and Tx node 1 & 2, the Symbol Error Rate (SER) dips, which means network becomes more reliable and efficient as with the increase in Transmit power as with it SNDR improves.

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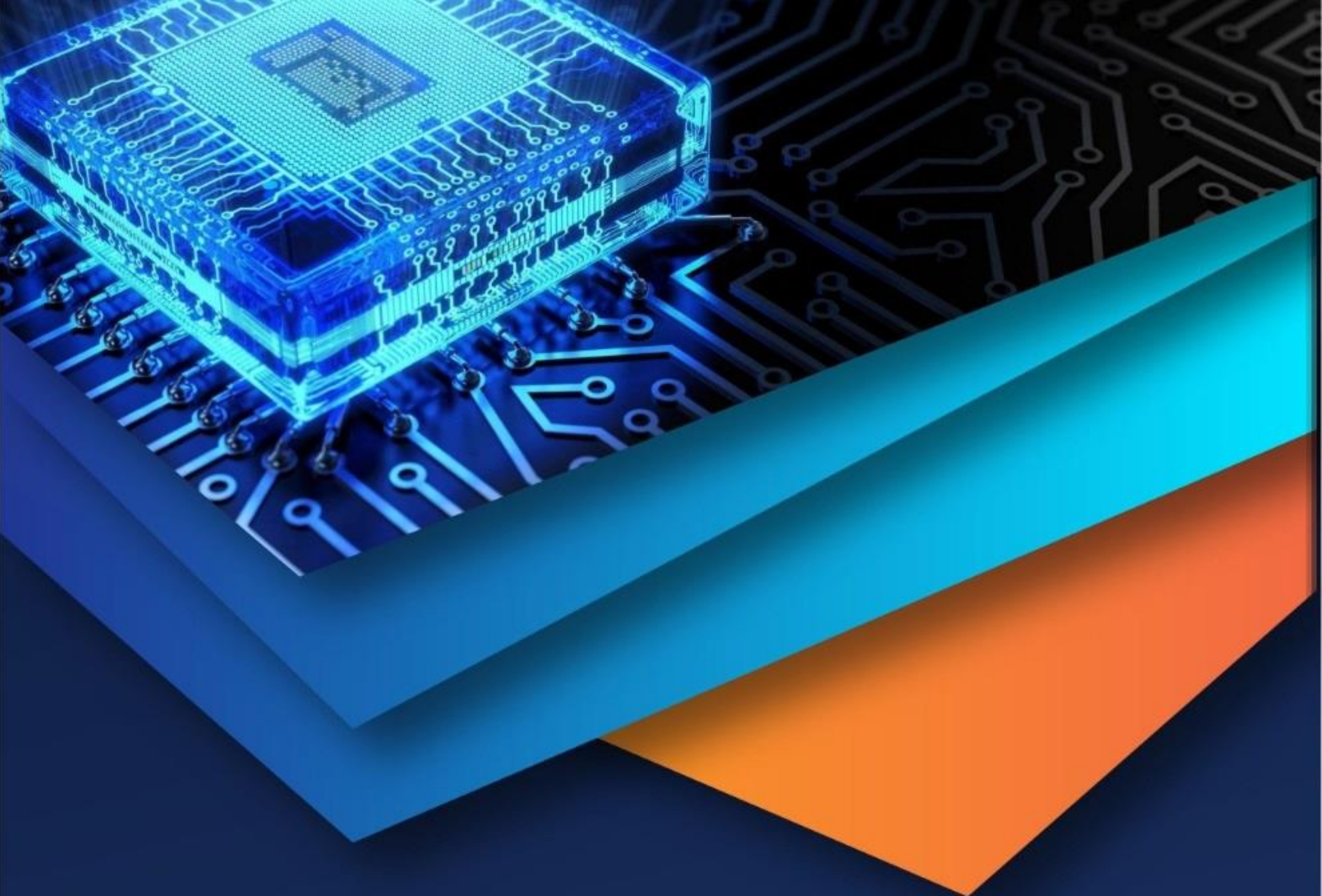

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