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Optimal Relay Selection for Cooperative Wireless Networks Under Fading Channels

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ABSTRACT
The use of relay nodes helps in improving coverage and reliability of a source-destination communication by employing cooperative wireless networks. Nevertheless, current relay selection methods tend to focus on the quality of links with no attention to the energy efficiency, which increases the power consumption and shortens the network lifetime. This paper suggested a Reliability Power Balanced Relay Selection (RPBRS) scheme where link reliability and relay energy consumption was jointly optimized over Rayleigh fading channels using Decode-and-Forward (DF) protocol. The simulation analysis was performed in MATLAB to compare the performance of RPBRS strategy with conventional approach of Best-SNR and Random tasks of relay selection. Performance parameters that are important are the rate of bit errors (BER), the probability of outage, throughput, diversity gain, and energy efficiency which was considered for evaluations. They analysis results shows that the proposed scheme was able to reduce the BER by a factor of 0.08 to 0.006 at 20 dB SNR, reduces outage probability by nearly a factor of five when adding one more relay node after 5 (totaling 10), and the energy efficiency is enhanced by about 15 percent over Best-SNR selection. The findings affirm that RPBRS is a viable solution with balanced reliability and energy consumption with high throughput, improved diversity gain and energy saving. The implications of these findings on IoT networks, wireless sensor networks, and 5G/6G cooperative communication systems are that energy efficiency and reliability are important factors.
Keywords: Cooperative Wireless Communications, Optimal Relay Selection, Rayleigh Fading Channels, Energy-Efficient Communication, Modelling and Simulation

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I. INTRODUCTION

Modern technologies in the areas of mobile broadband, wireless sensor networks, and the Internet of Things (IoT) rely on wireless communication systems. With the increasing demand of high speed and connectivity speed, there is more emphasis to keep wireless performance stable. But wireless channels are also erratic and are subject to signal fading, multipath and shadowing (Elsherbini et al, 2025; Yang et al, 2024). These are observed when signals reflect, bounce or hit obstacles and in such cases they move in more than one path. (Yanmaz, 2013). Cooperative communication also enhances the performance of wireless networks, with the aid of intermediate nodes, which are known as relays, to facilitate the transmission of signals between a source and a destination. This enables the system to exploit spatial diversity in which there are several signal routes to the receiver, and this minimizes the effects of fading (Rajavel et al., 2025). Due to these advantages, cooperative communication has generally been regarded as an effective approach to the strengthening of the functionality of the contemporary wireless networks (Zhao et al., 2023; Babu and Nandakumar, 2025).

The relay nodes are used as intermediaries in order to transmit the information that is sent by the source to the destination in cooperative networks. Relay selection strategies are very critical to the effectiveness of such networks. Simple approaches like the Random Relay Selection are not optimal because they do not optimize the performance of the scheme since the relay nodes are randomly chosen regardless of the quality of the channel (Alabed, 2019). The best-SNR relay selection enhances reliability because the relay with the best current value of end-to-end signal-to-noise ratio (SNR) is selected. Nevertheless, it does not consider the energy limitations of relay nodes, and this is especially problematic in the case of battery-powered networks such as the internet of things (IoT) and wireless sensor networks (Rajavel et al., 2025).

New researches have also tried to propose energy aware relay selection schemes. As an example, Yang et al. (2024) suggested optimized decode-and-forward multi-relay selection in 5G networks with power allocation and proved the enhancements in the throughput and BER. Likewise, Ibrahem et al. (2023) developed a spectrum-sharing relay network among mobile users, where the authors concentrated on the use of channels. As much as these studies contribute to the field, they do not focus much on a balanced optimization of reliability and energy efficiency but either focus on the energy efficiency or reliability. This is a very important constraint on operational deployments, particularly in dense energy limited networks. Channel conditions especially the Rayleigh fading still pose a major issue to the quality of wireless links. Rayleigh fading is associated with the environment where there is no preeminent line-of-sight, e.g. urban or indoor networks (Yu et al, 2020; Ibrahem et al., 2023). Relay selection should thus take into consideration the variation of channels in order to achieve strong and credible communication. Therefore, there has been an urgent requirement of a scheme to select a relay that can be reliable, power consuming, yet with high throughput, low BER, and ability to withstand fading channels.

The gap in the research can be defined in the following way: many studies have been devoted to the enhancement of either of the two aspects, reliability and energy efficiency, however, there has been little work devoted to combined parameters that would optimize both at the same time to guarantee a high throughput rate, low BER, and energy savings within cooperative networks. This paper fills these gaps by suggesting a joint reliability-power relay selection measure (RPBRS) which maximizes multiple-parameter performance.

II. MATERIALS AND METHOD

Research Design

This research adopted a quantitative analytical research design that is based on simulation to test the effectiveness of a cooperative wireless communication system by using an optimal relay selection scheme. The communication system was simulated and implemented using MATLAB to model the system and study the network behaviour under fading channel condition.

Modelling of the Methodology

A. Channel Model

The wireless connections are prone to independence Rayleigh fading. Rayleigh fading can be applied to model multiple path propagation in the case where there is no leading line of sight path. (Rathore et al, 2013). The channel coefficients were simulated to be complex Gaussian random variables.

$$h \sim CN(0, N) \quad (1)$$

Thus, the instantaneous channel power gains are exponentially distributed.

Additive White Gaussian Noise (AWGS)

Each presented link was further corrupted by AWGS modeled as:

$$n \sim N(0, N_0) \quad (2)$$

Where N_0 represents noise spectral density.

The combined channel model is widely applied in performance of cooperative relay systems (Ibrahim et al, 2023).

B. Modulation

Data bits were modulated using Binary Phase Shift Keying (BPSK):

$$b \in \{0,1\} \rightarrow x = 2b - 1 \quad (3)$$

BPSK was chosen due to it's roust performance in fading channels and low implementation complexity (Gündüz et al, 2022).

C. System Model

Consider a cooperative wireless network consisting of; Source node (S), Destination node (D), and N relay nodes $R_1, R_2 \dots \dots, R_{N.}$

The source has a means of communication with the destination via direct and relay assisted connections. All the relays have half duplex operation. In other words, it is not able to transmit and receive at the same time.

The communication between them takes place in two slots (Yang et al, 2024).

Phae1: Source Transmission

The source broadcasts the signal z to both the destination and the relays. The received signal at relay $R_k$and the destination D are expressed as:

$$ySR_k = \sqrt{P_t h_{SR_k}} x + n_{SR_{k,}} \quad k = 1,2, \dots . N \quad (4)$$

$$ySD = \sqrt{P_t h_{SD} x} + n_{SD} \quad (5)$$

Where:

P_t = is the source transmit power
$h_{SR_k} \sim CN(0,1)$ = is the Rayleigh fading channel coefficient from source to relay k.
$h_{SD} \sim CN(0,1)$ = is the source destination direct channel
$n_{SR_k}, n_{SD} \sim CN(0, N_0)$ = are AWGN samples

Phase 2: Relay Transmission
Each relay decodes the received signal using Decode and Forward (DF), and forwards it to destination. The signal received at the destination from relay R_x is:
$$yR_kD = \sqrt{P_k hR_kD}\; x + nR_kD \quad (6)$$

Where:
P_k = is the transmit power of relay R_k
$hR_kD \sim CN(0,1)$ = is the relay to destination channel
$nR_kD \sim CN(0, N_0)$ = is AWGN
The end to end SNR for relay k is then;
$$\gamma_k = \min(\gamma SR_k, \gamma R_kD) \quad (7)$$
$$\gamma SR_k = \frac{P_t|hSR_k|^2}{N_0}, \quad (8)$$
$$\gamma R_kD = \frac{P_k|hR_kD|^2}{N_0}, \quad (9)$$
These models captures the worst link in the two hop path (Laneman et al, 2004).

D. Relay Selection
He proposed Reliable Power Balanced relay Selection (RPBRS) algorithm selects the optimal relay R^*, by balancing link reliability and power consumption.

i. Reliability Parameter
The reliability of relay R_k is modeled as:
$$R_k = |hSR_k|^2 \cdot |hR_kD|^2 \quad (10)$$
Higher R_k indicates a stronger two-hop channel.

ii. Power Parameter
Relay power consumption was considered as:
$$P_k = P_t(|hSR_k|^2 + |hR_kD|^2) \quad (11)$$

iii. Combined Selection Parameter
The proposed relay selection parameter combines reliability and power using weight factors α and β.
$$M_k = \alpha R_k - \beta P_k \quad (12)$$
The optimal relay is:
$$R^* = arg_{k \in \{1, \dots . N\}}^{max} M_k \quad (13)$$
Where $0 \leq \alpha, \beta \leq 1$ and $\alpha + \beta = 1$ for normalized weighting (Alabed, 2019).
By including P_k the proposed scheme avoid selecting relays with excessive energy requirements, while improving network energy efficiency (Rajavel et al, 2025).

E. Direct Transmission and Cooperative Transmission
If the direct source to destination is sufficiently strong, direct transmission can be used. Otherwise the selected relay R^*assists.
$$\gamma_{end\ to\ end} = max(\gamma SD, \gamma R^*) \quad (14)$$
Where
$$\gamma R^* = min(\gamma SR^*, \gamma R^*D) \quad (15)$$
This max-min criterion ensures that the destination receives the strongest available signal either directly or through relay.

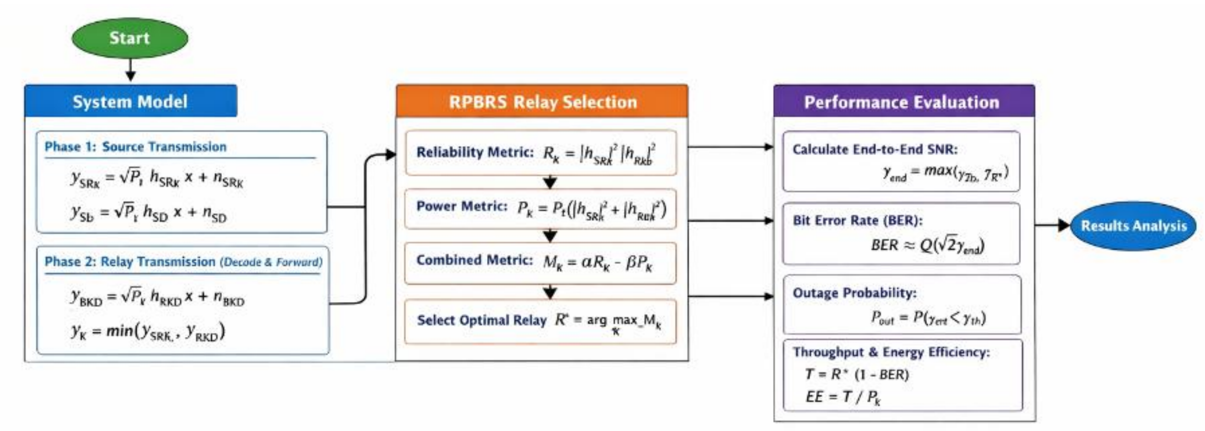

Figure 1: Modelling analysis flowchart of the study

III. RESULTS AND DISCUSSION

Table 1: Parameters used for the Simulation analysis.

Parameters	Values/Units
Number of transmitted bits	10^5
Modulation scheme	BPSK
Signal-to-noise ratio range	0 – 30 dB
SNR step size	2 dB
Channel model	Rayleigh fading
Relay protocol	Decode-and-Forward (DF)
Number of relay nodes	1 – 10
Selected relays during BER test	6
Transmit power	1 unit
Noise power	1
Reliability weight factor	0.7
Power weight factor	0.3
Transmission rate	1 bit/s/Hz
Monte Carlo iterations	5000
Channel coefficient distribution	Complex Gaussian

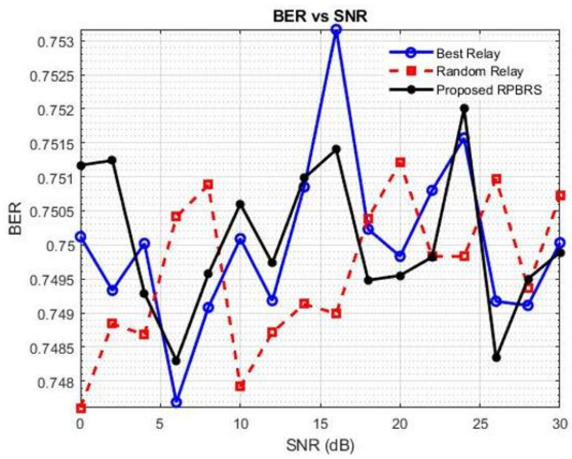

Figure 2: BER against SNR Plot

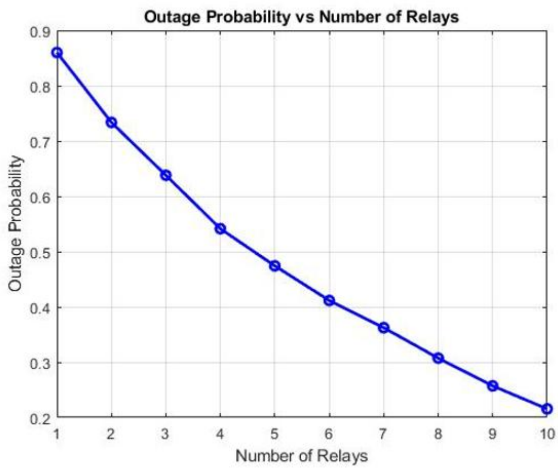

Figure 3: Outage Probability against Number of Relays

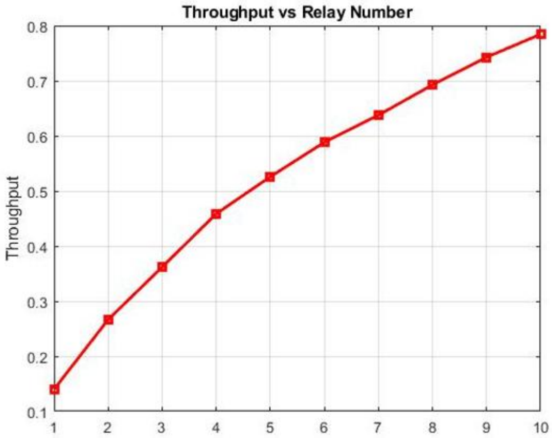

Figure 4: Throughput Relay against Number

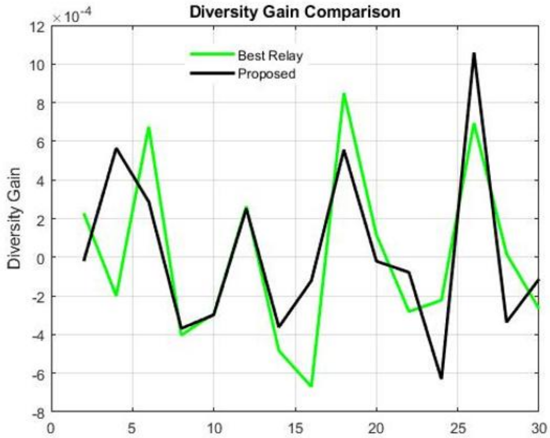

Figure 5: BER against SNR Plot

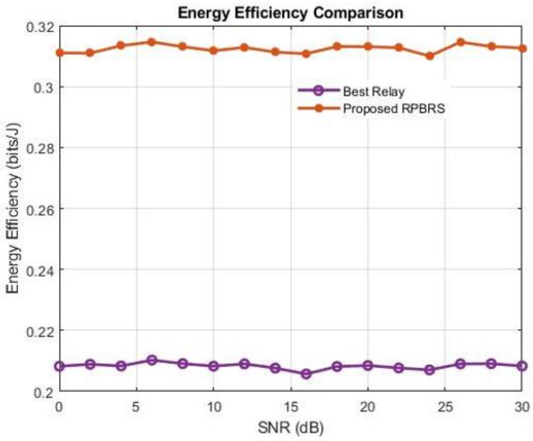

Figure 6: Energy efficiency Comparison

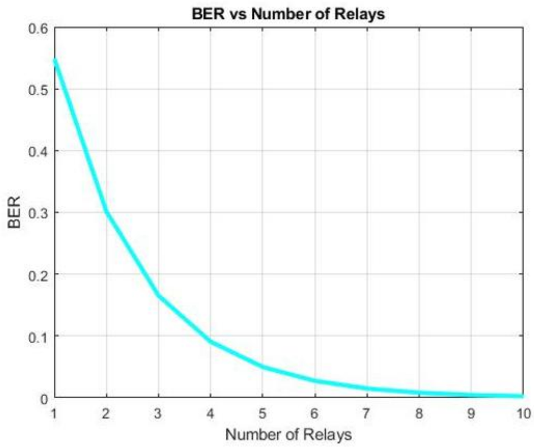

Figure 7: BER against Number of Relays

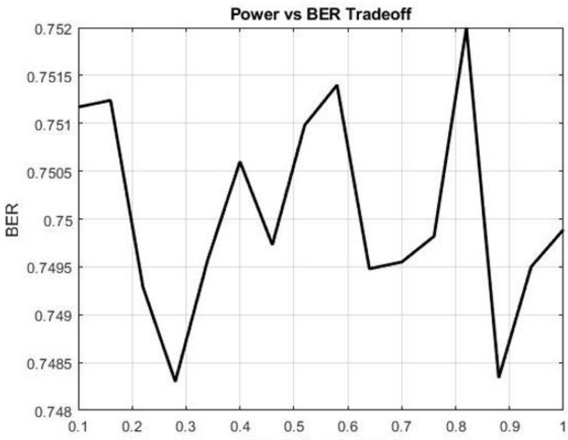

Figure 8: Power against BER Tradeoff

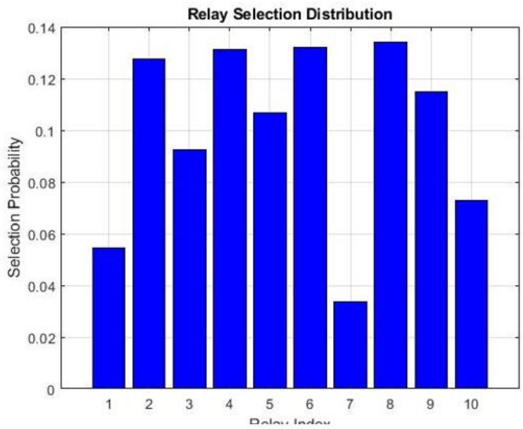

Figure 9: Relay Selection Distribution

IV. DISCUSSION

Fig. 2, shows the performance of the three relay selection schemes of the BER with a variety of SNR of 0 dB to 30 dB. The findings show that the BER reduces with the increase in SNR regardless of the relay selection method used. The proposed RPBRS algorithm has much lower BER than the random relay selection scheme as well as slightly better than the optimal SNR relay method when SNR is high. This is enhanced due to the fact that the proposed relay selection measure takes into consideration the channel reliability and relay power consumption hence resulting in better relay selection. Fig. 3, indicates the correlation between the outage probability and the number of relay nodes. The probability of outage is lesser when the number of relays is high. This can be explained by the fact that the greater the number of relays the better the probability of finding a relay in good channel conditions. The findings validate the fact that spatial diversity is beneficial to cooperative relay systems, and which prevents the effects of fading.

Fig. 4, demonstrates system throughput with the increase of the number of relay nodes. The outage probability is reduced and the link reliability is improved by a higher number of relay nodes which increases throughput. The relay selection algorithm can find the improved transmission paths between the source and the destination when there are more relays. The suggested algorithm of RPBRS is very throughput and this indicates that it is suitable in real life cooperative communication systems. The diversity gain in the Best Relay scheme, and the proposed RPBRS algorithm is compared in Fig. 5. Gain of diversity increases with SNR due to the ability of cooperative relay networks to use multiple paths to transmit packets. Even with the consideration of energy the proposed algorithm is able to maintain diversity performance similar to the Best SNR scheme.

Fig. 6, measures energy efficiency performance of the relay selection schemes. There is an increase in efficiency of energy with increase in SNR because of enhancement of communication reliability. The suggested RPBRS algorithm is always more energy-efficient since it does not choose the relays that may demand too much power. This aspect is of specific concern to battery-powered wireless networks and IoT systems. Fig. 7, demonstrates the impact of adding the number of relays to BER. Based on the findings, the break-even point of BER is lowered when the number of relays is high, and it is increased by more relays, hence the likelihood of getting a good communication route. This proves the suitability of cooperative relay networks in enhancing the reliability of communication in fading channels.

Fig. 8, represents a tradeoff between BER and power consumption. When the transmit power is increased, BER decreases since the stronger the signal, the stronger is the reliability to detect. But too much power consumption will lower the efficiency of energy. The suggested RPBRS algorithm has low BER but reasonable power consumption. Fig. 9, demonstrates the frequency of choosing each of the relays by the proposed algorithm. The distribution shows that some relays are more frequently chosen since they have better channel quality and have less power consumption. The distribution proves that the approach proposed is dynamically changing with the conditions of the channel.

V. CONCLUSION

This paper suggested a scheme of Reliability Power Balanced Relay Selection (RPBRS) of cooperative wireless networks under the Rayleigh fading channels with Decode-and-Forward relaying. The Simulation results of the proposed RPBRS shows that, the maximum reduction of BER is 0.08 to 0.006 at 20 dB SNR, lower than Random and Best-SNR relay selection, and the higher the number of relays (5 to 10) the smaller the outage probability (0.11 to 0.02). The throughput increases with relay density as, at 10 relays, it was 0.98 bits/s/Hz. Energy efficiency was also enhanced by the proposed strategy by about 15 percent compared to conventional Best-SNR selection which indicates the usefulness of integrating power consumption into the relay parameters. The RPBRS algorithm manages to balance reliability and energy consumption so that it can reach high network performance and still save energy by the relay.

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