Buffer-aided Relay Selection Technique in a Cooperative Communication Network

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ABSTRACT: The goal of cooperative communication is to increase spatial diversity and wireless network coverage. However, in a classical relaying setup, where a single best relay is chosen to receive the source's data in the first time slot and retransmit in the second time slot regardless of channel circumstances, channel mismatch occurs. In this paper, we have developed an enhanced relay selection technique at the relay nodes that incorporates buffers to address the aforementioned problem. The outage probability and throughput computations are derived using closed-form formulas. The results obtained show that the enhanced relay selection technique gives lower values in outage probability and higher values in throughput when compared with the conventional technique, providing it a desirable strategy for use in technical communication.

KEYWORDS: Relay, Cooperative communication, Buffer, Outage probability, Max-link, Throughput

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I. INTRODUCTION

Cooperative communication provides one of the most dynamic approaches to cater for the limitations of existing wireless networks. It improved spectrum and power efficiency, network coverage, and outage probability (Ibrahim *et al*, 2008). Relay selection has a lot of relevance in a cooperative communication network, in which a relay helps a source node convey its information to a destination node. The relay selection scheme is viewed as a viable method for extending wireless network coverage and providing a number of performance improvements (Bletsas et al., 2006). It is attractive owing to its high performance and efficient use of power and bandwidth resources (Liang et al., 2013). The selected relay obtains data from the transmitting node in the first time slot and re-transmits to the receiving node in the second time slot, according to traditional relay selection schemes. This fixed transmission schedule does not allow the most efficient receiving and transmitting channels to be utilized, thus limiting the performance of a cooperative network. Buffering at relay nodes was developed to get over the constraint of utilizing the same relay node to receive and send data (Ikhlef *et al*., 2011).

Many efforts have been made to address the challenges mentioned earlier. Krikidis *et al*., (2012), suggested a max-link relay selection algorithm that adaptively activates the link with the best fading circumstances at each slot to get the highest diversity gain. Their research implies that the source and destination are not connected directly. Also, in Poulimeneas *et al*., (2016), using Buffer State Information (BSI), two extensions of max-link were shown. The first extension achieved low average latency by sacrificing diversity, as buffers were frequently empty, while the second extension, which was delay and diversity conscious, ensured that a large number of links were available by avoiding empty buffers. However, because this system spread packets to different buffers, the latency grew as the number of relays rose. A Delay-Aware (DA) variant of max-link was proposed by Tian *et al*., (2017), prioritizing Relay-Destination selection for the sake of emptying the relays' buffer at a faster pace. When the signal-to-noise ratio (SNR) was low, the delay was reduced, but when the SNR was high, the delay converged to two time slots, regardless of the number of relays or buffer size. Siddig and Salleh (2017) proposed a Balancing Relay Selection (BaRS) scheme that enhances the outage probability, and keeps the buffers' states balanced with equal arrival and departure rates at the buffer. Relay selection is based on both Channel State Information (CSI) and BSI. The link that is selected for transmission in each time slot is the one that aims to mend the balanced state of the most unbalanced buffer.

Compared with max-link scheme in Krikidis *et al* (2012), BaRS has a lower outage probability as it results in more balance buffer. Nomikos *et al* (2018) proposed low-complexity (LoCo) link selection algorithm. This link selects the relay with the largest buffer length and executes broadcast Source-Relay (S-R) transmission. Their work lowers delay, maintains diversity and lowers complexity, compared with Krikidis *et al* (2012). A novel probabilistic buffer-aided relay selection scheme in cooperative network is proposed by Xu *et al* (2020). The scheme uses randomness in deciding the link selection

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outcome. This occur when a probabilistic selection is performed between the strongest available S-R link and the strongest available Relay-Destination (R-D) link. Different trade-offs between the outage probability and average packet delay can be reached by adjusting one specific parameter.

Raza *et al* (2018) introduced a buffer threshold that modifies the selection probability of S-R or R-D links. The link with the maximum weight is selected after reassigning the weight of the links that are calculated according to the buffer occupancy and buffer threshold. Raza *et al* (2019) extend the work in Raza *et al* (2018) and proposed a buffer limit for the buffer occupancy which manipulates the selection of the transmitting and receiving links of the relay. A link having the largest weight is activated, and the corresponding relay is chosen for transmission or reception. This work improved the performance of the relaying system for the average throughput. Also, Raza *et al* (2019) considers buffer occupancy-based relay selection schemes for Amplify and Forward (AF) and Decode and Forward (DF) relaying in nakagami-m fading channel. For the AF relaying, an updated threshold is employed to choose whether the relay should store or discard the received packets. The favored link selection enhances the average throughput.

Buffer-aided relay selection using hybrid Decode-Amplify forward relaying protocol is investigated in Nasir *et al* (2019). The link state is used in relay selection. The proposed scheme achieved a better outage probability in comparison to relay selection scheme using DF or AF relaying. A priority-based max-link relay selection for buffer-aided decode and forward cooperative network was proposed in Manoj *et al* (2019). First priority was given to relay buffers with full status, the second priority to the relay buffers with empty status, and the third priority to relay buffers with neither full nor empty status. The best relay node is selected corresponding to the link having the highest channel gain among the links within a priority class. Their result shows that the proposed relaying scheme has better performance gain over the conventional max-link scheme. Duarte and Lamare (2019) proposed a novel relay selection protocol that is based on switching concept and selection of the best link employed by max-link and also incorporates the Maximum Minimum Distance (MMD) selection criterion. Their result shows that the switched max-link performed better than the conventional max-link.

In (Charalambous *et al* 2019), a cooperative network with a buffer-aided multi-antenna source, multiple half duplex buffer-aided relays and a single destination is proposed to restore the multiplexing loss of the network. They presented two relay-pair selection policies, depending on the available CSI in the system. Their results show that the use of a powerful source can provide considerable performance improvements in terms of outage probability. Manoj *et al*, (2019) analyzed the outage performance of a buffer-aided cooperative network with co-channel interference and additive white Gaussian noise. They proposed a max-signal-to-interference plus noise ratio (SINR) relaying protocol in which the transmission of data takes place in the link having the maximum SINR among the available source-relay and relay-destination links. Their result improves the performance of the outage.

However, majority of the previous works focused mainly on a DF buffer-aided relaying technique and this leads to lower level of security for the transmitted data which may result in data loss before reaching the destination. Also, no combining technique was employed due to the assumption there is no direct transmission between source and destination. To increase the network's performance, this research created an AF buffer-aided relay selection strategy with the existence of a source to destination connection and the inclusion of a combining mechanism at the destination.

The main contributions of this paper can be summarized as follows:

- We proposed an AF buffer-aided max-link relay selection scheme. In this scheme, relay communication is selected on link quality;
- The closed-form expressions for the outage probability and throughput for the proposed scheme are derived; and
- Evaluated the performance of the proposed scheme in terms of outage probability and throughput. We confirmed that the proposed scheme offers reduced outages and increased throughput.

The rest of the paper is organized as follows: Section 2 introduces the system model and assumptions for the proposed relay selection scheme. In section 3, we provided the methodology and detailed analysis of the outage probability and throughput of the proposed scheme. Numerical results and discussion are provided in section 4 to evaluate the system performance. Finally, section 5 concludes the paper by summarizing the key findings.

II. SYSTEM MODEL

The system model consists of source S, destination D and a set R of N amplify and forward relays indicated by $R = \{R_{1,} R_{2,} \ldots, R_{N,}\}$ as shown in Figure 1. There is direct communication link between S and D. Each node is equipped with a single antenna and does not support simultaneous reception and transmission, i.e., they operate in half-duplex transmission mode. Every relay has a finite size data buffer of maximum L packets space to store the received data. Buffers allows first in first out (FIFO) access method to process the data. The count of elements in a buffer Q_N is denoted by $\psi(Q_N)$ where $0 \leq \psi(Q_N) \leq$ L. Only a neither empty nor full buffer can accept and transmit data. When a packet goes into a buffer, buffer $\psi(Q_N)$ gets a unit increment, likewise, when a packet departs from the buffer, $\psi(Q_N)$ gets a unit decrement. $S - R$ link is said to be open if its corresponding buffer is not full and $R - D$ link is said to be open if its corresponding buffer is not empty. The channel links are subjected to independent and identically distributed (i.i,d) Rayleigh fading. It is assumed that the received signals are impaired by additive white Gaussian noise (AWGN) with zero mean and N_0 variance.

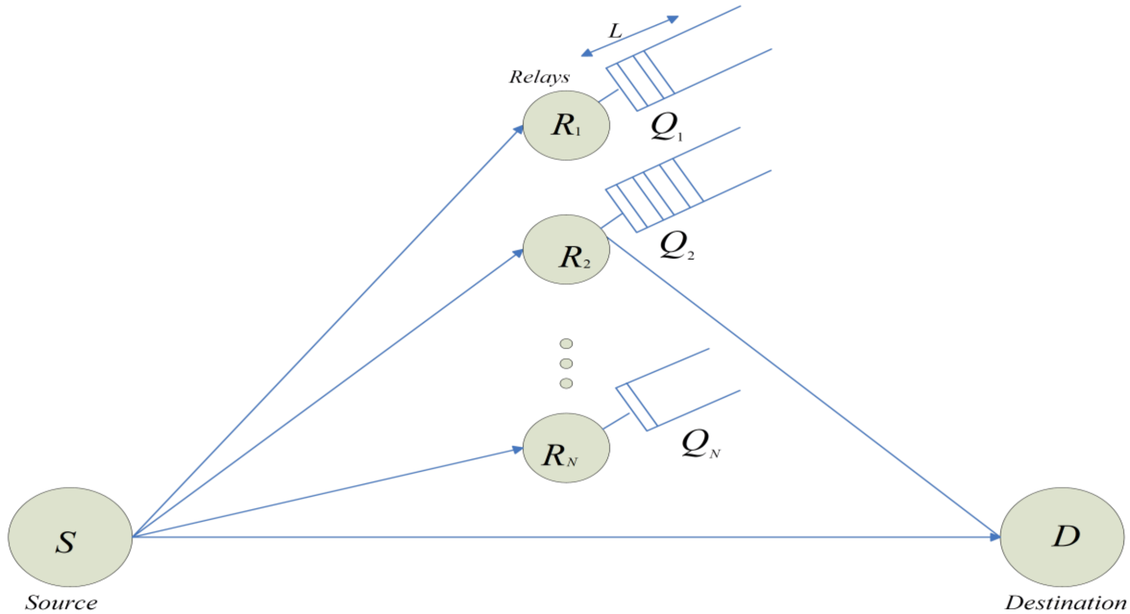

Figure 1: The system model of the enhanced technique.

III. METHODOLOGY

A. *Proposed Relay Selection Technique*

By integrating data buffers at the system's relay nodes, the conventional relay selection approach is improved as shown in Figure 1. A distributed mechanism is used in this technique to pick the optimal link among the available S-R and R-D links. Between all accessible links on both sides, the optimum relay for data reception and transmission is dynamically selected. The digital signal transmitted is first modulated and filtered using the Binary Phase Shift Keying (BPSK) signaling scheme and Square-Root Raised Cosine (SRRC) filter respectively. The filtered data is propagated over Rayleigh fading channel from the source to the relay selected for reception and stored in its buffer. The relay selected for transmission selects the packet from the buffer and transmits it to the destination where it is then filtered and finally demodulated using the SRRC and BPSK respectively. The received signals directly from the transmitter and the relay path are combined using Maximum Ratio Combiner (MRC).

The relay selection process is expressed as

$$R^* = \underset{R_N \epsilon c}{\operatorname{argmax}} \left\{ \bigcup_{R_N \epsilon c: \psi(Q_N) \neq L} \{\gamma_{SR_N}\}, \bigcup_{R_N \epsilon c: \psi(Q_N) \neq O} \{\gamma_{R_N D}\}, \right\} \quad (1)$$

where R^* is the selected relay

γ_{SR_N} is the instantaneous SNR of the $S - R_N$ link

$\gamma_{R_N D}$ is the instantaneous SNR of the $R_N - D$ link

L is the buffer size

Q_N is the data buffer

$\psi(Q_N)$ is the number of data packets in the buffer Q_N

The equivalent SNR at the destination node is expressed by Torabi *et al*, (2010) as

$$\gamma_{SRD} = \frac{\gamma_{SR}\,\gamma_{RD}}{\gamma_{SR} + \gamma_{RD} + 1} \quad (2)$$

The Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of the links over Rayleigh fading channel are expressed as

$$f_{\gamma_{XY}}(\gamma) = \frac{1}{\bar{\gamma}_{XY}} e^{-\gamma/\bar{\gamma}_{XY}} \quad (3)$$

$$F_{\gamma_{XY}}(\gamma) = 1 - e^{-\gamma/\bar{\gamma}_{XY}} \quad (4)$$

The CDF of the overall SNR of the Source–Relay-Destination (SRD) is given as

$$F_{\gamma_{SRD}}(\gamma_{th}) = P\left(\frac{\gamma_{SR}\,\gamma_{RD}}{\gamma_{SR} + \gamma_{RD} + 1} \leq \gamma_{th}\right) \quad (5)$$

By integrating Eqn. (5) with respect to γ

$$= 1 - \int_{\gamma_{th}}^{\infty} f_{\gamma_{RD}}(\gamma)\left[1 - F_{\gamma_{SR}}\left(\frac{\gamma_{th}(\gamma+1)}{\gamma - \gamma_{th}}\right)\right] d\gamma$$

$$= 1 - \int_0^{\infty} f_{\gamma_{RD}}(\gamma + \gamma_{th})\left[1 - F_{\gamma_{SR}}\frac{\gamma_{th}(\gamma + \gamma_{th} + 1)}{\gamma - \gamma_{th}}\right] d\gamma \quad (6)$$

Considering a scenario where a relay has L number of packets. Therefore, using order statistics, Eqn. (6) is expressed as

$$F_{\gamma_{SR}}(\gamma) = (1 - e^{-\gamma/\bar{\gamma}_{SR}})^L \quad (7)$$

Substituting Eqns. (7) and (3) with proper indices in (6),

$$F_{\gamma_{SRD}}(\gamma_{th}) = 1 - \int_0^{\infty} \frac{e^{-\frac{\gamma+\gamma_{th}}{\bar{\gamma}_{RD}}}}{\bar{\gamma}_{RD}}\left[1 - \left(1 - e^{-\frac{\gamma_{th}(\gamma+\gamma_{th}+1)}{\gamma}}\right)^L\right] d\gamma$$

$$= 1 - \int_0^{\infty} \frac{e^{-\frac{\gamma+\gamma_{th}}{\bar{\gamma}_{RD}}}}{\bar{\gamma}_{RD}} \times \left(\sum_{N=1}^{L} \binom{L}{N}(-1)^N e^{-\frac{\gamma_{th}(\gamma+\gamma_{th}+1)}{\gamma}}\right) d\gamma$$

$$= 1 + \sum_{N=0}^{L} \binom{L}{N}(-1)^N \frac{e^{-\gamma_{th}\frac{\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD}}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}}}{\bar{\gamma}_{RD}} \int_0^{\infty} e^{\left(\frac{-\gamma_{th} + ^N(\gamma_{th}+1)}{\gamma\bar{\gamma}_{SR}} - \frac{\gamma}{\bar{\gamma}_{RD}}\right)} d\gamma \quad (8)$$

Using the identity $\int_0^{\infty} exp(-\frac{\beta}{4x} - \alpha x)dx = \sqrt{\frac{\beta}{\alpha}}\ K_1\ (\sqrt{\beta\alpha}\ )$, $F_{\gamma_{SRD}}(\gamma_{th})$ is expressed as:

$$F_{\gamma_{SRD}}\ (\gamma_{th}) = 1 + \sum_{N=1}^{L} \binom{L}{N}(-1)^N \frac{e^{-\gamma_{th}\frac{\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD}}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}}}{\bar{\gamma}_{RD}}\ ^2\sqrt{\frac{\gamma_{th} + ^N(\gamma_{th}+1)\bar{\gamma}_{RD}}{\bar{\gamma}_{SR}}}\ K_1\left(^2\sqrt{\frac{\gamma_{th} + ^N(\gamma_{th}+1)}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}}\right) \quad (9)$$

where K_1 (.) is the modified Bessel function of second kind of first order Gradshtey and Ryzhik, (2007). To simplify the analysis, Eqn. (9) reduces to

$$F_{\gamma_{SRD}}\ (\gamma_{th}) = 1 + \sum_{N=1}^{L} \binom{L}{N}(-1)^N\ e^{\frac{-\gamma_{th}(\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD})}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}} \quad (10)$$

The CDF of SNR at the destination after the application of MRC is expressed as

$$F_{\gamma_D}(\gamma_{th}) = \int_0^{\gamma_{th}} F_{\gamma_{SRD}}\ (\gamma)\ f_{\gamma_{SD}}\ (\gamma_{th} \text{-}\ \gamma)\ d\gamma$$

$$= \int_0^{\gamma_{th}} \frac{e^{-\frac{(\gamma_{th}-\gamma)}{\bar{\gamma}_{SD}}}}{\bar{\gamma}_{SD}} \times \left(1 + \sum_{N=1}^{L} \binom{L}{N}(-1)^N\ e^{\frac{-\gamma_{th}(\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD})}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}}\right) d\gamma$$

$$= (1 - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}}) + \sum_{N=1}^{L} \binom{L}{N}(-1)^N \frac{\bar{\gamma}_{SR}\bar{\gamma}_{RD}\left(e^{\frac{-\gamma_{th}(\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD})}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}} - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}}\right)}{\bar{\gamma}_{SR}\bar{\gamma}_{RD} - \bar{\gamma}_{SR}\bar{\gamma}_{SD} - b\bar{\gamma}_{RD}\bar{\gamma}_{SD}} \quad (11)$$

B. Outage Probability ($\boldsymbol{P_{out}}$)

Outage Probability is the possibility of an outage on the system.

P_out is of the received signal for the developed model is expressed by Narasimhan, (2008) as:

$$P_{out}(\gamma_{th}) = \int_o^{\gamma th} f_{\gamma_D}(\gamma) = F_{\gamma_D}(\gamma_{th}) \quad (12)$$

where γ_{th} is the set threshold

$f_{\gamma_D}(\gamma)$ is the pdf of γ

$F_{\gamma_D}(\gamma_{th})$ is defined in (11)

Substituting Eqn. (11) in (12), outage probability of the enhanced technique becomes,

$$P_{out}(\gamma_{th}) = \left(1 - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}}\right) + \sum_{N=1}^{L} \binom{L}{N}(-1)^N \frac{\bar{\gamma}_{SR}\bar{\gamma}_{RD}(e^{\frac{-\gamma_{th}(\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD})}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}} - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}})}{\bar{\gamma}_{SR}\bar{\gamma}_{RD} - \bar{\gamma}_{SR}\bar{\gamma}_{SD} - b\bar{\gamma}_{RD}\bar{\gamma}_{SD}} \quad (13)$$

C. Throughput

Throughput is the number of data packets that have been successfully sent to the destination from a number of attempts at sending information every second.

The average throughput of the overall system network is mathematically expressed by Simon and Alouini, (2005) as:

$$\eta = R(1 - P_{out}) \quad (14)$$

where the average data rate R = ½ , then Eqn. (14) becomes

$$\eta = \frac{(1 - P_{out})}{2} \quad (15)$$

Substituting Eqn. (13) in (15), the throughput of the enhanced technique becomes

$$\eta = \frac{\left(1 - \left(1 - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}}\right) + \sum_{N=1}^{L} \binom{L}{N}(-1)^N \frac{\bar{\gamma}_{SR}\bar{\gamma}_{RD}\left(e^{\frac{-\gamma_{th}(\ )\bar{\gamma}_{SR} + ^N\bar{\gamma}_{RD}}{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}} - e^{\frac{-\gamma_{th}}{\bar{\gamma}_{SD}}}\right)}{\bar{\gamma}_{SR}\bar{\gamma}_{RD} - \bar{\gamma}_{SR}\bar{\gamma}_{SD} - k\bar{\gamma}_{RD}\bar{\gamma}_{SD}}\right)}{2} \quad (16)$$

D. Simulation Model

The system simulation model for the enhanced technique consists of the transmitter, set of relays with buffers, the Rayleigh fading channel and the receiver. Data acquisition is generated from the random integer generator, which is available within the MATLAB. The transmitter processes the randomly generated data for transmission and modulates it with BPSK signaling scheme. SSRC filter is used at the transmitter to reduce the bandwidth of transmitted signal for suitable transmission over the Rayleigh channel without losing the content of the digital data and thereby improving the bandwidth efficiency. The filtered data is sent to the relays as well as the destination. The selected relay receives the data and stores it in its buffer. The AF relaying protocol is used at the relay to process the signal it receives and then transmit it to the destination. The received signals over the Rayleigh fading channels are combined at the destination using the MRC. The output of MRC is then passed through the SRRC filter for further processing and finally demodulated with the BPSK demodulator. The complete simulation model for the enhanced technique is shown in Figure 2.

IV. RESULTS AND DISCUSSION

The values of P_out and throughput obtained for both Enhanced and Conventional relay selection technique are plotted against SNR as presented in Figures 3 and 4. P_out values obtained at different SNR are presented in Figure 3 for both Enhanced and Conventional technique at L=3 and number of relay N=4. The P_{out} values obtained for the Enhanced technique are 0.000218 and 0.000120 at SNR of 6 dB and 8 dB as against the Conventional technique with P_{out} values of 0.000783 and 0.000401 at the SNR of 6 dB and 8 dB. The results also shows that, as SNR increases,

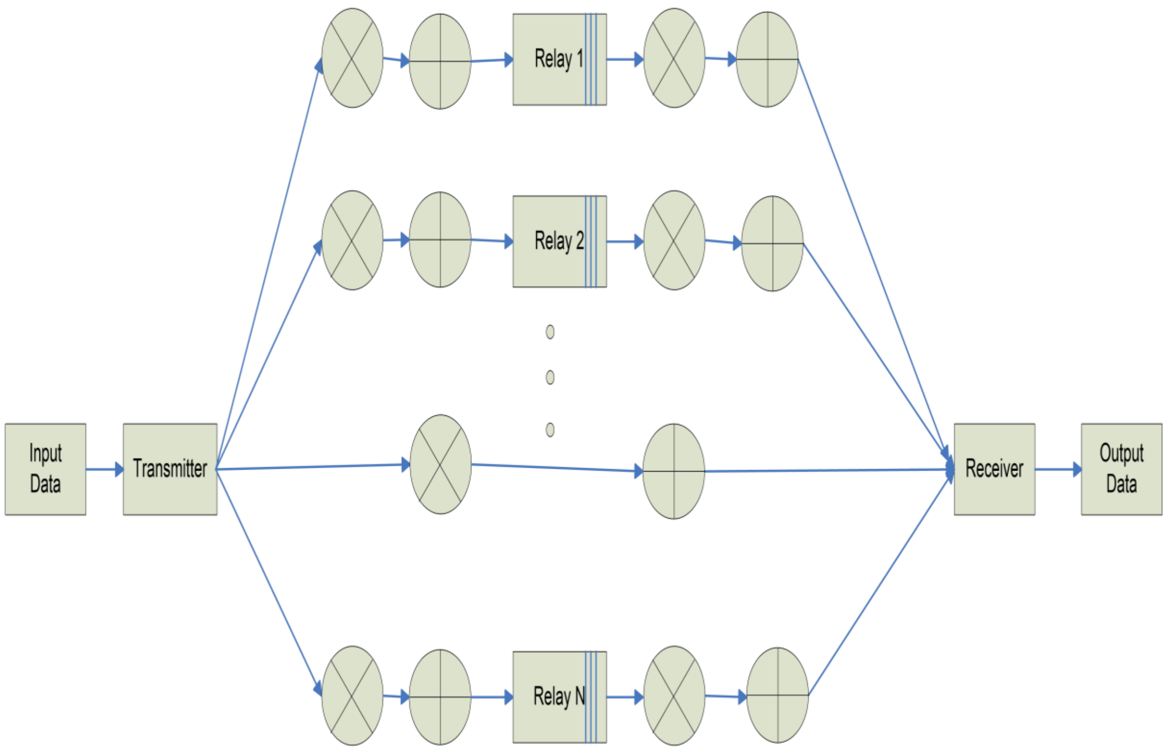

Figure 2: Simulation model for the proposed technique.

outage probability of the Enhanced technique reduces drastically than the Conventional technique, thereby eliminating the possibility of an outage in the system. This address the channel mismatch problem and set the channels in good condition. Due to the addition of data buffers at the relay nodes, the upgraded approach demonstrated higher performance with lower outage values when compared to Conventional technique. The throughput for both Enhanced and Conventional Technique is shown in Figure 4. Throughput values obtained for enhanced technique are 1.125920 and 2.032793 at SNR of 6dB and 8dB as against 0.756684 and 1.354020 obtained for conventional technique at SNR of 6dB and 8dB. The values show that Enhanced technique has higher throughput than the Conventional technique. The increase in throughput in the comparison is due to decrease in outage probability when evaluated against the increasing SNR.

Similarly, the P_{out} and throughput values obtained at different SNR at N=5 are presented in Figures 5 and 6. Figure 5 depicts the P_{out} obtained at different SNR for both Enhanced and Conventional technique. At SNR of 6 dB and 8 dB, P_{out} values of 0.000174 and 0.000093 are obtained for Enhanced technique as against 0.000577 and 0.000316 obtained for Conventional technique. It can be deduced that, P_{out} values decrease as SNR increases. These results shows that Enhanced technique gave a better outage performance than the Conventional technique, hence achieve higher diversity. Also, in Figure 6, throughput values of 1.422540 and 2.541992 are obtained for Enhanced technique as against the Conventional technique of 0.949796 and 1.695099 at the same value of SNR.

The results obtained revealed that, Enhanced technique gave better performance with higher throughput when compared with Conventional technique due to the incorporation of data buffers at the relay nodes, hence increase the rate of data transmission in the system.

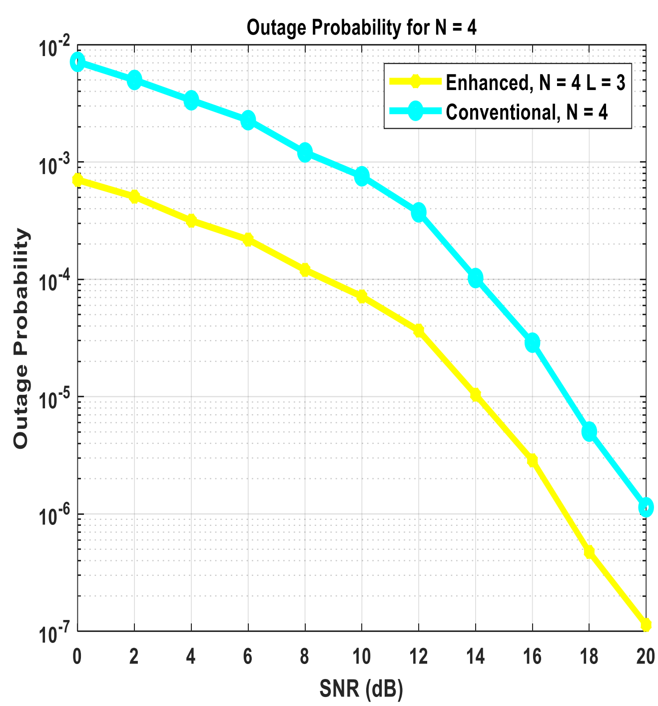

Figure 3: P_{out} versus SNR for enhanced and conventional technique at N=4 and L=3.

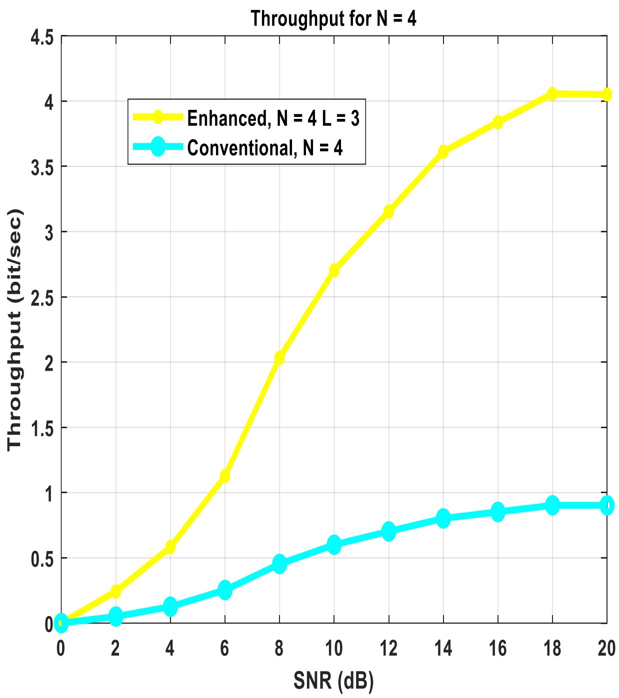

Figure 4: Throughput versus SNR for enhanced and conventional technique at N=4 and L=3.

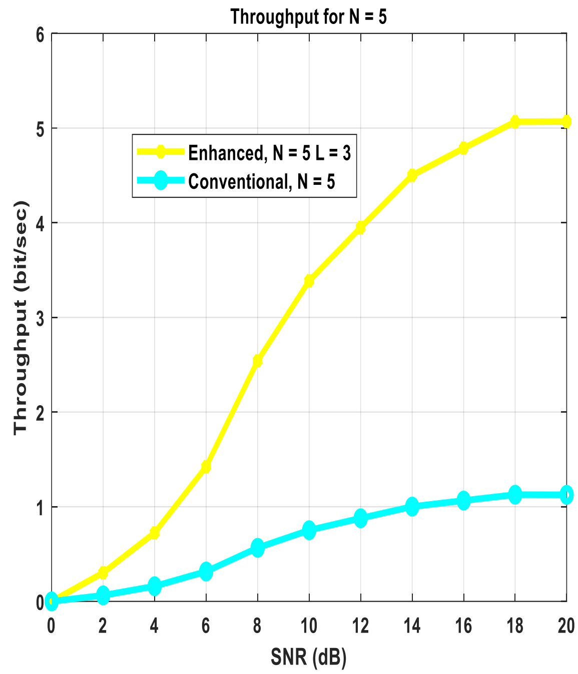

Figure 6: Throughput versus SNR for enhanced and conventional technique at N=5 and L=3.

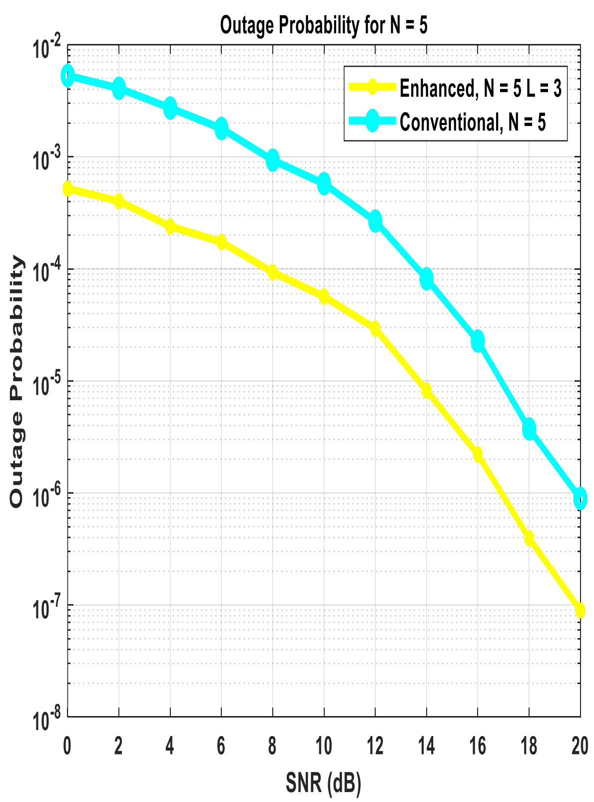

Figure 5: P_{out} versus SNR for enhanced and conventional technique at N=5 and L=3.

V. CONCLUSION

Employing buffers at the relay nodes over a Rayleigh fading channel, an improved relay selection approach in a cooperative communication network has been devised. A closed-form expression for the received signal for the enhanced technique is derived using CDF. The performance of the enhanced technique has been evaluated using outage probability and throughput as metrics. The results reveal that the augmented approach outperforms the standard technique in terms of outage and throughput. The improved performance is due to the inclusion of data buffers at the relay nodes, as well as the selection of the strongest connection among the available S-R and R-D links for either reception or transmission, making it a practical system. In future, we will extend our work by using Non-Orthogonal Multiple Access (NOMA) and combining the link quality, buffer size and physical layer security for smart selection of the link.

AUTHOR CONTRIBUTIONS

Ajibowu S. B. and Ojerinde I. A.: Conceptualization, methodology, software, format analysis, data curation, writing original and draft preparation. **Ajibowu S. B., Adeleke O. A., and Ojerinde I. A.:** Validation, resources, writing-review, editing and all authors read and contributed to the manuscript.

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