

# Relay-Based Cooperative Routing for Enhanced Energy Efficiency and Reliability in Wireless Sensor Networks

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**Abstract**—Wireless sensor networks (WSNs) consist of sensor nodes with limited resources, which cooperatively monitor environmental conditions and transmit data to a node at sink. Efficient routing is essential in WSNs to ensure reliable data delivery while minimizing energy consumption. In this work, a Relay-Based Cooperative Routing (RBCR) protocol is proposed to enhance communication reliability and energy efficiency in WSNs. The proposed protocol employs cooperative communication where selected relay nodes assist in forwarding data packets from the source to the destination. To identify optimal relay nodes for packet transmission, an effective relay selection mechanism is used based on residual energy, link quality and distance to the sink. The RBCR protocol performance is evaluated using the NS-2 simulation environment and compared with a conventional routing protocol. Simulation results show that the proposed protocol achieves high packet delivery ratio (PDR) and throughput by reducing energy consumption and end-to-end delay, thereby extending the overall network lifetime. The results show that the RBCR protocol provides an effective and reliable routing solution for improving performance in the wireless sensor networks.

**Keywords**— *Wireless Sensor Networks (WSNs), Cooperative Routing, Relay Node Selection, Energy-Efficient Communication*

## I. INTRODUCTION

Wireless sensor networks (WSNs) are composed of a high density of sensor nodes dispersed in space, which collaboratively sense the physical conditions or the environment, such as temperature, humidity, pressure or movement, and transmit their measurements to a central sink node or base station for further processing. These networks are commonly applied in environmental monitoring, healthcare systems, automation in industries, smart cities, and military surveillance. The small amount of energy, the processing power, and the communication distance of sensor nodes make the development of an efficient routing protocol one of the most important issues of WSNs [1,2].

WSN routing protocols should provide a reliable delivery of data using minimal energy, as the batteries that power sensor nodes are often difficult or impossible to replace once in position. Conventional routing methods usually use point to point communication or multi hopping of the nodes to the sink. Nevertheless, such solutions can result in high levels of energy consumption, loss of packets and network fragmentation in case of bad link quality or node failure. In order to overcome such limitations, in the recent years cooperation

communication and relay-based routing mechanisms have become a major focus [3].

Relay-based cooperative routing would take advantage of the broadcast characteristics of wireless communication where intermediate nodes are relay nodes that can help in transmitting data packets from the source to the destination. Such interconnection between nodes enhances reliability of links, provides better ratio of dots and heightens retransmission [4]. By intelligently selecting relay nodes based on residual energy, link quality and distance to the sink, energy efficiency and communication reliability in WSNs can be greatly improved through cooperative routing protocols. Moreover, it has been shown that cooperative routing techniques are capable of prolonging network life and enhancing network performance in general than other routing methods [5].

Although there have been many studies conducted on the routing protocols of WSNs, there are still many challenges that are still unaddressed. In the massive implementations, the network is likely to deteriorate due to failures in reliable wireless connections, interruptions, and node failures. Most traditional routing schemes focus on optimal energy usage, addressing reliability and fault tolerance. Furthermore, ineffective relay selection algorithm can result in unequal energy loss of nodes, lowering the lifetime of a network, and raising the count of lost packets. These constraints have motivated the necessity of a better type of relay based cooperative routing algorithm with the capability to optimize both reliability and energy efficiency of WSN communication systems [6-9].

Despite the availability of many cooperative routing protocols, most of them have several drawbacks, including inefficient selection of relay nodes, excessive computational demands, as well as the inability to scale to large-scale sensor field deployments. There are some protocols that focus primarily on reliability but omit the energy balance of nodes, and there are also some protocols that focus on energy conservation but not with communication reliability and packet delivery performance. In addition, various protocols have undergone evaluation just in few simulation conditions other than dynamic network conditions. Hence, it is essential to have a powerful relay based cooperative routing scheme that can strike the right balance between reliability, energy efficiency, and network lifetime in the context of WSN. [10]. The main objective of this research is to develop and model a Relay-Based Cooperative Routing (RBCR) protocol, which



enhances the communication reliability and energy efficiency of wireless sensor networks by efficiently selecting relay nodes and cooperative data forwarding. Some studies have concentrated on enhancing the efficiency, reliability as well as energy consumption of wireless sensor networks (WSNs). To improve the overall performance of the network, researchers have studied cooperative communication, relay node implementation, and smart routing schemes. The specific objectives of this work are:

1. To design a relay-based cooperative routing protocol that enables efficient multi-hop communication in WSNs.
2. To develop a relay node selection mechanism based on network parameters such as residual energy, distance, and link quality.
3. To evaluate the performance of the proposed RBCR protocol using simulation tools in terms of energy consumption, packet delivery ratio, and network lifetime.
4. To compare the proposed protocol with existing routing protocols to demonstrate its effectiveness.

## II. RELATED WORK

The prior research has highlighted the energy-efficient routing protocols to overcome the resource limitations of WSNs. As an example, Ramadan et al. suggested a routing scheme that takes into account not only the quality of links and the number of hops, but also the availability of buffers, to select relay nodes that can meet the needs of real-time communication. Their approach enhanced the ratio of packet delivery and decreased delay besides increasing the network lifetime. Nevertheless, the scheme is primarily focused on real time communication applications and does not fully capitalize on cooperative routing schemes among a number of relay nodes [11].

Equally, Wang et al. published a geographic routing approach framework combining link identifying and cooperation planning among nodes. The protocol is more reliable and energy efficient as it coordinates adjacent nodes in the routing process. Despite the fact the technique enhances the network performance, it is very much dependent on geographic information and might not work well on a network where the location of nodes is not available or very inaccurate [12].

Batool et al. designed a safe cooperative routing scheme that considers the routing efficiency as well as security issues in WSNs. They have integrated collaborative forwarding and security to reduce attacks when transmitting data. Although the scheme enhances secure communication, the security operations introduced come at a computational cost and energy usage to sensor nodes that have limited computing power [13].

The model of cooperative communication in wireless underground sensor networks as suggested by Radhakrishnan et al. relies on deep learning. Their structure makes use of relayed cluster communication to enhance reliability in data transmission and efficiency in the network. The outcomes of the simulation indicated that the ratio of packet delivery and the throughput were improved. Nevertheless, deep learning model can raise the computational load and demand extra

processing resources unattainable in low-power sensor nodes [14].

The other research stream aims at the network relay nodes placement schemes to enhance connectivity and reliability of the network. Amron et al. explored the method of optimization of relay placement based on multipath topology and the evolutionary algorithms, Particle Swarm Optimization and Genetic Algorithms. It shows that the use of relays is the most efficient way to increase the reliability and coverage of the network. However, their strategy is primarily that of network planning and not a dynamic routing strategy in the process of data transmission [15].

Heterogeneous WSN have also been examined using cooperative routing strategies. The adaptive cooperative routing schemes have been proposed by researchers, which enable cooperation between nodes with different energy capacities in the flow of data. These strategies increase the stability and lifespan of the network; these schemes dynamically switch between single-hop and multi-hop cooperative communication. But these schemes can be very complicated in terms of coordination between nodes, which can raise the overhead of communication [16].

Opposite routing and secure routing mechanisms have also been discussed in recent works. Yang et al. developed power-conscious opportunistic routing scheme that also considers security to authenticate communication in WSNs. This protocol enhances the ability of forwarding nodes to be selected based on energy and reliability parameters, which leads to better packet delivery and energy savings. Even with this progress, when two or more nodes are trying to send the same packet, opportunistic routing schemes can create redundancy in transmission [17].

Other studies have investigated hybrid routing models, which combine intelligent optimization algorithms such as Bayesian networks and genetic algorithms to improve quality of service and energy consumption. The approaches exhibit better routing choices and higher network performance. But the computational cost of these types of optimization-based methods can make them infeasible in large-scale WSNs [18].

Cloud-aided routing systems have also been suggested in order to circumvent the processing capacity of sensor nodes. These frameworks combine the cloud computing with the use of WSN routing mechanisms that enhance the throughput and the ratio of packet delivery. Even though cloud integration improves data processing, it brings with itself extra overhead and latency to the network [19].

Recently, hybrid clustering and chain-based routing strategies were developed to increase energy efficiency and network lifetime. These techniques use intelligently selected cluster head and dynamic relay to maintain data transmission. But keeping cluster structures and relay chains could raise control overhead in very dynamic network systems [20].

Based on the preceding literature, it is clear that, although a large number of routing protocols have been proposed in the case of WSNs, several issues are still under research, including effective selection of relay nodes, balancing of energy consumption and reliable transmission of data. Thus, the reliability and energy efficiency of wireless sensor networks can be greatly enhanced by creating a Relay-Based Cooperative Routing (RBCR) protocol, which will efficiently

combine cooperative communication with intelligent relay selection.

### III. PROPOSED RELAY-BASED COOPERATIVE ROUTING (RBCR) PROTOCOL

The following assumptions are considered in the proposed RBCR protocol:

1. A WSN consisting of  $N$  sensor nodes randomly deployed in a monitoring area.
2. A static base station (sink) located either inside or outside the sensing field.
3. All sensor nodes are equipped with limited energy and identical communication capabilities.
4. Nodes are aware of their neighboring nodes through periodic beacon messages.
5. Data communication occurs through multi-hop transmission when the destination is beyond the direct communication range.

Let  $S$  denote the source node,  $D$  denote the destination (sink), and  $R_i$  represent candidate relay nodes. In the RBCR protocol, communication between source and sink occurs with the help of relay nodes. The transmission process occurs in two phases:

1. Broadcast Phase: The source node transmits the data packet to neighboring nodes.
2. Relay Phase: Selected relay nodes forward the packet toward the destination.

The received signal at relay node  $R_i$  from the source node can be expressed as

$$y_{SR_i} = h_{SR_i}x + n_{R_i}$$

Where:

$x$ : Transmitted signal from source node

$h_{SR_i}$ : Channel gain between source and relay node

$n_{R_i}$ : Additive White Gaussian Noise (AWGN)

Similarly, the signal received at the destination node from relay node  $R_i$  is given by

$$y_{R_iD} = h_{R_iD}x + n_D$$

where

$h_{R_iD}$ : Channel gain between relay node and destination

$n_D$ : Noise at destination node.

The efficiency of cooperative routing depends largely on selecting suitable relay nodes. In RBCR protocol, relay selection is based on three parameters:

1. The residual energy of node  $i$  is given by

$$E_{res,i} = E_{init,i} - E_{consumed,i}$$

2. The Euclidean distance between nodes  $i$  and  $j$  is calculated as

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

where  $(x_i, y_i)$  and  $(x_j, y_j)$  are node coordinates.

3. A composite relay selection score is calculated as

$$Score_i = \alpha \frac{E_{res,i}}{E_{max}} + \beta \frac{LQ_i}{LQ_{max}} + \gamma \left(1 - \frac{d_{iD}}{d_{max}}\right)$$

where

$LQ_i$ – link quality indicator of node  $i$

$d_{iD}$ – distance between relay node and destination

$\alpha, \beta, \gamma$ – weighting coefficients satisfying

#### Algorithm 1: RBCR Cooperative Routing.

**Input:** Network nodes  $N$ , sink node  $D$

**Output:** Reliable routing path from source to destination

1. Deploy sensor nodes randomly in the sensing area.
2. Each node broadcasts periodic beacon messages to identify neighboring nodes.
3. When a source node  $S$  generates data, it identifies candidate relay nodes within its communication range.
4. Each candidate node calculates its relay score using the relay selection metric.
5. The node with the highest score is selected as the relay node.
6. The selected relay node forwards the packet toward the destination.
7. Steps 3–6 are repeated until the packet reaches the sink node.
8. Update residual energy values after each transmission.

### IV. SIMULATION SETUP AND PERFORMANCE METRICS

The network consists of a set of sensor nodes randomly installed in a square sensing area. Nodes periodically sense environmental data and transmit the information to the base station using the proposed RBCR routing mechanism. Relay nodes help forward packets, which improves reliability and reduces energy consumption. The simulation parameters used in this study are summarized in Table I.

TABLE I. THE SIMULATION PARAMETERS USED IN THIS STUDY.

Parameter	Value
Simulator	NS-2.35
Simulation Area	1000 m × 1000 m
Number of Sensor Nodes	100
Base Station	Fixed
Initial Node Energy	2 J
Packet Size	512 bytes
Traffic Type	Constant Bit Rate
MAC Protocol	IEEE 802.11
Radio Model	Two-Ray Ground
Transmission Range	250 m
Simulation Time	500 s
Channel Type	Wireless Channel
Antenna Model	Omni-directional
Routing Protocol	Proposed BCR

In the simulation, the sensor nodes are communicating with their neighbors and choosing the relay nodes depending on the suggested relay selection criterion. The sink node gathers packets of data that has passed by cooperative routing paths. The suggested RBCR protocol is tested through the comparison of its working with traditional routing protocols in the same conditions of the network. The comparison focuses on:

- Packet Delivery Ratio
- End-to-End Delay
- Throughput
- Energy Consumption
- Network Lifetime

The simulation results demonstrate the effectiveness of the RBCR protocol in improving reliability and energy efficiency in WSNs.

### V. SIMULATION RESULTS AND DISCUSSION

This section will talk about the workings of the given RBCR protocol as per the simulation results acquired through NS-2. Key measures used in the assessment of the performance include Packet Delivery Ratio (PDR), Throughput, Energy Consumption, End-to-End Delay and Network lifetime. The findings are compared to a standard routing protocol when the network is the same.

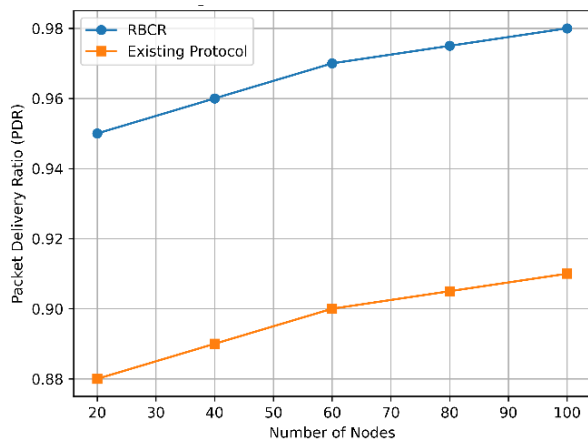


Fig. 1. PDR vs Number of Nodes

Figure 1 shows that Packet Delivery Ratio (PDR) varies with the number of sensor nodes. The higher the number of nodes, the better the PDR of the proposed RBCR protocol, because it can rely on the presence of multiple relay nodes to assist in the cooperative forwarding of data. The RBCR protocol has a better ratio of packets delivery than the current protocol since the relay node selection strategy will enhance the reliability of links and the packet losses during the transmission process will be minimized.

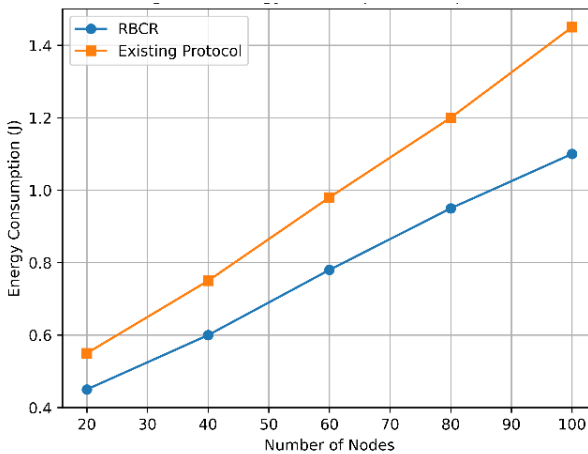


Fig. 2. Energy Consumption Comparison.

A comparison of the energy consumption of the proposed RBCR protocol and the conventional routing protocol is given in Figure 2. These findings show that RBCR uses much less energy with increase in the network size. This is done by choosing the relay nodes that have increased residual energy and have better links and, hence, reduce unnecessary retransmission and equalizes the degree of energy consumption among sensor nodes.

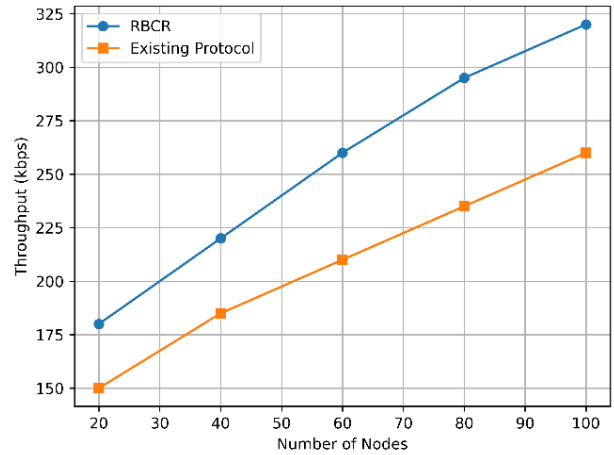


Fig. 3. Throughput Comparison.

The throughput comparison of various sensor node numbers is presented in Figure 3. The RBCR protocol has a better throughput as compared to the current routing protocol. The fundamental reason supporting this is the cooperative relay mechanism which makes the transmission of data more reliable and network resources utilized in an efficient manner resulting in increased rate of successful data delivery.

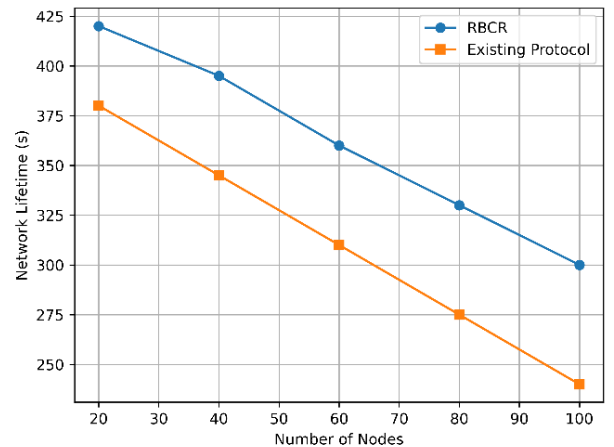


Fig. 4. Network Lifetime Comparison.

The network lifetime is compared as shown in Figure 4. The RBCR protocol suggested has a long network lifetime than the traditional protocol. The RBCR protocol will prevent the rapid degradation of energy of individual nodes due to communication tasks and will also achieve balanced energy usage on the network by delegating communication tasks to relay nodes in the network at appropriate energy levels.

Figure 5 shows the end-to-end delay caused by increasing the number of nodes. RBCR protocol has lesser delay than the current routing protocol due to the selection of cooperative relay which facilitates rapid and dependable packet relaying. The decreased delays in retransmission and the stability of the link also reduce in delays of packets transmissions.

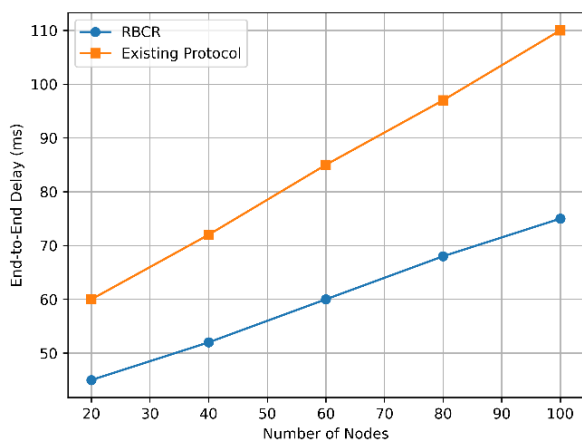


Fig. 5. End-to-End Delay vs Number of Nodes.

## VI. CONCLUSIONS

This research came up with a RBCR protocol to improve reliability and power savings in WSNs. This protocol uses cooperative communication, in which relay nodes help forward packets between the source and sink. With the aim of transmitting data at an optimal rate, a relaying mechanism was used to select the best relaying nodes based on the criteria of residual energy, link quality and distance.

The proposed RBCR protocol was evaluated through NS-2 simulations using performance metrics such as Packet Delivery Ratio, Energy Consumption, Throughput, End-to-End Delay and Network Lifetime. The results demonstrated that RBCR improves packet delivery and throughput, while reducing energy consumption and delay. Additionally, balanced energy utilization among nodes contributes to an extended network lifetime.

On the whole, the RBCR protocol will be an effective solution to routing that guarantees reliability in communication and energy-efficiency of a WSN. Future directions can be to incorporate adaptive relay selection functionality, mobility management and security functionalities to improve the network operation in dynamic networks even more.

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