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Original Article

Optimizing WBAN Lifetime with Hybrid Node Ranking and Energy-Aware Multi-Hop Routing

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Abstract *- Efficient clustering techniques were made possible by the necessity of optimizing network resources to extend the lifetime of densely deployed, large-scale Wireless Body Area Networks (WBN). This led to research on the development of these approaches. Clustering has shown to be a successful method for dividing a large-scale WBN into interconnected clusters, extending the networks' lifespan and dependability. The nodes' distances from the base station and one another can significantly affect how much energy they save and how long the network lasts. This research proposes a new technique that combines dynamic clustering, multi-CH selection, and node ranking. As per the Message Success Rate and Opportunistic Routing Scheme, the suggested method shows a mechanism of fuzzy ranking to rank forwarder nodes. This is done by listening to forwarder nodes' participation in Wireless Body Networks (WBNs) and determining their positions with respect to the base station, that is depletion of information gathered. Because it takes minimum energy to replace the node, this advantage will significantly improve the network lifetime.*

Keywords *- WBAN, Clustering algorithms, Fuzzy logic, Multi-hop routing, Energy efficiency.*

1. Introduction

The production of tiny, inexpensive sensors is now both technically and financially possible, thanks to recent technology advancements. The ambient conditions of the surrounding environment are measured by the sensing electronics, which afterwards transform them into an electrical signal. When a signal like that is processed, certain characteristics of nearby objects and/or events are disclosed. Numerous applications that call for unattended operations can network a large number of these disposable sensors [1].

These sensor nodes can number in the hundreds or thousands within a WBN. These sensors are capable of direct communication with an external Base Station (BS) or with one another. Accurate sensing across broader geographic regions can be achieved with more sensors [2]. Every sensor node is made up of power units, mobilizers, position-finding systems, processing, sensing, and transmission units (some of these components, like the mobilizer, are optional) [3]. Figure 1 depicts the architecture of a WBAN's communication system. In the sensor field, either in the area where they are deployed, sensor nodes are typically dispersed [4]. Coordinating amongst themselves, sensor nodes generate high-quality physical environment data. Every sensor node makes decisions based on its mission, available data, as well as an understanding of its energy, computation, and communication resources [5].

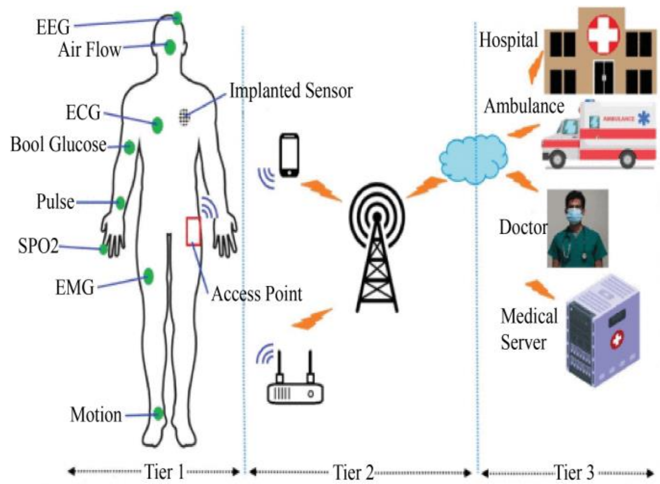

Fig. 1 Reconfigurable SDN-WBAN architecture [6]

Since sensors have limited capabilities, it is possible to first design communication with a sink without routing protocol. The flooding algorithm sticks out as the most straightforward solution using this premise [7]. According to this technique, data is broadcast by the transmitter and then successively retransmitted to reach the desired location. However, there are serious disadvantages to its simplicity [8]. First, when nodes redundantly receive numerous copies of the same data packet, an implosion is identified. Then, various data packets with comparable information are introduced into the network since the event may be observed by multiple nodes in the impacted area [9]. Furthermore, the nodes do not restrict their functionality based on their resources. Optimization is based on the algorithm for gossiping. By transmitting the message to a specific neighbor rather than alerting all of its neighbors, as in the standard flooding process, gossiping prevents implosion [10]. Overlap and resource blindness persist in any case. Moreover, these annoyances become more noticeable as the network's node count rises. The shortcomings of the earlier approaches make routing protocols essential in WBAN [11]. However, it is not an easy process to incorporate a routing system into a wireless sensor network. The identification of nodes is one of the primary limitations [12]. WBAN is made up of a large number of nodes, making it impractical to assign unique identifiers manually. It is not advised to utilize potentially unique identifiers like the GPS coordinates or the MAC (Medium Access Control) address since this requires a large payload in the messages [13]. This disadvantage is readily solved in WBN, though, as the destination node of a given packet may be identified without the use of an IP address. The characteristics of a WBAN are more suited for attribute-based addressing [14]. Here, the ultimate destination is determined using an attribute like sensor kind and node location. Routing protocols are responsible for creating and maintaining routes between distant nodes after nodes have been discovered. Routing protocols are suitable for several applications due to their distinct modes of operation [15].

The research article's main contributions are listed below.

1. The proposed novel algorithm for a sustainable IoT application that uses a mechanism of fuzzy ranking to rank (forwarder nodes) based on an Opportunistic Routing Scheme.
2. The new proposed algorithm is based on multi-CH selection, node ranking, and dynamic clustering.
3. For simulation as well as test-bed implementation, to validate the energy optimization parameters, including End-to-End delay (E2 delay), Packet Delivery Ratio (PDR), Message Success Rate (MSR), and Energy Consumption (EC) on both the suggested and conventional protocols.

In this paper first section explains the introduction to WBAN. The second section describes the work done by other authors related to energy efficiency in WBAN along with problems in WBAN. The third section describes the proposed protocol. The fourth section describes performance analysis with performance evaluation parameters. The conclusion and some future research directions are suggested in the fifth section.

2. Related Work

Using fuzzy- and cluster-based routing algorithms based on various network parameters, numerous researchers are utilizing IoT. The proposed protocol is presented and contrasted with the conventional routing protocols in this section. By using node migration and cluster chaining to secure IoT networks, this method guarantees balanced loads and trust. By using several parameters, it innovates cluster head selection and avoids energy problems. A main head oversees gateway instructions, while other cluster heads are used in the architecture to distribute workloads. This novel strategy furthers the study of edge computing [16]. The goal of choosing a cluster head is to distribute the load throughout a network while lowering energy usage and extending the network lifespan. The algorithm selects a cluster head for the next stage of action by looking at the starting energy, residual energy, and ideal CH value.

The R-LEACH model used in that method shows improved network performance with regard to speed, lower latency, more packets sent to the Base Stations (BS), and smart use of leftover energy. [17] shows ARIOR, a routing method that combines ARVN and VNS, which works well for Wireless Sensor Network (WSN) routing. ARIOR has benefits like a loop-free topology, fast convergence, and efficient distributed processing, making it a leader in volunteer node finding. This approach can be used on different kinds of WSNs, and it makes metrics like MSR, PDR, and CE better [18]. The ARFOR protocol uses threshold energy, Canberra distance, and adaptive fuzzy ranking to send as many packets as possible to the DODAG and make network measures last longer (LND, FND, MSR, EC, E2 delay, and PDR). It uses a fuzzy method to figure out the best number of volunteer nodes based on distance, threshold, and leftover energy. Getting less energy used (EC) is the main goal for keeping the network stable. The effectiveness of a protocol with regard to EC, packet delivery, and network longevity is demonstrated via NS2 simulations and comparisons. The outcomes validate its efficacy in guaranteeing stability and dependability [19].

2.1. Problems Identified in Related Work

Computer networks, and particularly IoT and wireless sensor sets, provide issues for routing protocols in terms of resource limits, dynamic topology changes, scalability, security, and a variety of Quality of Service (QoS) needs [20]. Additional complications include minimizing protocol overhead, achieving interoperability, adapting to heterogeneous networks, and maintaining loop-free topology [21]. The need for fault tolerance, mobility control, and real-world validation further increases the complexity of creating dependable routing protocols. Addressing these issues and developing effective, flexible, and safe solutions for a range of network contexts require ongoing research.

3. Proposed Protocol

In order to boost QoS measures, including EC, MSR, E2 latency and PDR, this section introduced a novel Opportunistic Routing Protocol (ORP). The approach is suggested and is based on dynamic clustering, multi-CH selection, and node ranking. Based on an Opportunistic Routing Scheme to rank forwarder nodes combined with an MSR, the proposed algorithm uses a fuzzy ranking mechanism, which is based on monitoring the energy levels and node positions with respect to the base station that acts as a sink for information gathered. By reducing the energy consumption linked to node replacement, this invention will greatly extend the network's life.

3.1. System Model

The principal objective is to select a volunteer node from the neighboring nodes comprising of source node. The key parameters for the choosing include the distance among nodes and the residual energy of the nodes. Each neighbor of the source node, in addition to the volunteer node at every single hop and the Cluster Head (CH), is prioritized and ranked in every single round, as shown in Figure 2.

The node, together with the highest residual energy and the shortest distance from the source node, is chosen as the volunteer node. To meet transmission needs, the routing table in the traditional opportunistic routing protocol is revised to improve the selection of the next forwarder as a volunteer node. Figure 2 illustrates how the source node's ID, transmission initiation time as broadcast time, ranked nodes for volunteer node selection, also the selected node for the next hop are used to support route information stability.

Example 1: Node ID-1 is the source, Node ID-3 and Node ID-7 are the highest-ranked nodes at each hop, also Node ID-12 is the CH due to its residual energy and proximity to a source node. If the CH is far away from the source node, increasing the risk of packet loss, the selected volunteers combine all the packets and transmit them on the way to the CH within the transmission time.

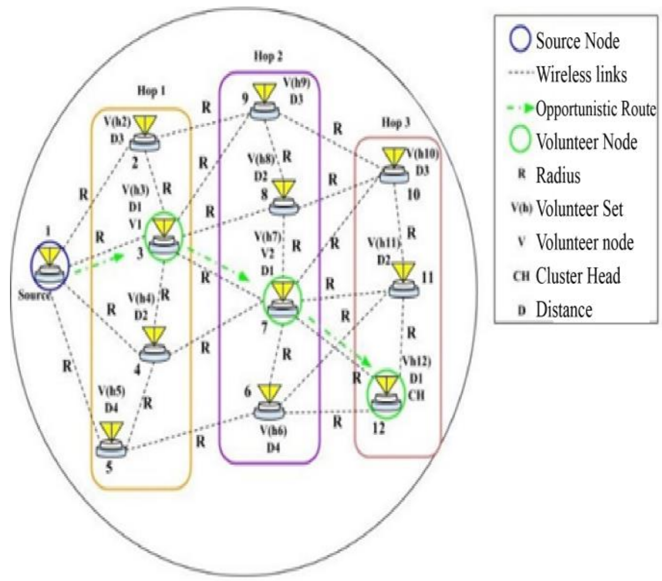

Fig. 2 System model of the proposed method

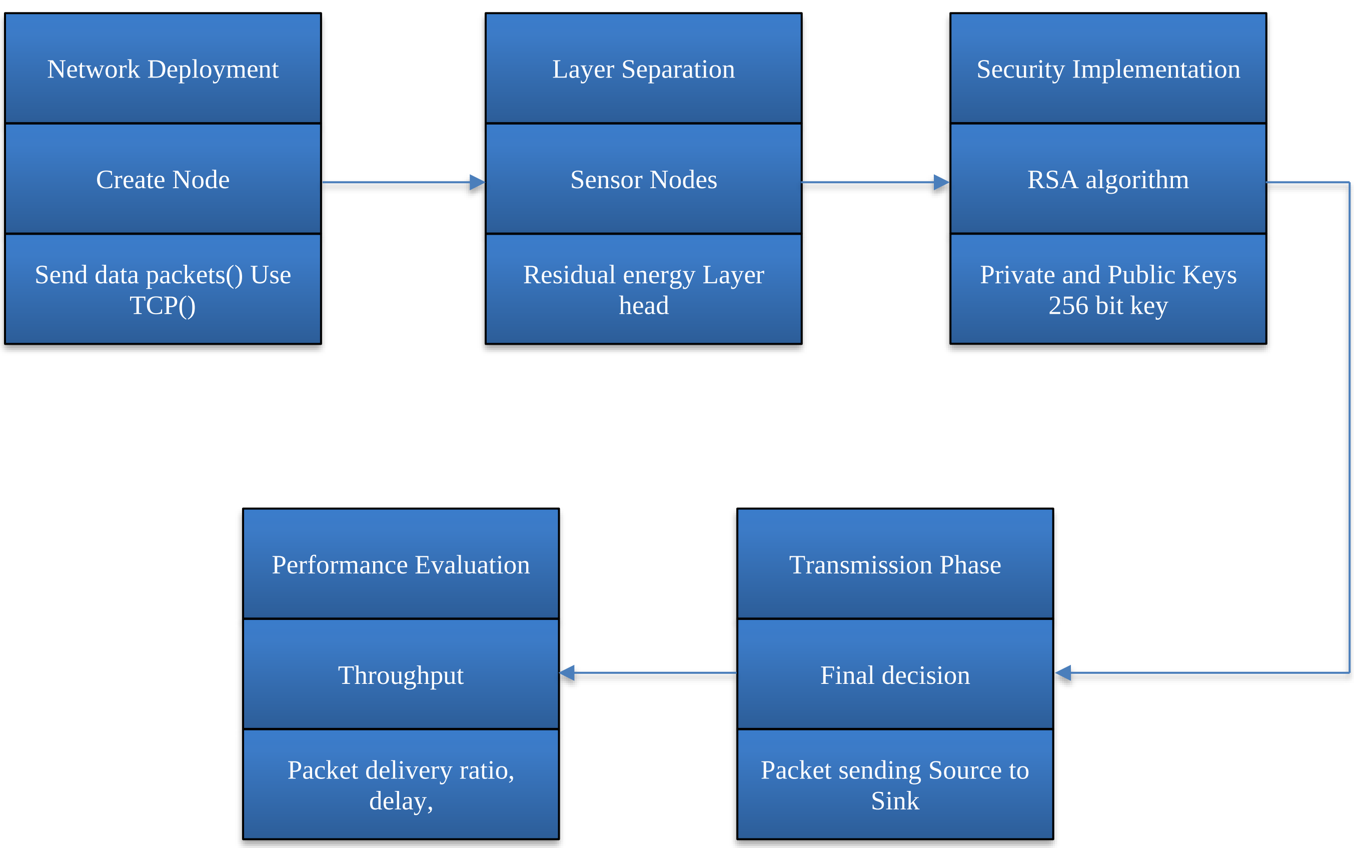

Fig. 3 Communication system architecture

Figure 3 illustrates a communication system architecture consisting of five essential phases: network deployment, layer separation, security implementation, transmission phase, and performance evaluation. During the network deployment phase, nodes are established and configured to transfer data packets using the TCP protocol, ensuring reliable connectivity. In the transition to layer separation, sensor nodes are deployed, and a layer head is chosen based on the node's residual energy, thus enabling energy-efficient communication. The system utilizes the RSA algorithm for security, ensuring safe data transmission through the use of 256-bit private and public keys for encryption and decryption. In the transmission phase, a conclusive decision is rendered concerning data transmission, and packets are relayed from the source node to the sink node, which serves as the data aggregator. Finally, the performance evaluation phase assesses the system's efficiency and dependability by analyzing critical performance indicators, such as throughput, packet delivery ratio, and communication delay. This system is expected to be relevant for IoT platforms, wireless communication, or sensor networks, necessitating secure and efficient data transmission.

3.2. Algorithm

Numerous problems with standard routing protocols have been noted within the literature. Yet, energy-efficient routing protocols are the best option for efficient transmission in Regard to the suggested solution for the current research issue.

Algorithm – Pseudocode of CH and Neighbour Node Selection

Input: Node Residual Energy (NR_{egy}), Cluster head C_H , Distance (D), and RSSI.
Output: Selection of CH and Neighbour Node (N_n)
Step 1. The retransmission timer is started.
Step 2. Choose the neighbor set $N(h)$ from secondary list nodes $S(h)$.
a. For every node ($N \in C(h)$)
if NR_{egy} & D & $RSSI$ between Ns & C_H is appropriate for sending packets
Transfer packets to C_H from Ns
else
Select Nn from set $N(h)$, i.e. proceeding nodes in ranking.
b. Using $MSR(v(h)), Nne, nHp$ rank the neighbour set and update the routing table
for every node ($Nn \in Nh$)
$calculate\ MSR(n(h))$;
$Calculate\ \ Nne$;
Send the data packet to the network;
c. For every node $Nn \in N(h)$
acquire the data packet;
after checking the ID of the sender and initiating a new time stamp;
d. If Nv node, having the highest ranking, obtains the data packet correctly
send an acknowledgement to the sender (as an alert)
for every node $Nn \in N(h)$ containing nHp
take the data packet and halt the timer;
else
if the ranked node dies within the time cycle
set $Nn = Nn'$ where Nn' containing the value of the next higher rank in the routing table;
select the node from neighbour set $N(h)$
e. If the data packet was not received successfully by the neighbor node
if the time of retransmission is terminated, then drop the packet
else
Set the next neighbor's position again

The provided algorithm outlines the process for selecting a Cluster Head (CH) and Neighbour Node selection in a wireless sensor network. It carries inputs such as Node Residual Energy (NRegy), Cluster Head (CH), Distance (D), and Received Signal Strength Indication (RSSI) and outputs the selected CH and Neighbor Node (Nn).

The algorithm initiates by starting a retransmission timer. It then proceeds to select a neighbor set (N(h)) from a candidate list of nodes (C(h)). For each node N in C(h), it checks if the residual energy, distance, and RSSI between N and CH are sufficient for packet transfer. If conditions are met, packets are transmitted straight forward from N to CH; otherwise, the algorithm chooses Nn from N(h) based on a ranking. The ranking is performed using Metrics for Sensor Routing (MSR) values, and factors like Nne and nHp are included in the routing table.

Table 1. List of acronyms used

$\boldsymbol{N}$	Total no. of nodes in a wireless network
$\boldsymbol{Ns}$	Source node
$\boldsymbol{CH}$	Cluster Head
$\boldsymbol{N(h)}$	neighbor node set
$\boldsymbol{C(h)}$	Candidate list nodes
$\boldsymbol{Nr}$	No. of packets received by the node
$\boldsymbol{Nt}$	No. of packets transmitted by the node
$\boldsymbol{D}$	Distance between Ns and Nf
$\boldsymbol{Prp}$	Receiving power of packet
$\boldsymbol{Ptp}$	Transmitting power of packet
$\boldsymbol{Nne}$	Highest energy of a volunteer node set
$\boldsymbol{Ni}$	The initial energy array of all nodes
$\boldsymbol{Nn}$	Next neighbor as a forwarder
$\boldsymbol{nHp}$	Number of hops
$\boldsymbol{Prs}$	Receiving size of each packet
$\boldsymbol{Nn'}$	Next volunteer from the volunteer set
$\boldsymbol{(x1, y1)}$	Location of a source node
$\boldsymbol{(x2, y2)}$	Location of a forwarder node
$\boldsymbol{Nre}$	Residual energy of a node
$\boldsymbol{Nme}$	Optimum energy of a node
$\boldsymbol{Nst}$	Time when a node starts to transmit
$\boldsymbol{Nsp}$	Time when a node stops to transmit

The data packet is broadcasted, nodes in N(h) obtain the packet and timestamp, and check the sender ID. Suppose a node with its uppermost rank (Nv) successfully receives the data packet. In that case, acknowledgment is sent to the report sender, and the algorithm stops the timer and withdraws the data packet. If no neighbor node successfully receives the data packet, the algorithm considers returning the message and checks if the retransmission time is over; otherwise, it sets the position of the next neighbor. The algorithm handles scenarios where the ranked node's time cycle expires, and it selects the next higher-ranked node from the route table. If no neighbor node successfully receives a data packet after retransmission, and retransmission time is completed, the packet is dropped; alternatively, the algorithm resets the position for the next neighbor.

4. Performance Evaluation

This section examines how well the proposed algorithm performs using the NS2 simulator. In order to assess performance, factors like EC and PDR, packet MSR, E2 latency, FND, and LND are taken into account.

4.1. Message Success Rate

This is the rate at which something can be produced or processed. The percentage of messages delivered successfully over a communication channel is known as the message success rate. How many packets are sent during a transmission? The results of the proposed system will surpass those of previous efforts.

Message Success Rate = ∑in recv_size / (stop_time – start_time)

Where,
Recv_size-receiving size of each packet
Start_time-time at which a node starts transmitting
Stop_time-time at which a node stops transmitting

Packet Delivery Ratio: PDR is a statistic used by many WBN protocols to determine the optimal path, transmission rate, or power.

PDR= (scount/rcount)*100;
Where,
scount = sending count (TCP)
rcount = receiving count (TCP)

Delay: It evaluates the latency of the proposed system against the current system. The proposed system is less delayed than the previous efforts.

Delay[i] = ∑in (rt[i] – st[i])

Where
delay[i] - symbolizes delay for every single node that transmits data packet information from source to sink.
rt[i] - end of time
st[i] - Start of time

Energy Consumption:

CE =(∑in Initial_Energy – Final_Energy [i])n

Where,
CE - Consumed Energy
i - Initially, i is 0
n - total number of nodes

Total energy:

TE + = CE[i]

Using overall Consumed Energy (CE), total energy is computed.

Average Energy

AE = TE / n

The calculation of total energy involves dividing the total energy by the number of nodes. An essential performance metric in wireless networks is computed: the EC.

Figure 4 shows how much energy is consumed by a node. The proposed model gives better results in comparison to earlier existing models.

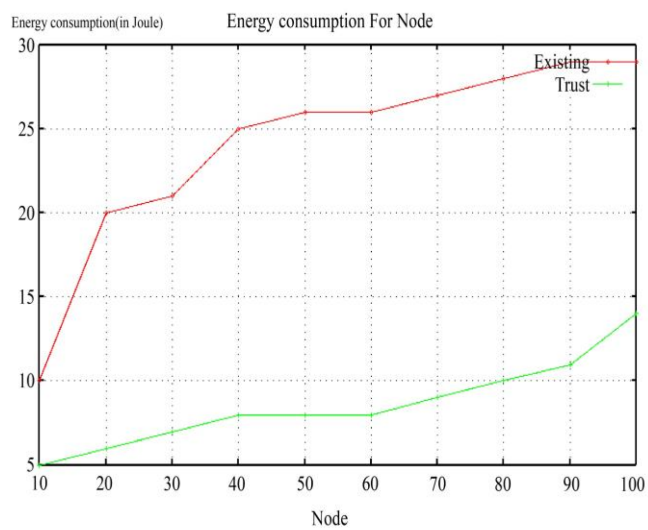

Fig. 4 Performance analysis of energy consumption

Table 2. Energy consumption for node

Node	Existing Energy Consumption (Joules)	Trust Energy Consumption (Joules)
0	10	5
20	20	6
40	25	7
60	28	7
80	28	10
100	30	14

Table 2 provides a simplified representation of energy consumption for each node. Table 2 represents data from Figure 4 titled “Energy Consumption for Node.” The table will have columns for Node, Existing Energy Consumption (in Joules), and Trust Energy Consumption (in Joules)

Figure 5 compares how much delay is there while delivering the packets. The earlier model has a higher delay than the proposed one. Table 3 represents the data from Figure 5 titled “Packets vs Average delay (ns).” The table will have columns for Packets (bytes), Existing Energy Consumption (Joules), and Proposed Energy Consumption (Joules)

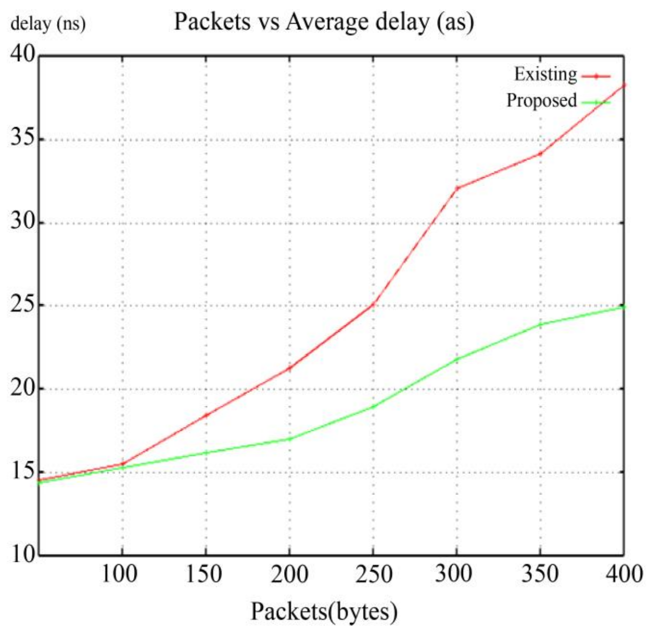

Fig. 5 Performance analysis of E2 Delay

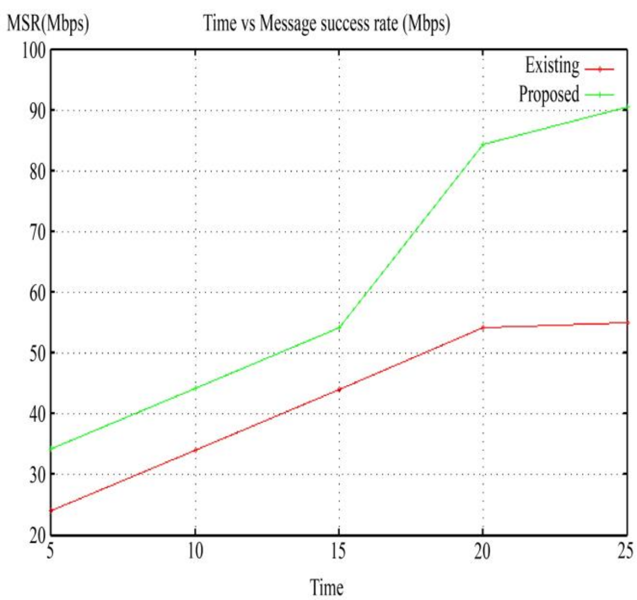

Fig. 6 Performance analysis of message success delay

Table 3. Packets vs Average delay (ns)

Packets (bytes)	Existing Energy Consumption (Joules)	Proposed Energy Consumption (Joules)
50	14	14
100	15	16
200	17	22.5
300	22	33
400	25	38

Table 4. Time vs Message success rate (Mbps)

Time	Existing MSR (Mbps)	Proposed MSR (Mbps)
0	40	30
5	24	34
10	35	45
15	44	54.5
20	54	86
25	55	90

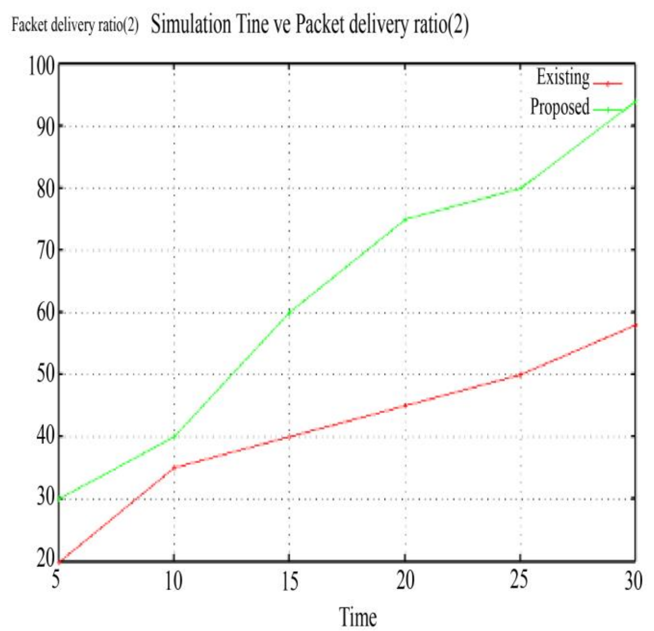

Fig. 7 Performance analysis of the packet delivery ratio

The MSR determines the number of data packets sent over participating SNs in transmission time. Figure 6 compares the successful message delivery over a communication channel. The outcome of the suggested system will be superior to that of earlier research. Table 4 represents the data from Figure 6 titled “Time vs Message success rate (Mbps).” The table will have columns for Time, Existing Message Success Rate (MSR) (in Mbps), and Proposed Message Success Rate (MSR) (in Mbps). The ratio of successfully transmitted packets to PN is calculated using PDR. Figure 7 shows the rate at which packets are delivered as a metric to select the optimal route, transmission rate, also power from source to destination. The proposed model gives better performance in comparison to the existing one.

Table 5 represents the data from Figure 7, titled "Simulation time vs Packet delivery ratio (%)." The table represents the packet delivery ratios for both the "Existing" and "Proposed" scenarios over a simulation time. Each row corresponds to a specific time interval, and the values indicate the percentage of successfully delivered packets. In Table 6, "MSR Improvement" and "PDR Improvement" represent the gains achieved by each technique in those metrics. "Node Ranking," "Residual Energy," and "Dynamic Routing" indicate whether each technique incorporates these features. This table provides a comparative overview of how the proposed algorithm stands out from other techniques in terms of these key aspects. Figures 8 and 9 show the comparative analysis on the basis of MSR and PDR, as shown in Table 6.

Table 5. Simulation time vs Packet delivery ratio (%)

Time (Simulation)	Existing Packet Delivery Ratio (%)	Proposed Packet Delivery Ratio (%)
5	0	30
10	36.5	40
15	40	60
20	45	75
25	50	80
30	58	94

Table 6. Comparative overview

Metric	Proposed Algorithm	Existing Protocol	Existing Protocol
Protocol Name	Enhanced BeeSwarm optimization Protocol	R-Leach	ARIOR
MSR Improvement	0.29%	0.15%	0.20%
PDR Improvement	0.32%	0.25%	0.10%
Node Ranking	Yes	No	No
Residual Energy	Yes	No	No
Dynamic Routing	Yes	No	No

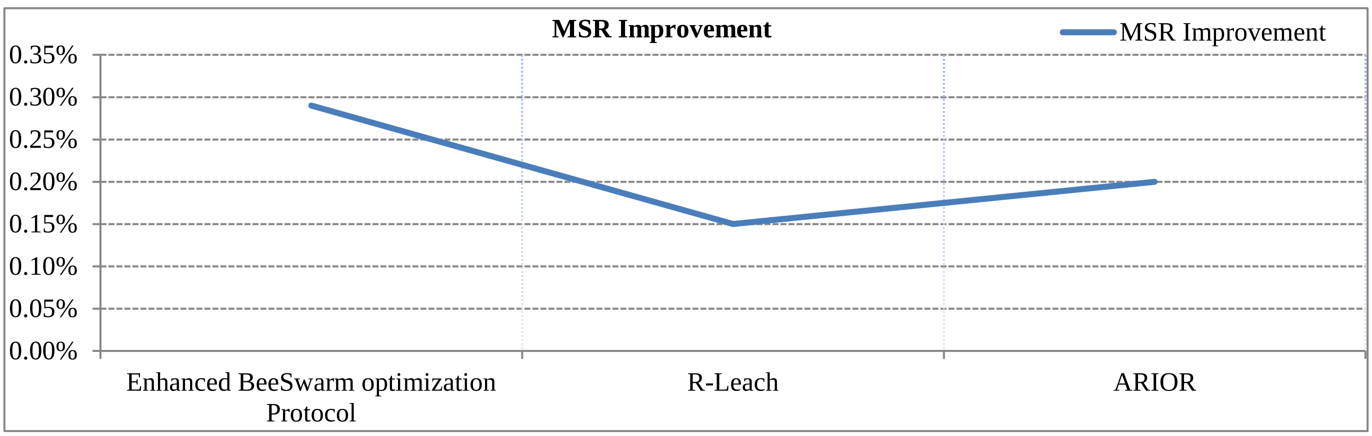

Fig. 8 Comparative analysis on the basis of MSR

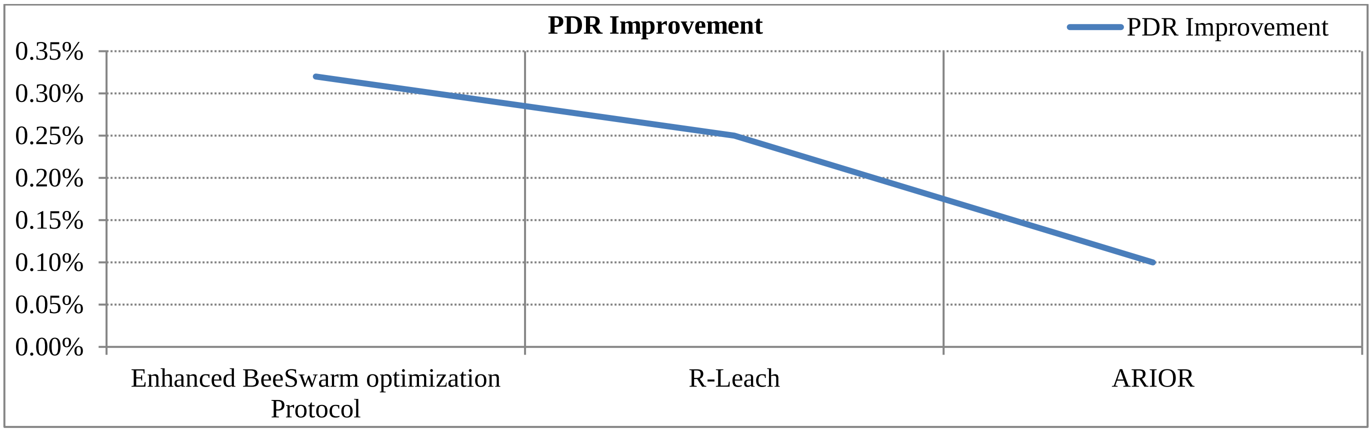

Fig. 9 Comparative analysis on the basis of PDR

5. Conclusion and Future Scope

The proposed process integrates adaptive dynamic ranking, dynamic clustering, and the participation of multiple Cluster Heads (Multi-CH). The simulation results validate that the proposed system outpaces other protocols in relation to message success rate. To enhance the security of the process, future implementations will incorporate additional security measures. Specifically, plan to integrate one-way hash function encryption as well as decryption for the packets, ensuring a more secure transmission of data. This step aims to fortify the communication channels within the system, supplying an extra line of defense against possible security risks. The proposed algorithm, in particular, exhibits notable improvements, achieving an incremental gain of 0.289% over a prevailing protocol for MSR. This improvement is attributed to the protocol's emphasis on node ranking and the precise selection of nodes based on the residual energy in each hop. Additionally, a 0.316% gain for PDR is observed owing to the dynamic nature of the routing table data, which differs with each transmission. Nodes are nominated for transmission based on a high probability of successfully sending packets from source to cluster head. These incremental enhancements contribute to increased reliability in communication within the proposed system. The continuous refinement of the process will contribute to its robustness, adaptability, as well as reliability in real-world applications.

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