Priority based energy efficient hybrid cluster routing protocol for underwater wireless sensor network

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Article Info

Article history:

Received Aug 3, 2022
Revised Sep 5, 2022
Accepted Sep 11, 2022

Keywords:

Clustering
Energy efficiency
Routing protocol
Underwater wireless sensor network

ABSTRACT

A little change in the environment that goes unnoticed in an underwater communication network might lead to calamity. A little alteration in the environment must also be adequately analyzed in order to deal with a potential crisis. A priority-based routing protocol is required to ensure that the vital data perceived by the sensor about the environment changes. The priority-based routing system guarantees that vital data packets are delivered at a quicker pace to the destination or base station for further processing. In this work, we present a priority-based routing protocol based on the energy efficient hybrid cluster routing protocol (EEHRCP) algorithm. The suggested approach keeps two distinct queues for lower and higher priority data packets. In order to ensure that these packets get at their destination without any information loss and at a quicker rate, all of the crucial sensed data is passed through a higher priority queue. Test findings show that the suggested technique increases throughput, delivery percentage, and reduces latency for the crucial data packets.

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1. INTRODUCTION

Water is an essential commodity for both humans and industry. Deeper seawater is utilized to capture renewable energy, which is mostly employed by sectors such as oil and gas. Deeper under the water, minerals such as nickel, copper, cobalt, gold, and silver are mined. Building and maintaining the necessary infrastructure is required for such mining activities [1]–[5]. Because the ocean is vast and most of it is unknown to users, monitoring underwater activity is a difficult undertaking. Underwater wireless sensor networks (UWSN) vary from terrestrial networks in several ways. Low bandwidth and significant propagation delay are not common in terrestrial networks, but they are important problems in UWSN. UWSN also faces issues such as reduced data rates, high attenuation, high latency, increased packet loss, and poorer throughput.

The topology of the UWSN changes as the nodes move with the water. Predicting node movement patterns is likewise a tough job in UWSN. Because all of the sensor nodes are battery-powered, energy utilization should be optimized. As a result, the routing protocols used for terrestrial networks, delay tolerant networks, mobile ad hoc networks, and wireless sensor networks (WSNs) cannot be utilized directly for UWSN [6]–[10]. Many researchers have created many protocols, which may be roughly classed as location free routing protocols and location-based routing methods. When using location-based routing protocols, it is necessary to have a thorough understanding of the network structure and the nodes' locations beforehand.

The nodes consume more energy when location-based protocols are employed since the nodes' positions are known before data transfer. When nodes are used underwater and move continually with the flow of water, the position of the nodes must be first determined before making a routing method.

Underwater communication is used by the military to send secret information and to detect suspicious activities. Entry of an unauthorized person through the sea borders must also be monitored at higher priority. The data packets containing this critical data require low delay and must be reached at the destination without any loss of information. The sensor may also monitor other things where delay and packet loss can be tolerated to some extent, and because of the delay, there is not much harm caused. This information is referred to as low priority information [11]–[14].

This paper proposes a priority-based routing protocol with the main intention of reducing the delay and packet loss for high priority sensed information. The major contribution of this paper can be summarized as: i) we propose a cluster based priority routing protocol where the data packets with higher priority are transferred through multipath and a single path is used for lower priority packets, and ii) to achieve high speed data transmission, we make use of a hybrid approach of optical-acoustic communication. Section 2 given below gives the related work required for carrying out this research work. The system modelling and detailed descriptions related to this research are given in section 3. The priority-based energy efficient hybrid cluster routing protocol (PB-EEHRCP) methodology adopted in implementing this research is given in section 4 under the methodology head. The simulation setup for carrying out research and the results obtained are highlighted in section 5. The conclusion of the research is given in section 6 of this research paper.

2. RELATED WORK

In a vector-based routing system proposed by Mazinani *et al.* [15], nodes near the radius of the routing pipe assist in directing the packet to its destination. A lot more nodes may assist in steering the packet since the radius is large enough, but doing so uses more energy. When the radius is narrow, fewer nodes are involved in directing the path, which lowers the packed delivery ratio. Latif *et al.* [16] have presented two routing techniques, one for energy gradation and the other for depth correction. When the energy-gradation technique is used, the original energy is split up into a number of junks. A depth-based routing system is suggested by Balsamo *et al.* [17] in which any node with a depth value lower than the sender serves as a forwarder. Each node, in this case, calculates the holding time depending on the depth difference. A hop-by-hop vector-based routing protocol is discussed by Ahmed *et al.* [18]. It produces a vacuum zone where the nodes are not accessible due to mobility issues or energy loss. The next forwarding node along the path is chosen using the suggested approach, which takes into account the distance from the source node and the relative position of the virtual vector. A protocol for balancing the energy consumption in nodes at different depths has been proposed by Qin *et al.* [19]. Radio wave communication links are established with sink nodes, which are placed on the surface of the sea when sensor nodes are employed deep inside the sea.

The performance of UWSN can be analyzed in dense mode by the creation of spherical division-based forbidden regions by Javaid *et al.* [20]. A depth and latency-sensitive cooperative routing method is suggested to maximize throughput while reducing delay. The number of hops between the source and destination is decreased when packet delivery is successful. The performance of UWSN could be analyzed using a new type of algorithm. Khosravi *et al.* [21] proposed a methodology whereby the algorithm is a hybrid approach of vector-based and spherical-based approaches. Wang *et al.* [22] proposes an energy-aware and void-avoidable routing protocol which is executed in two phases, where in the first phase layering is done and in the second phase data collection is carried out. Opportunistic directional forwarding strategy (ODFS) is utilized to exchange packets within the nearness of the void nodes. A proactive routing strategy for underwater communication networks is suggested by Khan *et al.* [23]. The suggested technique is applied to many network types, including sparse, somewhat dense, and dense networks. Layering ideas are used in the primarily dense network to find the fastest and shortest path, and clustering techniques are used for transmission in the sparse area. An opportunistic routing protocol for underwater wireless sensor networks has been proposed by Guan *et al.* [24]. Each node in the network measures and maintains a hop count distance to the sink nodes. The shortest path to reach the sink is identified, and further packets are transmitted along the shortest path identified. Jin *et al.* [25] have presented a reinforcement learning-based congestion avoidance routing scheme. The routing protocol takes into account both the node energy level and the network congestion. For reinforcement learning to help with the congestion control problem, a reward function is created.

3. SYSTEM MODEL

The underwater environment keeps changing very frequently. The data collected during the abrupt changes in the environment can be treated as the most critical data, as it may give information about the harsh environmental changes. There is a requirement for a priority-based routing algorithm (PBRA) which routes the higher priority data packets to the base station for processing. The PBRA is an extension of the energy efficient hybrid cluster routing protocol (EEHCRP) routing algorithm. Figure 1 depicts the system model of PB-EEHRCP. The system consists of anchor nodes, relay nodes, and sink nodes. The anchor node senses the underwater environmental data and then forwards it to the relay nodes. The relay nodes also act as the cluster head (CH). The high-power relay node collects the data sensed from the anchor nodes and then identifies the priority of the sensed data. When the priority of the data is high, the data packets are routed to the sink node for further processing through multiple paths. Lower priority data packets are transferred through a single path. To increase the data transmission speed, an optical link is used. The nodes also use the acoustic link to transfer the data packets wherever optical communication is not feasible. The sink nodes, which are placed on the sea bed, further, transfer the data packets to the monitoring station. The relay node, after identifying the data packet as higher priority, broadcasts the data packet to all the CH that are within the range of the relay node. The CH in turn transfers the packets to the sink node through multiple paths.

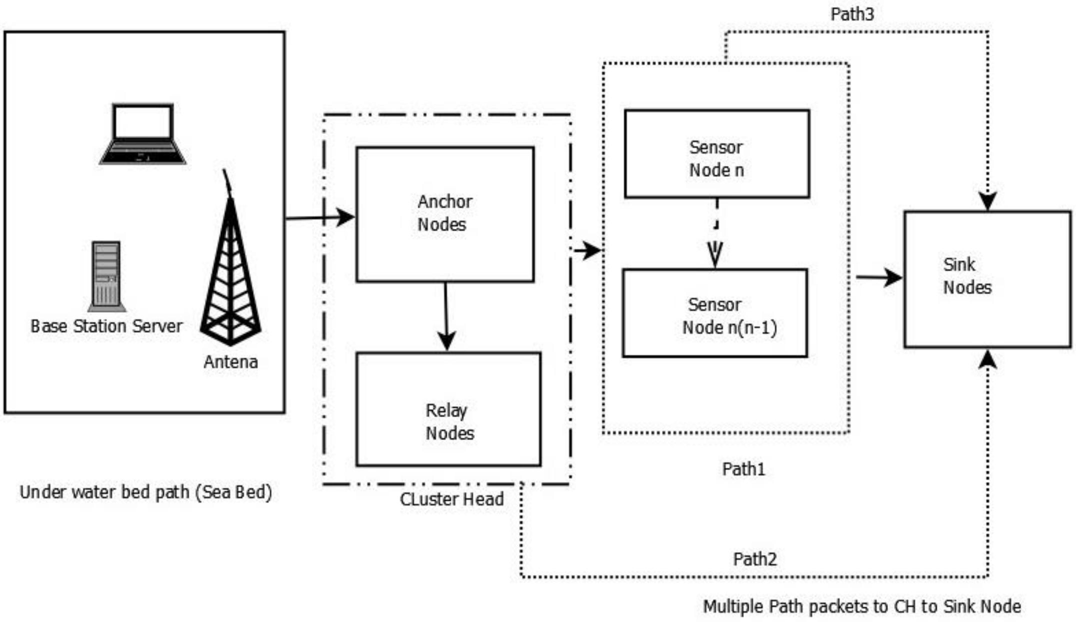

Figure 1. System model for packets transfer through multiple paths to sink node

4. PROPOSED SYSTEM

The data packets can be classified as higher priority or lower priority data packets. The importance of the data packets may be recognized based on the uncertainty caused in the underwater environment. Losing the critical data may be cost effective and may cause certain serious real-time problems. So, there is a requirement for a reliable routing methodology that can route the critical data packets to the base station at a faster rate.

In the proposed system, the node broadcasts the HELLO packet to all the nodes that are reachable to gather information about its closest nodes. The node that obtains the HELLO packet replies with a HI packet. The HI packet contains all the information about the node, like its error rate, latency, location, and residual energy. This information is maintained in a table which gives the complete details of all the neighboring nodes. When the node transfers critical data, the data maintained in the neighboring table is used to decide whether the critical data packet needs to be forwarded to the path. Each node maintains two types of queues for differentiating between higher and lower priority data packets. All the data packets with critical information are placed into the higher priority queue, and the data packets that hold normal sensed information are assigned to the lower priority queue. By implementing two buffers for higher and lower priority, the latency can be reduced for critical data packet delivery.

The waiting time for each packet may be calculated to estimate the delay that can be caused during the packet transmission. A threshold can be set as to the number of packets that can be maintained in a queue. A packet with the same priority, a higher priority, or a lower priority may arrive at a node. Packets that hold critical data can be represented as Qh, packets with the same priority can be represented as QS, and packets with a lower priority can be represented as QL. The expected waiting time (EWT) of a packet at the queue Qi for a particular node Z can be calculated as (1):

$$EWT = (RTS)x + t\sum ST(Qh), ST(Qs), ST(QP) \quad (1)$$

where, $(RTS)x$ is the remaining time for the packet to provide the service; $ST(Qh), ST(QS)$ are service time for the packets with higher or same priority; and $ST(QP)$ is service time for a higher priority packet when it arrives during the P's waiting time. Using the (1) the end-to-end delay can also be calculated which is the sum of waiting time of the packet in and the queue and the time required to process the request.

Critical sensed data packets must be reached to the destination at the fastest speed. The data packets with critical information need to be dispatched at correct time to the base station without any loss of information. The nodes having the critical information data packets first check the state of their neighboring node before routing the packet. Each node maintains the table of information related to the nodes that are reachable to it. This information is used to take a decision about whether to forward the critical data packet to the next identified neighbor or not. The result of (2) is used to identify the next node along the path.

$$f(decision) = f(Re) + f(Pdr) + f(Dis) + f(Lq) + f(Load) \quad (2)$$

where, $f(Re)$ is indicates the residual energy of the node. The node having higher residual energy can be selected as it guarantees that the packet will not be lost due to node failure; $f(Pdr)$ is indicates the packet delivery ratio of a node. It also depicts how reliable is a node in routing the packets; $f(Dis)$ is indicates the distance between the node and the base station. The nodes that are nearer to the base station can be chosen. Short distance transmission consumes less nodes energy and also results in increased lifetime; $f(Lq)$ is indicates the link quality of the node. If the nodes link quality is high it ensures that the packet will not be lost and will be routed to the destination; $f(Load)$ is indicates the load of a particular node. When a node is heavily loaded than the data packet spends most of their time waiting in the queue. The value of the function $f(decision)$ is between 0 to 1. This value is used in deciding the next node along the routing path. If $f(decision)$ value is between 0 to 0.5 it indicates that the node is not feasible to be selected as the next forwarding node. $f(decision)$ value with 0.5 to 1 then such node is selected along the path to route the critical data packet to the base station.

5. SIMULATION AND RESULT DISCUSSION

The simulation settings of PB-EEHCRP are similar to EEHCRP. Around 500 nodes are positioned in the network area with a dimension of 1,000*2,000 m^3. The entire network area is split up into 16 sectors, which are further grouped into different clusters. The nodes are laid with a distance of 80 m between them. Nodes' initial energy is around 10 kJ, and the depth is set to 2.0 km. PB-EEHCRP uses a hybrid approach of optical and acoustic channels while transmitting. The parameters used for the optical channel are as: The wavelength is 532 nm, beam width is 3 mm, maximum beam divergence is 20, link distance is 20 m, and we assume default water quality is clear water with 0.31 mg m-3.

5.1. Performance comparison

EEHCRP protocol is designed for hybrid underwater environment. The proposed methodology reduces the energy utilization of the nodes, delay and also increases the throughput and network lifetime when compared with other underwater routing protocols. The PB-EEHCRP identifies the packets with critical data and routes them to the base station with higher priority. Losing the critical information may result in unidentified environment changes that may cause additional damage. PB_EEHCRP separately routes the packet with critical data with higher priority and ensures that the data packets are reached at the fastest speed to the bases station without any loss of information. Here we compare the performance of EEHCRP and PB-EEHCRP with reference to delay, packet delivery ratio, throughput, energy efficiency and reliability. Table 1 depicts the throughput comparison values.

Figure 2 depicts the network throughput comparison of PB-EEHRCP critical and non-critical data packets with EEHCRP routing protocol. It is noticed that the network throughput is increased by 15% for PB-EEHCRP with critical data packets. As the higher priority data packets are routed and maintained in a separate queue and they are processed at the faster rate. Before transferring the critical data packets the path is checked for feasibility and checking the neighboring table. The critical data is forwarded to the neighboring node only if it is capable of forwarding the data packet quickly and correctly or else the alternate path is followed and ensured that the packet is delivered correctly within the short time. This results in the raise of the network throughput.

Table 1. Network throughput comparison

Simulation Time (s)	Network Throughput (Kbps)			
	EEHCRP with critical data packet	PB-EEHCRP with critical data packet	EEHCRP with normal data packet	PB-EEHCRP with normal data packet
5	60	100	75	90
10	110	160	106	109
15	150	200	140	150
20	160	225	175	180
25	198	280	225	240
30	295	390	288	260
35	350	400	340	360
40	400	440	415	425
45	410	455	408	415
50	430	462	435	440

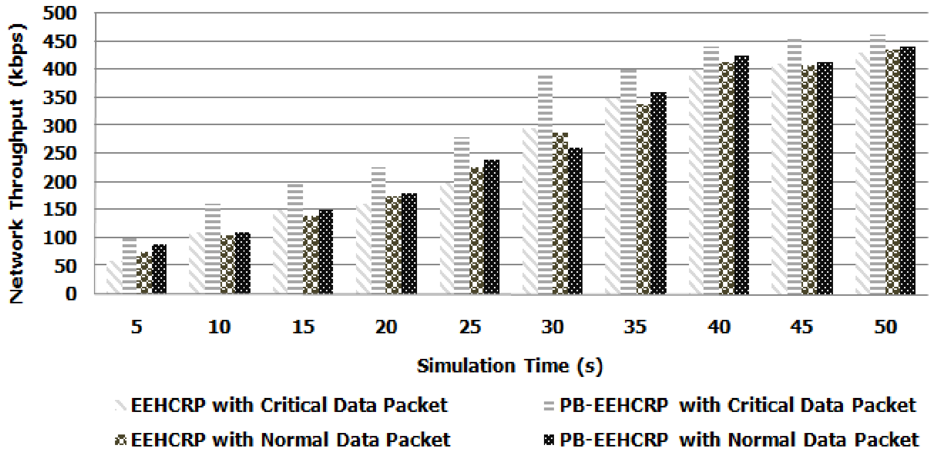

Figure 2. Comparison of network throughput for critical data packets and non- critical data packets

Table 2 depicts end to end delay comparison values and the Figure 3shown depicts the end-to-end delay comparison of PB-EEHCRP and EEHRCP with critical and non-critical data packets. It is observed from the graph that the delay is reduced by 12% for the critical data packets when compared with the non-critical data packets. All the non-critical data packets are processed through a lower priority queue, which results in the increased delay when compared with the critical data packets. Both EEHRCP and PB_EEHRCP use a hybrid approach of acoustic and optical communication channel. The high-speed optical channel transfers the packet at the higher rate and hence results in the reduction of dely.

Table 2. End to end delay comparison

Simulation Time (s)	End-to-End Delay (Secs)			
	EEHCRP with Critical Data Packet	PB-EEHCRP with Critical Data Packet	EEHCRP with Normal Data Packet	PB-EEHCRP with Normal Data Packet
5	2.5	1.4	2.4	2.1
10	3	1.5	2.5	2.2
15	3.4	1.9	2.9	2.8
20	3.8	2.1	3.6	3.5
25	3.6	2.8	3.3	2.9
30	4	3.1	4.1	4
35	4.8	3.9	4.7	4.5
40	6.2	5.2	6	5.8
45	8.5	6.1	8.2	7.8
50	10	8.4	9.8	8.8

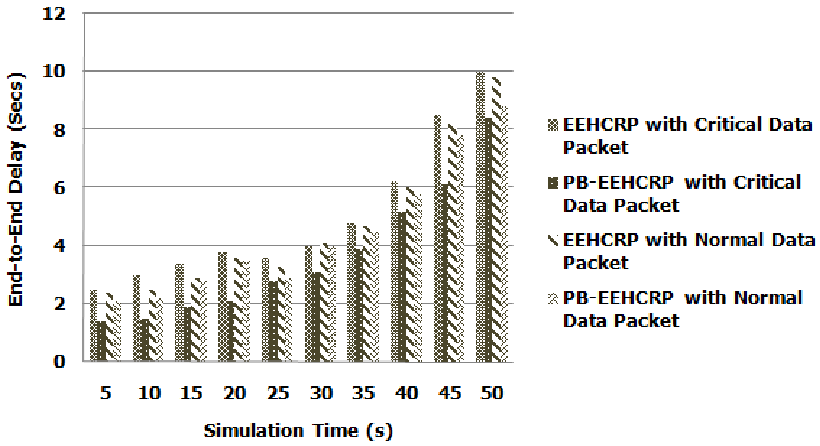

Figure 3. Comparison of end-to-end delay for critical data packets and non- critical data packets

The comparison of the packet delivery ratios of PB EEHCRP and EEHCRP for critical and non-critical data packets is given in Figure 4 and its values are listed in Table 3. The findings indicate that, as compared to non-essential data packets, there is a 14% increase in the packet delivery ratio for crucial data packets. A sudden calamity might happen if a crucial data packet is lost. Using a dependable and quick route for data transfer guarantees that all crucial packets get to their destination in time for processing. The energy usage of the nodes is seen in Figure 4. Every time a node participates in a data transfer, it is active. To preserve their energy level, the nodes spend the rest of the time in an idle state. From the graph, it can be seen that the PB-EEHRCP method uses less energy than the EEHRCP algorithm by a factor of 0.2%.

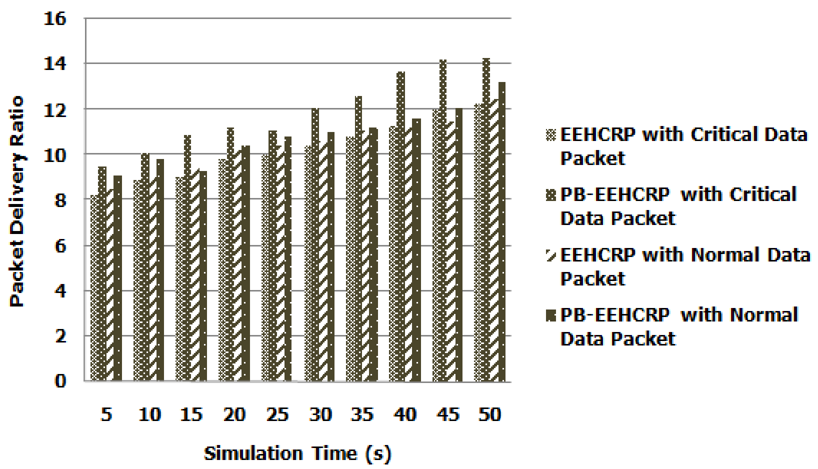

Figure 4. Comparison of packet delivery ratio for critical data packets and non-critical data packets

Table 3. Packet delivery ratio comparison

Simulation Time (s)	Packet Delivery Ratio			
	EEHCRP with Critical Data Packet	PB-EEHCRP with Critical Data Packet	EEHCRP with Normal Data Packet	PB-EEHCRP with Normal Data Packet
5	8.2	9.5	8.5	9.1
10	8.9	10.1	9.1	9.8
15	9	10.9	9.4	9.3
20	9.8	11.2	10.2	10.4
25	10	11.1	10.4	10.8
30	10.4	12.1	10.6	11
35	10.8	12.6	11.1	11.2
40	11.3	13.7	11.2	11.6
45	12	14.2	11.5	12.1
50	12.3	14.3	12.5	13.2

Energy efficiency comparison values are listed in Table 4 and the Figure 5 shows the energy consumption of the nodes. The nodes are active whenever they are involved in the data transfer. Rest of the time the nodes are in the idle state to maintain their energy level. It is observed from the graph that the energy consumption of the PB-EEHRCP is reduced by 0.2% when compared with the EEHRCP algorithm.

Table 4. Energy efficiency comparison

Simulation Time (s)	Energy Efficiency			
	EEHCRP with critical data packet	PB-EEHCRP with critical data packet	EEHCRP with normal data packet	PB-EEHCRP with normal data packet
5	109	93	100	98
10	151	98	120	115
15	238	150	220	174
20	318	215	300	194
25	428	248	320	235
30	500	359	400	379
35	542	424	590	514
40	698	527	710	562
45	785	672	700	665
50	795	587	650	615

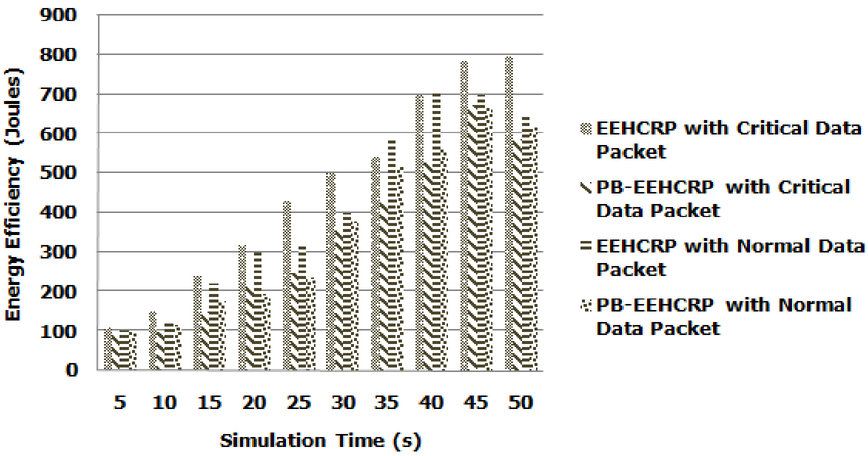

Figure 5. Comparison of energy efficiency for critical data packets and non-critical data packets

6. CONCLUSION

In this research work, an energy-efficient cluster-based priority routing protocol for UWSN is proposed. The methodology adopted maintains two queues for higher and lower priority data packets. Information like sudden and drastic changes in the underwater environment or the transfer of hidden data at the borders is considered critical data. This critical data needs to be delivered to the destination at a faster rate without any loss of data packets. The proposed methodology ensures faster delivery of data packets with critical data to the base station without losing any data.

This research looks into the impact of critical and non-critical data on a variety of network characteristics, including throughput, end-to-end latency, packet delivery ratio, and energy efficiency. The simulation findings demonstrate a 15% increase in network throughput for crucial data packets in comparison to non-essential data packets. The suggested method increases throughput by routing crucial data packets along a quicker, more reliable path. The system maintains two distinct queues for data packets with varying degrees of priority. Higher priority data packets are handled first and sent to their destination right away. This results in a reduced end-to-end delay by 12% when compared with routing non-critical data packets. The packet delivery ratio is increased by 14% for the proposed system with critical data packets. In the proposed system, before transferring the critical data to the next node along the path, the node’s energy level and status are checked to ensure that the reliable path is followed. This results in a rise in the packet delivery ratio.

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