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RESEARCH ARTICLE

A Priority Based Energy-Efficient Metaheuristic Routing Approach for Smart Healthcare System (SHS)

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ABSTRACT The advancement in IoT expedites the traditional healthcare system from one-to-one interaction to telemedicine. Smart Healthcare System (SHS) offers enormous physician and patient-centric solutions. Alongside, delay and energy degradation-related challenges in healthcare services put the patient's lives at risk. This is because the healthcare data have not been prioritised and all the IP-based data packets are treated the same during the routing process. Inspired by this, a hybrid and robust priority-based Duty-Cycled with Ant Colony Optimisation Routing (DC-ACOP) mechanism has been proposed in this study. The body sensor nodes use their radios to get activated and deactivated. So, dynamic duty cycling has been introduced to activate the communication unit of sensor nodes on demand. The data packets are defined with precedence to serve the highest priority packets first in the Type of Service (ToS) field of IP packets. The precedence-based data packets facilitate the healthcare services on time based on the criticality of the patient. The priorities on the wireless relay node are defined by comparing the encrypted disease levels and thresholds. For efficient route determination, a metaheuristic-based improved ACO approach has been employed in SHS. The proposed DC-ACOP approach has been evaluated and compared with other state-of-the-art approaches to accomplish tangible results in terms of quality metrics such as residual energy, throughput, network lifetime, delay with prioritisation and without prioritisation, packet delivery rate, and the number of non-alive nodes.

INDEX TERMS Ant colony optimization, duty cycling, energy-efficiency, healthcare system, quality metrics, routing, smart priority.

I. INTRODUCTION

The IoT has revolutionized the way it delivers healthcare services without availing the necessity to have patient-centric communication interpersonally. Thus, it helps to offer healthcare services to the people at the earliest without visiting the doctor physically. However, the process of delivering data packets is not always smooth. The data congestion problem in Smart Healthcare System (SHS) creates a hurdle for the efficient delivery of data packets to the destination because of the slow processing or the risk of data loss during routing.

Smart Healthcare includes various entities like patients, doctors, and research organizations. Multidimensional smart healthcare involves disease prevention and recovery, diagnosis, medical research, and decision-making [1]. The technologies like IoT, fog/edge computing, big data, smart biotechnology, and artificial intelligence form the main pillars of Smart Healthcare. For example, wearable devices

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are used for monitoring health conditions seeking medical help through virtual assistants, and offering remote services. Similarly, intelligent decision-making assists in the timely diagnosis of patients via doctors. Also, the role of surgical robots and reality technology becomes paramount for performing surgery precisely in SHS. With the aid of multiple smart technologies in the healthcare sector [2], [3], it is possible to minimize the overall cost and risk associated with lifelong medical procedures and resources. SHS offers personalized and ubiquitous medical services. Currently, virtual assistant bridges the communication gap among doctors, patients, and hospital units to make medical functionalities more affordable. Virtual assistants facilitate medical services by converting the daily actions of patients into medical terminology via smart devices. The virtual assistant responds to appropriate information based on the data received by patients by inculcating medical procedures carefully to save time and cost.

In a Smart Healthcare System (SHS), wearable sensors are attached to the human body to aggregate health-related data as depicted in Figure 1. The transmitter embedded in the sensor device forwards healthcare data as IP packets to the cloud remotely [1]. Then, the healthcare data is routed to the endpoints through an intelligent routing mechanism. Through an intelligent mechanism, the process of routing data takes a fraction of a second to reach the appropriate destination. Sometimes the IoT network faces a huge overflow of IP packets that cause processing time to stretch longer than expected. The overflow of IP packets in the network increases the overall energy consumption. The IP packets in Smart Healthcare are not distinguishable based on the severity of the data. Therefore, all the healthcare IP packets were treated the same during routing without any knowledge of packets holding critical or normal data. This is because of the traditional approaches followed in the routing process without any advanced priority mechanisms. The healthcare packets often get delayed at the physician's end due to congestion. This delay in data puts the patients' lives at risk. Hence, there is a need to tackle the issue of delayed packets before it becomes unmanageable. The delay in delivering data packets increases energy consumption too.

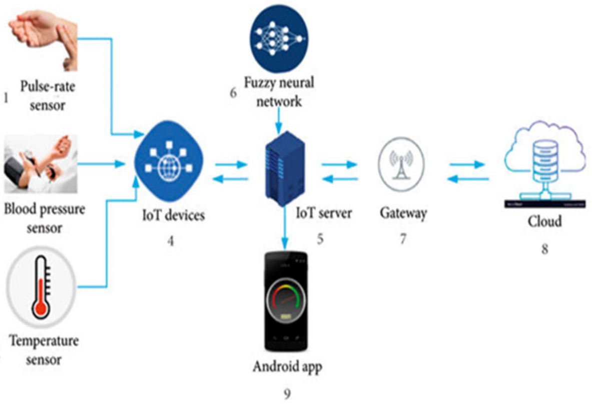

FIGURE 1. Overview of smart healthcare system [4].

Energy optimization in Smart Healthcare Systems (SHS) is becoming vital nowadays due to the limited battery power, memory, and processing of sensor nodes. Various energy-aware routing mechanisms in literature have been utilized for determining the computation cost and routing path to transmit the data. One of the methods is data aggregation clustering which intends to minimize the number of packets in an IoT network [5]. However, the data aggregation methods result in extra control overhead to form cluster heads repetitively. The distributed clustering approaches manage the extra control overhead to some extent [6]. The distributed clustering approach [7] uses local message passing to form hierarchical topologies. Other approaches are tree-based and directed acyclic graphs [8] that necessitate dynamic network orchestration to build a particular routing topology. In these techniques, continuous network management is required because of the link outage and node failure challenges.

The appropriate scheduling of healthcare data packets with an efficient routing mechanism would improve the excessive energy loss and delay problems [9]. Routing is the process of forwarding the data packet from the originator to the destination. This research study deals with delay and energy loss problems in the Smart Healthcare domain by managing duty cycling, priority management, and routing mechanisms. The proposed hybrid approach is the so-called Duty Cycled Ant Colony Optimisation with Priority (DC-ACOP).

The priority assignment to data packets is done according to the threshold data values on the occurrence of an event. The packets are prioritized based on the type of event. The type of event determines the disease models and the respective thresholds owned by the medical units. The sensor nodes use on/off radios to save energy. This is known as the duty cycling of nodes. The proposed DC-ACOP activates the nodes on demand, only when communication is required. The highest priority is assigned to the most critical data by prefixing the binary label. Then, the next lowest priority is assigned to the on-request data. Subsequently, the next lowest priority is assigned to normal data. And, the general purpose data is assigned with the least priority, and so on. The priorities are assigned based on the disease models and thresholds. For an efficient routing of data to the network by an optimal path, an improved ACO is employed along with priority assignment. The overall crux of the proposed approach is showcased in Figure 2.

A. CONTRIBUTION AND ARTICLE ORGANIZATION

The major contributions of the research article are listed therein.

1. To mitigate the delay and energy consumption issue in Smart Healthcare Systems (SHS), a priority-based routing mechanism has been proposed.
2. A duty-cycled and priority-based efficient routing framework has been proposed in Smart Healthcare

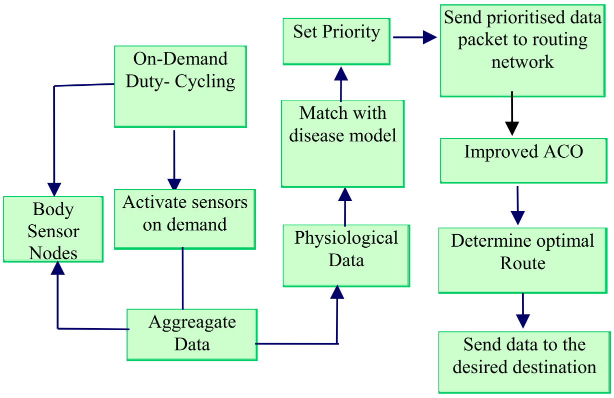

FIGURE 2. Research article organization.

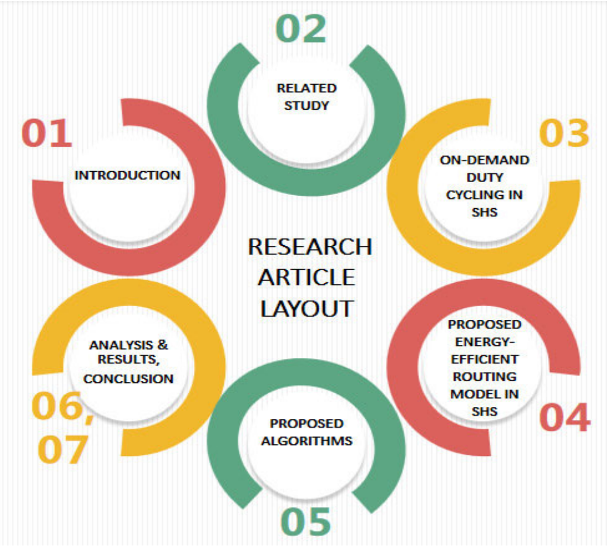

FIGURE 3. Research article layout.

Systems for giving higher preference to critical data packets to reach the healthcare units.

3. For efficient routing in a mobility-based Smart Healthcare System (SHS), a metaheuristic-based improved Ant Colony mechanism has been employed to determine the path stochastically.
4. The proposed duty-cycled energy-efficient priority-based routing approach (DC-ACOP) is assessed with state-of-the-art approaches in terms of key performance metrics like throughput, energy-consumption, network lifetime, number of dead nodes, and delay.

The rest of the research article is formulated as follows. Section II elaborates on the related study for gaining energy efficiency in Smart Healthcare Systems. The duty-cycled-based communication of data in SHS is comprehended in Section III. The energy-efficient priority-based metaheuristic routing model is proposed in Section IV. The mechanism of priority allocation to healthcare data packets along with the Ant Colony routing strategy is showcased and discussed in the subsections of Section IV.

The proposed algorithms for priority allocation and efficient routing are illustrated in Section V. Section VI evaluated the proposed DC-ACOP approach with the existing priority-based approaches. The comparison and analysis of the proposed approach are assessed in terms of quality metrics like throughput, end-to-end delay, number of dead nodes, and network lifetime. The conclusion of the research article is summarized in Section VII. The structured layout of the research article is depicted in Figure 3.

II. RELATED WORK

In [10], the authors developed a strategy to report priority levels of medical packets to the gateway empirically to monitor the data transmission. The priority-based strategy overcomes the misleading delivery information of priority levels to the WBAN gateway. This strategy for a Smart Healthcare System mitigates the delay issue and meets the QoS requirements by incorporating priority concerns. On similar lines, a virtual gateway MAC placement approach [11] was provided to minimize delay, and improve throughput and robustness by choosing an optimal host to run the virtual gateway instances.

The authors present a Privacy-Preserving Priority scheme (PPC) [12] scheme to minimize the latency of the system. The PPC scheme relays classified data packets without disclosing the confidential data of users, disease models, and healthcare units. The PPC scheme is investigated in terms of computational costs and transmission overhead. Likewise, a Joint Topology Control and Routing (JTCR) approach for reliable communication in UAVs is presented in [13] to manage mobility while gaining maximum coverage. The JTCR approach employs three modules. The first module emphasizes on mobility control of UAVs. The second module is based on fuzzy clustering to aggregate data. The third module performs optimised Q-routing to transmit the aggregated data from the UAVs cluster head to the base station. The JTCR approach outperforms in terms of coverage rate, overall latency, energy consumption, and the number of retransmissions.

Bharathi et al. [14] applied an improved energy-efficient Particle Swarm Optimization (PSO) approach for choosing the optimal Cluster Head (CH) from disparate IoT nodes in a Smart Healthcare System. The cluster head aggregates the healthcare data from the IoT nodes to transmit it to the cloud via fog devices. After the storage of healthcare data on the cloud, the diagnosis and severity of the disease are done using the Artificial Neural Network model. The UCI dataset is used for experimentation purposes to predict various levels of disease severity and to generate an alert system.

In [15], comprehended the allocation of resources such as channel assignment in a Wireless Body Area Network (WBAN). The sensor nodes continuously send data to the access points that emit energy in regular communication. The authors presented the priority-based non-pre-emptive scheduling to keep the process running for maximum time to accomplish reliability. The process continuously runs until interrupted by the hub in case of emergency signal generation. The goal of the devised scheme is to avoid starvation with the least waiting time during the execution of user processes. Irregular communication and interference are mitigated in case of high traffic signals by assigning higher priority.

Nandan et al. [16] defined an approach to form clusters using Optimal Genetic Algorithm (OGACHS). The OGACHS approach chooses the optimal cluster head by introducing the fitness criteria for distance, node density, energy, and heterogeneity of nodes. The OGACHS approach employs a mechanism to deploy heterogeneous sensors in a structured way. The sensor nodes are positioned in an area of interest. The sensor nodes in the range of mobile sinks would gradually decrease energy consumption. This phase governs the unwanted constrained deployment of high-energy nodes. Also, the concept of introducing multiple mobile sink nodes mitigates the hotspot issue. Mobile sink nodes move in a trajectory outside the network to ameliorate the distance thereby cluster head chooses the nearest sink for data transmission [17]. The OGACHS is assessed on several metrics like network lifespan, stability factor, residual energy, and throughput.

Most of the clustering algorithms handle non-numerical data in the same fashion by considering it as categorical attributes. But in the context of IoT, mixed data is generated that couldn't be treated in the same manner. Thus, it results in some similarity measurement errors by using existing classification. Therefore, to deal with non-numeric data, the work in [18] classifies the data into categorical, descriptive, and gradable as per the characteristics. The initial center of clustering is set by using the max-min distance and divergence simultaneously. The inter-cluster entropy method is used to determine the optimal cluster number.

The standard LEACH protocol for clustering offers an equal opportunity for nodes to become cluster head [19]. Due to this, the entire energy of nodes exhausts within a short period. Therefore, to mitigate the energy consumption issue, an improved LEACH-R protocol is defined in [20] that prioritizes the nodes based on residual energy. The improved LEACH-R protocol changes the position of the cluster head as per the higher energy level of nodes. The improved protocol LEACH-R shows enhancement in throughput by 60% and 64% in residual energy. After the initial election of cluster heads in a cluster, the CH uses Time Division Multiple Access (TDMA) for member nodes to transmit data in schedules to avoid data collision.

The study in [21] devised a priority and robust RPL routing technique for IoT systems. The routing protocol is meant for low-power and lossy networks. The data is transmitted to the destination in particular time slots by taking into account the traffic, audio, and imaging data. The priority-based routing technique is robust enough to deal with congestion. This technique attempts to reduce overall overhead on mesh, delay, and energy ingestion. Therefore, it increases the overall efficiency in terms of transmitting data packets.

Likewise, a routing protocol for reliable data transmission based on priority in Smart Healthcare Systems is given in [22]. The Healthcare data is classified into emergency and vital data. The emergency data is given the highest priority for data transmission first. The vital data is the data demanded by doctors for monitoring patients. Direct mode and multi-hop communication are adopted for vital data delivery. Result findings show improvement in energy consumption and network lifespan of sensor nodes while ensuring the reliability and packet delivery ratio.

The unbalanced energy in a single sink network is a critical issue nowadays because the energy of the nodes near the sink node degrades faster. The single sink network faces the issues of link invalidation, unbalanced energy, and network load. The traditional techniques only consider the least count of hops and the shortest path. Therefore, the study in [23] developed the priority-based routing (PBR) approach and system architecture to balance the energy in a multi-sink environment. The PBR approach considers the energy consumption and the number of transmissions to prolong the network lifespan.

III. ON-DEMAND DUTY CYCLING IN SMART HEALTHCARE SYSTEM

The extensive transformation of connected health results in the Smart Healthcare System which intends to connect mundane mobile devices with wearable devices for monitoring blood pressure, glucose levels, number of calories burned, body fat level, etc. The implanted healthcare devices assist in monitoring the patient's health even from a distant location [24]. Smart Healthcare offers timely services on demand with low expenses for several medical conditions. The data gathered by microchips is sent to the remote server via a WiFi network such as a physician's laptop. For instance, wearable sensors act as collecting units for measuring patients' physiological signals [25]. The collected data is pooled to get deeper insights regarding the latest trends in healthcare verticals across different countries.

In Smart Healthcare, sensed data from body sensors are routed to the central base station *i.e.* wireless relay node from where the important information is delivered to respective end systems via wireless access points. Healthcare medical devices consume most of the energy in different states such as activation, deactivation, transmission, reception, and idle which is often managed by a process known as Duty-Cycling of nodes. Duty cycling is the periodic shifting of node states during communication to preserve energy. Therefore, the requisite for body sensor networks is energy preservation and optimisation because of the minimum lifespan, miniaturization, and limited battery power. Along with duty-cycling, an efficient routing approach facilitates for identification of the optimal route to deliver the data to the desired location. In Figure 4, the body sensor nodes work close to the human body under the physical layer.

The body sensors include temperature sensors, pulse sensors, motion sensors, and ultrasonic sensors that are used for

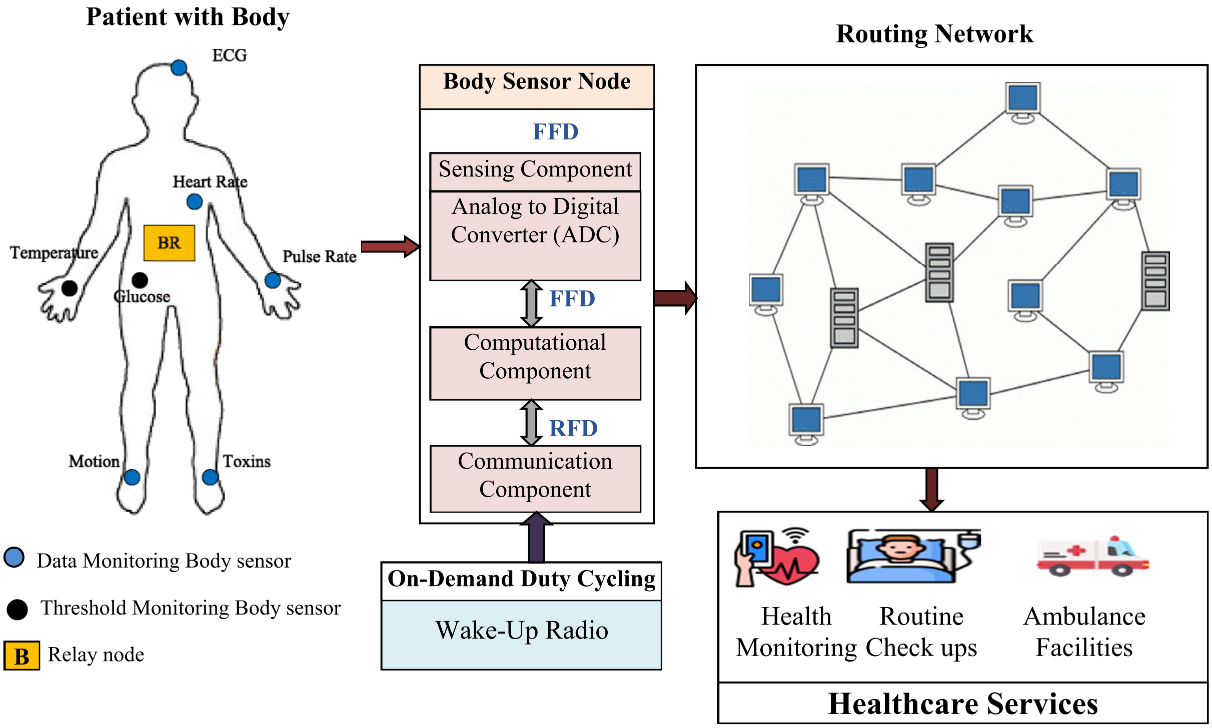

FIGURE 4. On-Demand wake-up radio (WuR) in smart healthcare system.

monitoring different health conditions. The heart rate, pulse rate, motion, toxins, and ECG are measured by data monitoring sensors. On the other hand, glucose and temperature are the threshold sensors.

The *BR* node depicts the relay node for forwarding data to the appropriate routing device. The different entities in a sensor node are the sensing unit, computation unit, and communication unit.

For the optimal use of radio dissipation, the on-demand wake-up radio has been employed. The wake-up radio has been employed on the communication unit of the sensor node as it consumes more energy. That means it is kept as a Reduced Functional Device (RFD) *i.e.* it activates only when communication occurs and switches back to the inactivation state. The sensing unit senses the analog signals and converts them into digital signals via an Analog-to-Digital (ADC) converter. The digitized data gets processed by the computational unit. The communication unit encompasses the transceiver for sending and receiving data. The entities in a sensor node are classified as Full Functional (FFD) and Reduced Functional (RFD) based on the functional time of each entity.

IV. PROPOSED ENERGY-EFFICIENT PRIORITY BASED ROUTING MODEL IN SHS

The proposed energy-efficient priority-based routing model entails the physical layer followed by the priority assignment, network routing layer, and healthcare services layer depicted in Figure 5. The physical layer depicts the medical sensors attached to the human body to sense medical signals. The sensor nodes are activated only when required by using on-demand duty cycling on the physical layer. The IP-based healthcare data packets are prioritized by adding the prefix label in binary format to categorize and analyze the severity of data. The most disease-severe patients have been chosen for routing medical data to the desired destination by using the advanced metaheuristic routing approach so-called improved Ant Colony Optimisation. The efficient data transmission via multiple hops would improve the quality of service metrics at the physician's end.

A. PHYSICAL LAYER

The physical layer in the Smart Healthcare model represents the body sensors attached to the human body such as strain, moisture, temperature, blood pressure, gyroscope, etc. as these are considered highly efficient acquisition devices. These smart sensors constantly sense the data for monitoring healthcare conditions, seeking medical assistance, disease diagnosis, and enhancing decision-making by using Body Area Network (BAN). Smart Healthcare System (SHS) entails technologies like IoT, mobile internet, and wearable devices to retrieve information dynamically. SHS interlinks people, tangible objects, and healthcare institutions to manage, and respond dynamically and intelligently [26].

1) ON-DEMAND WAKE-UP RADIO

The On-Demand Wake-up scheme uses a Radio Frequency (RF) wake-up sensor. The radio frequency sensor senses

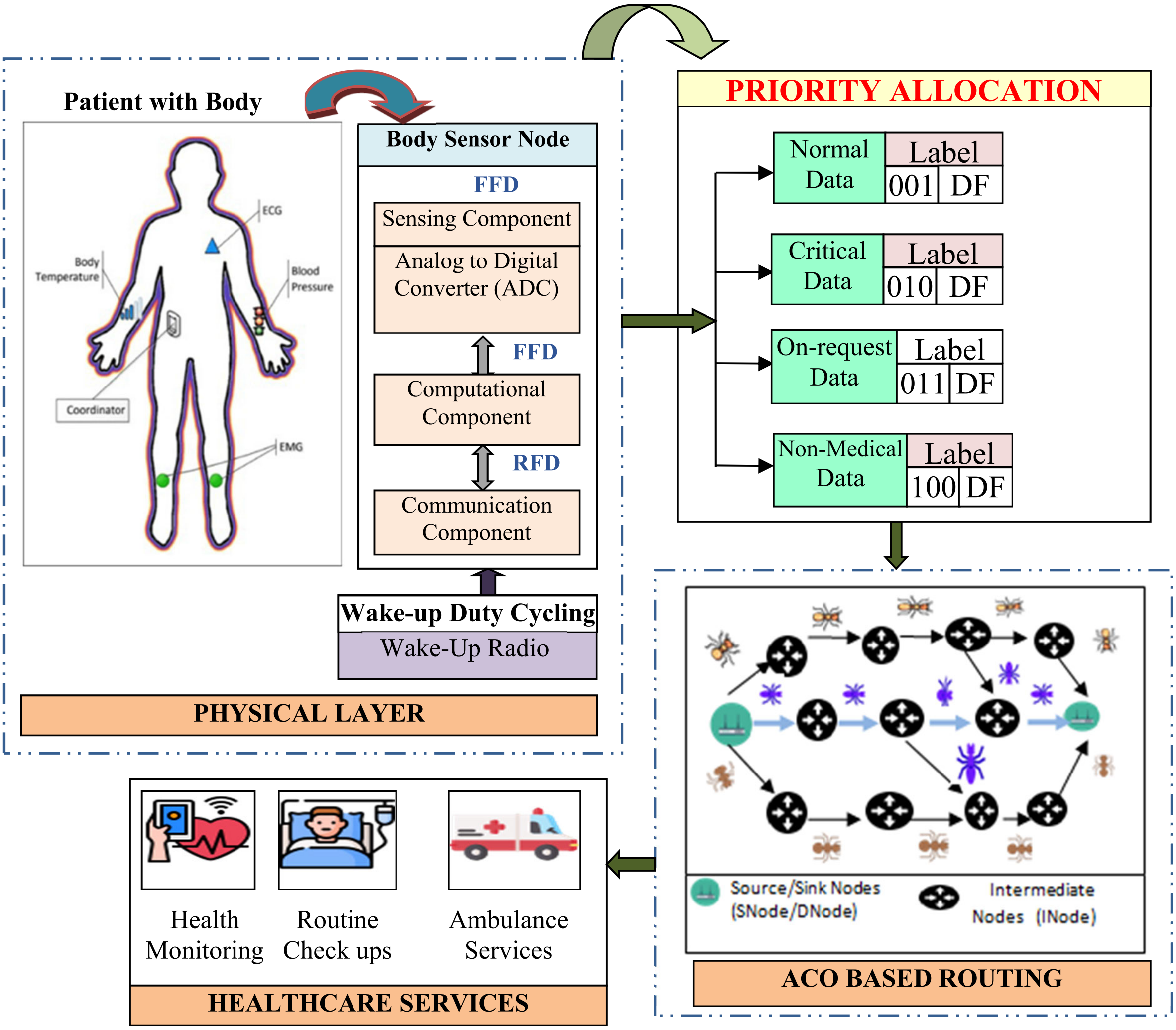

FIGURE 5. Proposed priority based metaheuristic routing model for smart healthcare system.

the carrier signal to detect the communication status [27]. The channel management function is different from the RF communication entity. Once the signal is caught by the RF sensor which has a stronger intensity than the preset threshold, it notifies the processor regarding the communication event [28]. The RF communication module is activated by the processor by generating an ON signal. Similarly, the RF communication module is turned off when no carrier signal is detected. Figure 6 shows the structure of a sensor node with an RF wake-up sensor.

The same channel is accessed by the communication unit and the RF wake-up sensor. The RF wake-up sensor activates the neighbor nodes using a signal that is used for charging the capacitor as it is strong enough. This signal is called a wake-up signal [29]. The transmitter waits for a fraction of the time until neighbor nodes turn on their radios.

This time is known as guard time [28]. The wake-up signal is transmitted before the communication starts. Once the wake-up signal is detected over the carrier, the RF sensor is turned off until the communication is over [30].

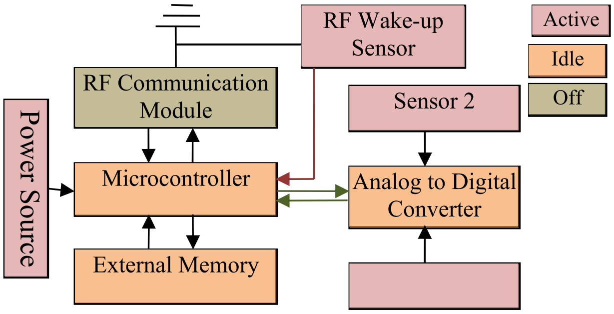

FIGURE 6. Structure of a sensor node with an RF wake-up sensor [28].

The communication process with the wake-up signal is shown in Figure 5. "The duty cycling of the RF sensor was calculated using (1) which is the fraction of response time and sensor cycle." The T_{wksig} and T_{res} depict the wake-up signal length and the response time. T_{res} indicates the time to sense the incoming signal by the RF wake-up sensor. This time includes the activation and the charging time of the capacitor of the RF wake-up sensor.

$$\boldsymbol{Dc} = \frac{\boldsymbol{T_{res}}}{\boldsymbol{T_{sens\_cyl}}} \tag{1}$$

$$Dc = \frac{T_{res}}{T_{wksig} - T_{res}} \tag{2}$$

$$\boldsymbol{T_{wksig}} = \boldsymbol{2T_{res}} + \boldsymbol{T_{sleep}} \tag{3}$$

Substituting eq^n. (3) in eq^n (2)

$$D_c = \frac{T_{res}}{T_{sleep} + T_{res}} \tag{4}$$

"The energy expended by a sender and receiver was calculated using (5)," which is the time taken by the individual operations performed. E_{swh}, and T_{swh} depicts the energy and time expended for switching the states of the communication module. T_{cm}, and E_{cm} are the time and energy consumed in a single communication. $T_{wt_{cm}}$ is the time taken by the receiver for initiating communication. P_{tx}, and P_{rx} are the energy consumed for transmission and receiving data in the communication module.

$$T_{sndr} = T_{wksig} + T_{swh} + T_{cm} \tag{5}$$

$$E_{snder} = E_{wksig} + E_{swh} + E_{cm}$$

$$E_{sndr} = E_{wksig} * P_{tx} + E_{swh} + E_{cm} \tag{6}$$

$$T_{rvr} = T_{res} + T_{wt_{cm}} * P_{rx} + T_{cm} \tag{7}$$

$$E_{rvr} = T_{res} * P_{rx} + T_{wt_{cm}} * P_{rx} + E_{cm} \tag{8}$$

2) PRIORITY ALLOCATION

Priority is a mechanism to give precedence to data packets so that the most important data would be transmitted first. Billions of IP packets are transmitted through the routing mechanism without taking into account which packets are the most prominent and carry important information. The IP packet has several fields like header, options, sequence number, time to live, checksum, etc. The header section keeps track of the source and destination address. The time to live field indicates the time the packet remains in the network until discarded by the router. The checksum field ensures the validity of the frame. If the cyclic redundancy check matches with the frame, then the frame is valid otherwise not. Payload is the actual data carried by the packet. In Smart Healthcare, IP-based medical data is routed from body sensors using a Body Area Network (BAN) more effectively. The priority assignment to critical healthcare data reduces the transmission delay at the physician's end. The IP header format with ToS field is illustrated in Figure 7. The Type of Service (ToS) field holds 8 bits. The initial 3 bits from 0 to 2 indicate IP precedence. The higher precedence value represents the importance of the data packet. The next 4 bits indicate the Type of Service (ToS). The ToS field is used to represent QoS like minimized or normal delay, high or normal throughput, and high or low delay. The last bit is reserved and Must be Zero (MBZ). Later on, RFC 2474 revamped ToS as the Differentiated Services (DS) field [31] shown in Figure 8. A DSCP value is 6 bits (0 to 5) of the DS field in the range of 0 to 63. The remaining 2 bits (6 and 7) are reserved and used for Explicit Congestion Notification (ECN) defined in RFC 3168. The precedence values of ECN are further classified into two ranges i.e congestion management and non congestion management. The DSCP value also known as codepoint affects the per-hop behavior.

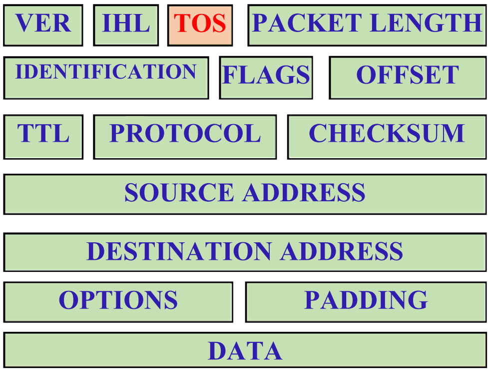

FIGURE 7. IP header format with TOS field.

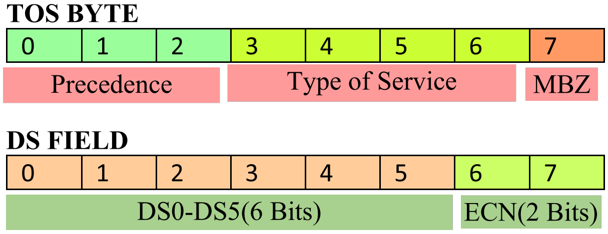

FIGURE 8. Structural difference between TOS and DS field in IP header.

Some legacy devices support IP precedence and the upcoming network devices support Differential Services (DS). To accomplish compatibility between the both, the class selector codepoints are used. The default IP precedence values are depicted in Table 1.

The DSCP field in the IPV$_6$ header prioritizes and classifies network traffic. The DSCP field assists routers and switches to differentiate between various classifications of data packets. The DSCP values range from 0 to 63 and depict the precedence or service levels. The DSCP is used by networking devices to make forwarding decisions and incorporate Quality of Service (QoS) policies [31]. The primary classes defined by DSCP are Lower Effort (LE), Default Forwarding (DF), Assured Forwarding (AF), Expedited Forwarding (EF), and Class Selector (CS). The LE and DF values range from 0-15. The AF DSCP traffic values range from 16-47. The EF DSCP values range from 48-63. High-numbered requests with AF subclasses depict lower priority, for example, AF42 has lower priority than AF41. Similarly, AF21-AF23 has lower priority than AF11-AF13. The Class Selector (CS) values are used for selection of class types not for the priority.

The DSCP governs the precedence of Class of Service (CoS). The Class of Sevice (CoS) is utilized at layer 2 of the Open System Interconnection (OSI) model to prioritize

TABLE 1. IP precedence.

IP precedence (decimal)	IP precedence (binary)	Description
0	000	Routine
1	001	priority
2	010	immediate
3	011	flash
4	100	flash-override
5	101	critical
6	110	internet
7	111	network

frames provided a Virtual Local Area Network (VLAN) tag is there. The CoS manages the data traffic in a network by classifying various types of data based on traffic type such as voice over IP, Email, and video streaming, as defined by IEEE. The CoS values range from 0 to 7 (3 bit) was defined by IEEE as per 802.1Q standard where 0 depicts the lower and 7 depicts the higher priority. After the prioritization of a frame with a priority number, the QoS enabled switches at layer 2 decides the outbound delivery of frames based on priority values. The CoS only works on a trunk link whereas the DSCP offers End to End (E2E) quality of service capabilities anticipated by a specific network traffic at layer 3(network layer). The CoS and DSCP are both used by QoS queuing strategy.

In Smart Healthcare System, priority is allocated to data packets by altering the information in the header section of the packet [31]. Depending on the priority assigned by the QoS to data packets, they are allocated to outbound port queues with the same priority levels. The port acquires different data classifications based on priority. The priorities have been decided by comparing the thresholds and the severity level of the disease models in the case of a Smart Healthcare System. The exit of packets is determined by the queue based on priority. The packets having the highest priority will be delivered first. In the proposed model, the medical packets are assigned with identifiers in binary format to set the different priorities of the data frame (DF). The label (001) depicts the normal data with low priority. The label (010) depicts the critical data with a very high priority. The label (011) is the on-request data with high priority. The label (100) depicts the non-medical data with very low priority. The classification of priorities is done by comparing the data generated and disease-level models that have been discussed subsequently.

3) SYSTEM MODEL

The proposed energy-preserving system model assumes a dual environment between user and remote cloud-based healthcare centers. The interaction between users and healthcare entities involves a Wireless Body Area Network (WBAN) node. The WBAN node catches the medical packets from different users and relays them to medical centers in the context of the criticality of data packets [13], [32]. The entities in a system model are mentioned in Figure 9.

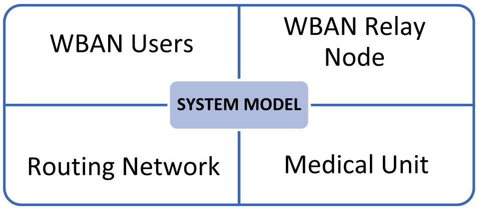

FIGURE 9. Entities in a system model.

a: MEDICAL UNIT

The medical unit has abundant facilities for rendering early medical services and disease recognition using different disease models [12]. In a nutshell, the healthcare unit provides personalized services based on the severity of the disease and various physiological conditions. The medical thresholds and disease models would be kept confidential due to their intellectual property.

b: WBAN RELAY NODE AND ROUTING NETWORK

The WBAN is accountable for relaying medical data packets to healthcare unit that relies on a priority-based scheme. The data packets are collected periodically by the WBAN relay node [10], [33]. The relaying of data to the desired medical center employs a routing network that ensures the delivery of data via the shortest path through an efficient routing mechanism.

c: WBAN USERS

The users notated as $\{U\varepsilon\ u_1,\ u_2,\ u_3,\ \ldots\ldots\ldots u_n\}$ are equipped with body sensors that have been registered by a medical unit using a smartphone. The delivery of sensor values and other relevant information gains insight into disease models and thresholds [11], [12]. Thereafter, sends prioritized data packets to healthcare centers via the WBAN node.

4) PRIORITY SCHEME

We assume that the disease models are defined by: $\vec{D} = \{d_1, d_2, d_3, d_4 \ldots . d_k\}$, thresholds $TH = \{th_1, th_2, th_3, th_4 \ldots . th_l\}$ and the physiological data generated $\vec{Y} = \{y, y_2, y_3, y_4 \ldots . y_n\}$ by body sensors.

Step1: Initially users are validated one by one to get access to the disease models $\vec{D} = \{d_1, d_2, d_3, d_4 \ldots . d_k\}$ and the thresholds $TH = \{th_1, th_2, th_3, th_4 \ldots . th_l\}$. The disease model and respective thresholds are owned by the medical unit. The medical unit finds an appropriate disease model for monitoring the user. The number of thresholds may vary as per the number of users. "The disease model and the threshold are encrypted that resides with the medical unit using (9) and (10)."

$$D_i = [d_i] = g^{\beta d_i} h^{r_i}, \quad i = 1, 2, \ldots, k \tag{9}$$

$$TH_j = \left[th_j\right] = g^{\beta(d_i+\gamma)} h^{r_j}, \quad j = 1, 2, \ldots, l \tag{10}$$

In (10), $\beta, r_i, \gamma, r_j \epsilon W_n$ are secret random values chosen by the medical unit for encryption. The encrypted D_i and TH_j are sent to the authorized user by the medical unit.

Step 2: The physiological data is aggregated periodically $\vec{Y} = \left\{y, y_2, y_3, y_4 \ldots . y_n\right\}$ and the following computation is performed on all the thresholds.

$$Product = \prod\nolimits_{i=1}^{k} D_i^{y_i} \tag{11}$$

$$CD_j' = TH_j.product.h^{r_j} \tag{12}$$

The computed data CD_j' is sent to the WBAN relay node. Also, the medical unit sends a hash set and hash function *HSH()* to the WBAN relay node as follows:

$$HSH_i = HSH\left(e\left(g, g\right)^{\alpha\beta\mu(\gamma+i)}\right), \quad i = 1, 2, 3, \ldots\ldots .th_{mx} \tag{13}$$

Here, the th_{mx} is the upper limit of the threshold. For example, each disease holds the respective thresholds associated with it *i.e* say for disease 1 $(dss = 1)$ the threshold $th1 = 50$, for disease 2 $(dss = 2)$ the threshold $th2 = 55$, for disease 3 $(dss = 3)$ the threshold $th3 = 47$ so the priority considered is $th_{mx} = 55$ for $dss = 2$.

Step 3: The body sensors aggregate the physiological data to send to the smartphone. The user computes the $um = \sum_{i=1}^{n} d_i.y_i$. The data packet entails the physiological data, sum, user info, and the set of thresholds that is sent to the WBAN relay node to decide the priority of a data packet.

Step 4: To decide the priorities, the consecutive thresholds are compared as follows:

$$if\,(th_i < sum < th_j)$$

$$setpriority = j$$

OR

$$if\ (sum > th_l)$$

$$setpriority = l + 1$$

For any user U_i, two assumptions are considered:

Assumption 1: The inner product of physiological data $\vec{Y_u}$ and disease model $\vec{D_u}$ must be a non-negative value.

$$\vec{Y_u}.\vec{D_u} > 0 \tag{14}$$

Assumption 2: For any user to be in normal state the inner product of physiological data and disease model is less than the related threshold th_{rel}. In other case, where the user's situation is critical, the inner product of physiological data and disease model is greater than or equal to the related threshold.

$$\vec{Y_u}.\vec{D_u} < th_{rel}, \quad user\ is\ in\ normal\ state \tag{15}$$

$$\vec{Y_u}.\vec{D_u} \geq th_{rel}, \quad user\ is\ in\ critical\ state \tag{16}$$

B. IMPROVED ACO-BASED ROUTING

The ACO mechanism mimics the foraging nature of tiny creatures *i.e.* ants. The artificial ants act as data packets in dynamic IoT networks [34]. The pheromone chemical is used for communicating among ants to find the food source via the best achievable path. Similarly, the amount of pheromone laid on edges decides the optimal path in a communicative IoT network [35]. The transition criteria in ACO [36] choose the next hop out of multiple hops in a stochastic fashion [37]. The high-traffic networks encounter the challenge of load balancing due to the data forwarding on multiple paths for the same destination. For such issues, ACO performs better for quite a while due to their iterative and proactive nature by eliminating errors by choosing the trusted route. ACO improves the exploration capabilities for finding the best solutions thereby avoiding stagnation problems by reducing pheromone on edges. The ACO emphasizes the best global solution based on the earlier optimal solutions obtained in each iteration [38].

The traditional ACO suffers from stagnation and convergence issues because of the consideration of only limited parameters such as distance and its heuristic value. Also, the existing versions of ACO do not consider the other factors in the context of IoT such as mobility of nodes, remaining energy, network lifetime, energy expended, and stability factor. The improved ACO in the proposed model intends to tune the parameters that are most alarming to IoT networks such as mobility, path length, residual energy, and the average and minimum energy expended.

"The probability P_{uv}^{w} that the ant w moves from node u to node v is given by the transition rule using (17) and (18)."

$$\boldsymbol{P_{uv}^{w}\left(t\right)} = \left\{\begin{array}{c}\dfrac{\left[\tau_{uv}(t)\right]^{\propto} * \left[\eta_{uv}\right]^{\mu} * \left[\emptyset_{uv}\right]^{\delta}}{\sum_{h\varepsilon allowed_w(t)}\left[\tau_{uv}\left(t\right)\right]^{\propto} * \left[\eta_{uv}\right]^{\mu} * \left[\emptyset_{uv}\right]^{\delta}}, \\ \boldsymbol{if\ u\epsilon allowed\ nodes\ ants\ can\ visit}\end{array}\right\} \tag{17}$$

$$\boldsymbol{P_{uv}^{w}\left(t\right)} = \left\{\boldsymbol{0, if\ ants\ are\ not\ allowed\ to\ visit}\right\} \tag{18}$$

The $\tau_{uv}(t)$ is the intensity of the pheromone, η_{uv} is the visibility criteria, and $\emptyset_{uv}$ is the stability factor based on the mobility of nodes. The $\propto$, μ, δ are the constants to control the pheromone level, visibility factor, and stability factor.

After building a tour in n iterations each ant w leaves the amount of pheromone on edge *(u,v)*. The variation in pheromone accumulated on edge *(u,v)* is depicted by $\Delta\tau_{uv}(t, t+n)$. "The updated pheromone on edge *(u,v)* at time $(t+n)$ was calculated using (19)."

$$\tau_{uv}\left(t+n\right) = \left(1-\rho\right)\tau_{uv}\left(t\right)^{old} + \Delta\tau_{uv}(t, t+n)^{new} \tag{19}$$

"In (19), ρ is the evaporation factor having value (0,1)." If the value of ρ equals 1, then the evaporation of the pheromone occurs. If the value of ρ equals 0, then the pheromone does not evaporate. "The laid pheromone $\Delta\tau_{uv}^{w}$ by the w^{th} ant on edge (u,v) was calculated using (20)." The Q is the constant, $EN_{min} = min\ (EN_{res})$ is the minimum residual energy required by the nodes that have been visited. The EN_{avg} denotes the average of leftover energy fractioned by path distance which must be minimum.

$$\Delta\tau_{uv}^{w} = \left\{ \begin{array}{ll} \frac{Q*EN_{min}*EN_{avg}}{L_w}, & if\ ant\ transit\ on\ edge\ (u,v) \\ 0, & otherwise \end{array} \right\} \tag{20}$$

"The transmitted energy is evaluated using the standard first-order radio model shown in (21)." EN_{elec}, and EN_{rec} denotes the transmitting and receiving energy. ε_{ampl} is the amplifier energy and B is the number of bytes to be transmitted. The raise to the power of ds is the propagation loss index. The ds is the distance between the source and the destination and DS_0 is the threshold distance. "For receiving data bytes, an additional quantity of energy is required called aggregation energy shown in (22)."

$$EN_{Transmit} \left\{ \begin{array}{ll} B*EN_{elec} + B*\varepsilon_{ampl}ds^2 & if\ ds < DS_0 \\ B*EN_{elec} + B*\varepsilon_{ampl}ds^4 & if\ ds \geq DS_0 \end{array} \right\} \tag{21}$$

$$EN_{rec} = B*\left(EN_{elec} + EN_{aggre}\right) \tag{22}$$

"The remaining energy of node u could be calculated by subtracting the expended energy ($EN_{u_{Transmit}}$) from the total energy ($EN_{u_{tot}}$) using (23)." "Also, the remaining lifetime of a node was evaluated using (24)."

$$EN_{u_{rem}} = EN_{u_{tot}} - EN_{u_{Transmit}} \tag{23}$$

The remaining lifetime of a node could be calculated concerning the rate of decaying energy (EN_{rate}).

$$RE_{LT} = \frac{EN_{u_{rem}}}{EN_{rate}} \tag{24}$$

V. COMPUTATION OF QUALITY-OF-SERVICE METRICS

The performance of the proposed DC-ACOP approach is evaluated by taking into account the performance metrics like network throughput, network lifetime, energy consumption, and delay. The mathematical formulation of the performance metrics is described below.

A. NETWORK THROUGHPUT (NT)

Network Throughput measures the total quantity of data transmitted over the network in a given time. Throughput is the measure of speed at which the data can be sent, processed, and received.

$$NT = \sum_{p=1}^{n} \frac{PK_p * PK_{len}}{Time} \tag{25}$$

In "(25)," PK_p represents the number of data packets, PK_{len} is the packet length, and $Time$ represents the simulation time in seconds which depicts the transmission time.

B. RESIDUAL ENERGY (RE)

The residual energy is the energy depleted from the total energy. Initially, the total energy of the network is considered as the residual energy then the energy of the network gets degraded gradually after each simulation round.

$$RE = E_{tot} - E_{trans} \tag{26}$$

In "(26)," E_{tot} depicts the total energy of the network and E_{trans} is the energy lost during data transmission.

C. DELAY (D)

Delay is the time required to transmit the aggregated data from the source node to the desired node. The delay is denoted by 'D'.

$$D = \frac{T_{se}}{T_{re}} \tag{27}$$

In "(27)," the T_{se} is the time taken by the agreegated data to transmit and T_{re} depicts the time of the received data at the receiving end.

D. PACKET DELIVERY RATIO (PDR)

The packet delivery ratio determines the fraction of a number of packets received correctly to the total number of packets sent from the source to the destination node. The increase in PDR maximizes the network performance too.

$$PDR = \frac{D_{dl}}{D_{dl} + D_{lost}} \tag{28}$$

In "(28)," D_{dl} depicts the data delivered correctly and D_{lost} depicts the lost data.

VI. ALGORITHMS

The development of algorithms introduces three approaches. The first algorithm is the management of duty-cycling with channel access to data. Initially, the sensing part and the computation part of the sensor node are kept as high which means in full functional mode. The communication part of the sensor node is kept at a low means in the reduced functional mode because most of the energy gets degraded during the transmission of data. Once the data is fetched from the sensor node, it is converted to digital using analog to digital converter. If the processed data is greater than the limit set then the channel is accessed by the data packet, and all other tasks get suspended. This happens after the status change of the communication part of the sensor unit to high. i.e. in full functional mode.

Algorithm 2 depicts the priority allocation of the computed data to relay to the destination. The computed data is the encrypted data. The sum denotes the disease risk score calculated by the submission of disease levels and physiological data generated. For priority allocation, two consecutive thresholds are compared with the disease risk score. If $\mathrm{th_i} < \mathrm{sum} < \mathrm{th_j}$ holds then priority is set to j. If the sum is greater than the maximum threshold, then the priority is set to $l + 1$. The prioritised packet is pushed into the relay max heap to get

Algorithm 1 On-Demand Duty Cycling

```
Initialization: L(001), L(010), L(011), L(100), $S_{cp}$ = High, $C_{cp}$ = high, $CM_{cp}$ = low
Steps:

Start
while(true):
    $S_{da} = fetch$ (S_Node)
    $DI_{da} = AD\_convert(S_{da})$
    $SP_{da} = process(DI_{da})$
    if ($SP_{da} >= LT$) AND ($SP_{da} != null$) then
        $CM_{cp} = high$
        Grant channel access
        label++
    else($SP_{da} <= LT$) AND ($SP_{da} != null$)
        $CM_{cp} = low$
    end if
Stop
```

Algorithm 2 Priority_Assignment_Relay()

```
Input: Computed Data ($CD_1$, $CD_2$, $CD_3$, - - - $CD_j$)
Priority Allocation to medical packet ($MP_u$)
Relay_node do:
    for ($j = 1$ to $n$)
        if($th_i < sum < th_j$)
            set $MP_u = j$;
            // eq^n (6)
        else($sum > th_l$)
            set $MP_u = l + 1$;
            // eq^n (7)
        end if
    end for
$CD$.priority = $MP_u$
relay_heap.push (CD)
Relay medical packet
for($i = 1$ to relay_heap.len())
    mpacket = relay_heap. Mpacket(i)
    mpacket.priority + +
end for
```

Algorithm 3 Efficient and Improved ACO Routing (EIACO)

```
Input: Set initial parameters
Output: Dynamic and optimal route discovery
Start
Optimal path->Nil
While
    Randomly place $N$ ants on $U$ nodes initially
    for ($an$= 1; $an < N$; $an$ ++ )
        for ( $u$=1; $u < U$; $u$ + + ) // building tour
            Select the next hop using transition rule
                eq^n. (11) & (12)
        end for
    end for
update the best tour locally
    for ($an = 1$; $an < N$; $an$ ++) //updating pheromone
        for ($L_{ij}$ =1; $L_{ij} < L$; $L_{ij}$ ++) //each edge in ant's tour
            Calculate the pheromone deposited on
            each edge of the ant's tour eq^n. (13)
        end for
        Calculate the total pheromone deposited on the
            path globally
    end for
until stopping criteria reached
Return Best_tour
```

TABLE 2. Notations used in the algorithms.

Notation	Meaning	Notation	Meaning
L	Label	SP_{da}	Processed data
S_{cp}	Sensing component	CD	Computed Data
C_{cp}	Computation component	MP	Medical Packet
CM_{cp}	Communication component	th_i , th_j	Two consequetive thresholds
LT	Max. Limit	th_l	Maximum threshold
S_{da}	Sensor data	an	No. of ants (packets)
DI_{da}	Digitised data	mpacket	Medical packet

forward it to the medical centre. The prioritised data is routed via an optimal path determined by an efficient Ant Colony optimisation routing strategy.

The third algorithm is the Efficient Ant Colony Optimisation (EIACO) routing approach for optimal route identification. The EIACO uses heuristic information to select the path in a probabilistic fashion. The heuristic value depends on the distance, mobility, residual energy, and average energy consumption of the network. The initial parameters used in the EIACO approach are illustrated in Table 3. "The transition rules in (11) and (12) are used to find all the optimal routes locally." From the set of optimal routes, the best solution is returned globally based on the high pheromone value on that particular path. The notations used in the algorithms are depicted in Table 2.

VII. ANALYSIS AND RESULTS

The network is simulated as a set of nodes randomly distributed in the square area of 500 X 500 m. The experimental evaluation of the proposed algorithm is performed in the MATLAB environment. The values of the parameters are depicted in Table 3. The experiment has been repeated for a simultaneous number of iterations to demonstrate the performance and durability of the proposed approach. The proposed approach DC-ACOP is compared against three approaches namely Characteristic Time Routing (CTR) [33], Priority Based Routing Approach (PBRA) [23], PriNergy [21] and Joint Topology Control and Routing (JTCR) [13].

TABLE 3. Simulation parameters used in the experiment.

Simulation Parameters	Value	Simulation Parameter	Value
Number of rounds	400 ~ 4000	Mobility rate	0 - 50 *m/s*
Number of nodes	50 ~ 100	Simulation time	200 *s*
Data packet size	80 *bytes*	Dimensional Area	500 *X* 500
Packet number	400	Initial Pheromone level	10
Transmission range	100-250 *m*	MAC Protocol	IEEE 802.11
Data Rate	50 *kbps*	α, μ, δ	1
Pheromone evaporation rate	1*s*	Initial Energy	100 *J*

The evaluation of the proposed approach is done in terms of key performance indicators like throughput, network lifetime, residual energy, average end-to-end delay, and number of non-alive nodes.

The evaluation of network lifetime is demonstrated in Figure 10. The network lifetime is assessed by the amount of residual energy retains in the network after each simulation round. The residual or remaining energy is calculated by using the equation (26).

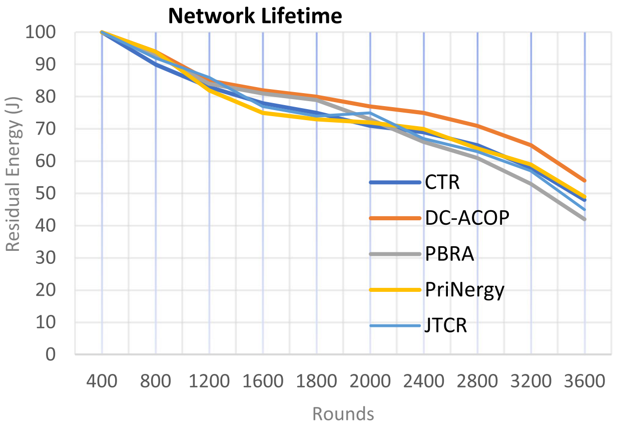

FIGURE 10. Analysis of network lifetime.

The evaluation of network lifetime is demonstrated in Figure 9. The network lifetime is assessed by the amount of residual energy retains in the network after each simulation round. The residual or remaining energy is calculated by using the equation (26). The initial energy of the network is set as 100 *joules*. The CTR and JTCR recorded 48 and 45 *joules* of remaining energy at the end of the simulation rounds. The PBRA and PriNergy recorded the residual energy of *42* and *49joules* respectively. The DC-ACOP has retained the maximum amount of residual energy of 54 *joules* because of the delivery of prioritized data via the shortest route in a probabilistic manner.

The throughput is the rate at which packets are delivered to the desired destination. The CTR and PBR received less number of data packets per second after each simulation round as compared to the proposed approach DC-ACOP. The PBRA and CTR scheme achieves throughput of *81* and *79* percent demonstrated in Figure 11. The throughput in the case of PriNergy and DC-ACOP in percentage is *80.5* and *85*. The existing approaches achieve minimum throughput because of the less stability and route identification process. The proposed approach shows significant improvement in throughput because of the consideration of stability factor and prioritized data routing through an optimal path.

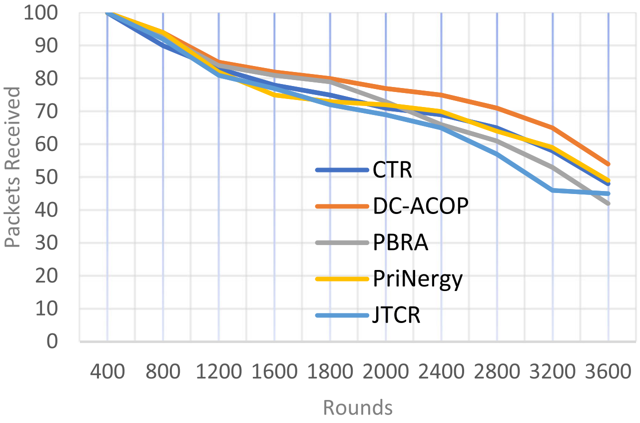

FIGURE 11. Throughput evaluation.

The end-to-end delay is the total delay it takes a packet to route from the source node to the destination node. It comprises transmission time, propagation time, and the priority checking of a packet. The delay measured in the case of CTR, JTCR, and PBRA is 77s,76s, and 69*s* illustrated in Figure 12. Also, the delay measurement in DC-ACOP, and PriNergy is 66*s* and 73*s* upon packet delivery of 450. The DC-ACOP encounters less delay due to the prioritization of data and the data delivery via the shortest route by using the elitism strategy after the completion of each round. The heuristic cost function takes into account the mobility factor of the nodes that ensures the minimum link outage and faster delivery of data.

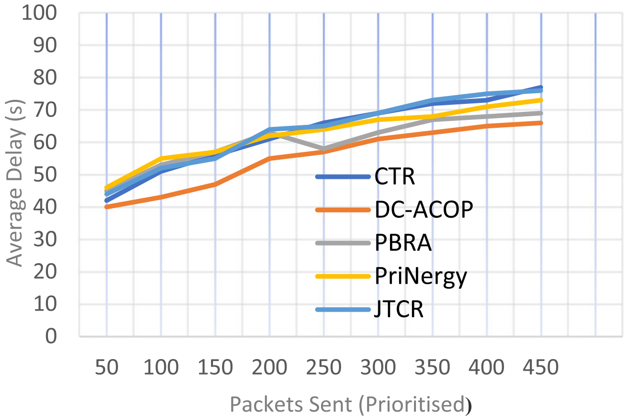

FIGURE 12. Analysis of average end-to-end delay.

Figure 12 shows the comparison of the total number of dead nodes versus the number of rounds. The dead nodes appear when the residual energy of the node becomes

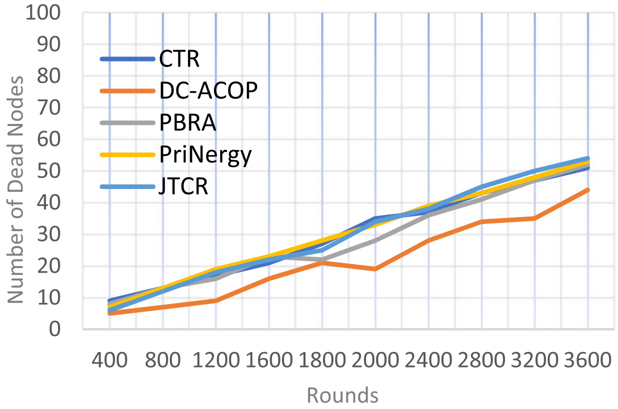

FIGURE 13. **Total number of dead nodes.**

zero gradually after each simulation round. The proposed DC-ACOP approach encounters *44* percent of dead nodes which is the least when compared with other approaches. In other techniques, more than *50* percent of nodes exhausted their energy fully *i.e.* CTR, JTCR, PBRA, and PriNergy. This is because of the more routing overhead and mismanagement of adaptive duty cycling in sensor nodes. The sensor nodes use low radio signals in case of no communication and only get activated when communication occurs which minimizes the number of dead nodes.

The average end-to-end delay in the case of non-prioritized data versus the number of packets sent per second is demonstrated in Figure 14. It has been observed that the delay in the case of data without priority is greater when compared with the delay encountered in prioritized data. This is because the non-prioritized data carries more bytes and is considered as of low priority that is needed by physicians on regular demand. The delay in the case of the proposed approach lies in the range of delay encountered in other techniques i.e. 74s.

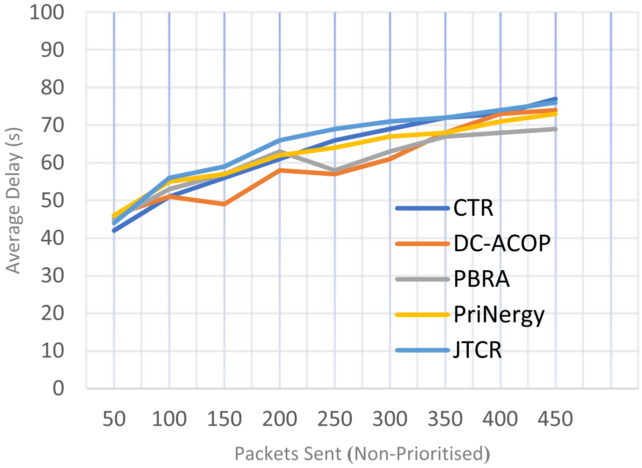

FIGURE 14. **Analysis of end-to-end delay without priority.**

VIII. CONCLUSION

In this research article, we have proposed an energy-efficient priority-based routing method for the Smart Healthcare domain with a particular interest in minimizing delay at the physician's end. This will assist critical patients to avail treatment facilities on time. The developed method takes into account energy consumption and delay problems during the transmission of data packets to the end destination. This could be handled by allocating priority to data packets based on the criticality of the data. The different classifications of data depict different types of data such as normal, critical, on-request, and general-purpose. The priorities have been assigned according to the disease risk score and thresholds. Also, the sensor node uses radio energy for communication therefore the adaptive duty-cycling has been also accounted. The proposed duty-cycled proficient routing mechanism with prioritization (DC-ACOP) is compared with CTR, PBRA, JTCR, and PriNergy for assessing the energy-relevant metrics like throughput, residual energy, number of dead nodes, delay with prioritization, and delay without prioritization. The simulation experiment has been run for *3600* rounds. As far as the residual energy is concerned, the DC-ACOP measured the residual energy of *54J* which is the maximum of all other algorithms. The other metric is the percentage of the number of dead nodes. The number of dead nodes in CTR, PBRA, PriNergy, and JTCR is measured above 50% whereas DC-ACOP encountered 44% of dead nodes. The number of dead nodes in the case of PEERP, PBR, and PriNergy is more because it took more time for the identification of routes and node outage problem. The maximum throughput in the case of DC-ACOP, PBRA, and PriNergy is *87%, 81%,* and 80.5%. The CTR measured the maximum throughput of *88%*. The proposed DC-ACOP results in less delay of *66s* with prioritization of data and *74s* without prioritization of data. Therefore, introducing priority to data packets with an efficient routing mechanism would be of great significance in minimizing delay and maximizing the efficiency of IoT-based applications.

AUTHOR CONTRIBUTIONS

Conceptualization, Formal Analysis, Investigation and Project Administration, Resources, Supervision, and Writing: Bharti Rana, Yashwant Singh, Pradeep Kumar Singh, and Wei-Chiang Hong. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

There is no specific data whose details should be provided.

COMPETING INTERESTS

No, the authors declare that they have no competing interests as defined by MDPI, or other interests that might be perceived to influence the results and/or discussion reported in this article.

THIRD PARTY MATERIAL

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