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WETRP: Weight Based Energy & Temperature Aware Routing Protocol for Wireless Body Sensor Networks

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ABSTRACT The technological advancements in wireless communication and miniaturization of sensor nodes have resulted in the development of Wireless Medical Sensor Networks (WMSNs) which can be effectively used for remote patient monitoring. Remote patient monitoring is one such application of wireless sensor networks which is becoming increasingly prevalent in healthcare. The healthcare applications of the WMSNs are delay-sensitive and require timely delivery of patient-critical data. However, the frequent exchange of critical data packets results in higher delays, collisions, packet drop, and re-transmissions. Consequently, it brings a detrimental impact on the performance of the WMSNs. In addition, the implanted biomedical sensor nodes produce electromagnetic radiations, pose a serious threat of damaging sensitive tissues in the human body. Protecting tissue damage requires thermal-aware routing protocols. However, most of the thermal-aware routing protocols developed for the WBSNs primarily focused on minimizing temperature, while overlooking the energy conservation goal and optimization of route selection. In this paper, we propose a weighted, QoS-based, energy and temperature-aware routing protocol, referred to as (WETRP), for the WMSNs that utilizes a composite routing metric by keeping in view temperature, remaining node energy, and link-delay estimation during route selection decisions. The simulation results presented in the paper demonstrates the efficacy of the proposed scheme in terms of preventing temperature rise, dealing with hotspot nodes, and maximizing network's lifetime.

INDEX TERMS Wireless body sensor network, routing protocols, QoS, energy efficiency, temperature, hotspot nodes.

I. INTRODUCTION

This Wireless Body Sensor Networks (WBSNs) is a type of wireless sensor networks (WSNs) that is specifically related to healthcare applications. A WBSN consists of minute biomedical sensor nodes which can be placed strategically on the body or implanted inside the human tissues that promise to provide cost-effective and real-time solutions for health monitoring by diagnosing various life-threatening diseases at their preliminary stage [1]. WBSNs serve both medical and non-medical applications like sports, entertainment, military, health care and many more [2]. The objective is to provide improved and cost-effective solutions for one's quality of life [3]. WBSNs besides having similar characteristics with WSN [4] and MANET [5] have some unique constraints, such as node heterogeneity, radiations effect on tissue heating, local energy awareness, postural body movement, transmission range and global network lifetime [6]. Therefore, routing protocols proposed for WSN and MANET are not suitable for WBSNs [5], [7]. Furthermore, radio signals generated by wireless communication are absorbed by human tissue which results in a temperature rise around the implanted sensor nodes and could result in sensitive tissue damage [8]. Therefore, to be on the safe side, the extent of radiation absorption

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in the human body must be observed. The measure of the rate at which electromagnetic radiation is absorbed by human tissues per unit weight, called Specific Absorption Rate (SAR), measured in watt per kilogram, given by equation 1,

$$SAR = \frac{\sigma |E|^2}{\rho} \tag{1}$$

where σ describes tissues electrical conductivity, the induced electrical field is described by E and tissue density is represented by ρ. Mainly there are two major sources of tissue heating: Antenna radiations of biomedical sensor nodes absorbed by surrounding tissues and the heat produced due to the circuit of biomedical sensor nodes as mentioned in [8], [9]. The rate of temperature rise can be calculated by using the Penne's bioheat equation [10] as mentioned in equation 2:

$$\rho C_p \frac{dT}{dt} = K\nabla^2 T - b\,(T - T_b) + \rho SAR + P_c \tag{2}$$

where C_p is the specific heat of the tissue, $\frac{dT}{dt}$ refers to the rate of temperature rise, $K\nabla^2T$ represents the amount of temperature rise due to tissue's thermal conductivity, $b\,(T\text{-}T_b)$ represents the heat due to blood perfusion, ρSAR is the antenna radiation absorption, P_c refers to the heat that is caused by nodes power circuitry.

In recent past, several thermal-aware routing protocols have been proposed for WBSNs aiming to reduce temperature rise and refrain frequent hotspots (a node whose temperature rises above a certain threshold value). A summary of these thermal-aware routing protocols with their pros and cons are mentioned in [1],[4], [6], [11].

Moreover, WBSNs need to operate appropriately for a longer duration of time without replacing or recharging the battery, specifically in a case when biomedical sensor nodes are implanted inside human tissues [12]. Therefore, effective energy utilization is also a key challenge for routing protocols to be designed for WBSNs. Keeping in view thermal effects and limited energy challenges, the concept of relay nodes has been coined by [13]–[16] to increase network lifetime and minimize temperature rise of the biomedical sensor nodes implanted inside human tissues.

In addition, healthcare applications of WBSNs are delay sensitive and require real-time delivery of patient data. However, network nodes due to varying data rates might experience significant level interference and congestion in the network. Therefore, it results in higher delays, transmission disruption, packet loss, buffer overflow and insufficient bandwidth. Consequently, causing the degraded performance of the network. Moreover, it is observed that thermal-aware routing protocols exclusively focus on temperature rise while the focus of the energy-aware schemes is to maximize network lifetime. However, link status also plays a key role in minimizing transmission delay and energy consumption, as the congested link may result in loss of critical data packets.

Therefore, by considering the above-mentioned issues, we propose a Weighted QoS-based energy and temperature aware routing protocol for WBSNs (WETRP) that addresses the limitations of existing energy and temperature-aware routing protocols for WBSNs. Considering the unique constraints of WBSNs, the design of WETRP is centered on residual energy, temperature and link-status. Although, the design of WETRP exclusively focuses on minimizing temperature rise but additionally it makes sure that the selection of the end-to-end route should be on the basis of the current energy level of intermediate relay nodes. In addition, WETRP gives equal significance to link's status which is vital for the timely delivery of critical data packets. The weight factor in our scheme lays a significant impact on route selection; we have assigned equal weights to each parameter i.e. energy, temperature, and link status in the route selection process, which uniformly distributes traffic across the network, therefore, maximizing network lifetime. Moreover, the proportion of the weights can be varied according to the application requirement. The simulations of the proposed scheme WETRP show improved results with regards to throughput, average temperature rises and average energy consumption against the compared schemes.

The rest of the paper is structured as follows: section-II describes the related work, section-III present the details of WETRP, section-IV present the results and section-V conclude and present the future work.

II. RELATED WORK

In the past decade, various routing protocols have been designed by keeping in view unique constraints of WBSNs such as limited energy, antenna size, radiation absorption, sensitive tissue damage, reliable and real-time data delivery. The thermal-aware routing protocol in this regard aims to minimize the average temperature rise around implanted sensor nodes due to radiation absorption. To the best of author's knowledge, the first effort to address temperature issue was proposed in [9] named as thermal-aware routing protocol (TARA) for Wireless Body Area Networks (WBANs). In TARA cluster leadership and sensor's locations are considered for reducing the effect of temperature rise around tissues. TARA overhears the transmission and counts the number of sent and received packets from its neighbors in order to determine temperature change in a particular session. It marks its neighbor a hotspot node if its temperature reaches a certain threshold. The information regarding hotspot relay node is spread out to other relay nodes by using packet withdrawn policy. When the temperature of the hotspot relay node dropdowns to certain threshold value its status disseminated to other relay nodes. However, delay and packet drop ratio increases due to packet withdrawn policy. Moreover, due to frequent hotspot nodes, it keeps on finding alternate routes which result in increased average retransmissions which consume more energy per packet transmission. Hence, the network lifetime is compromised.

Authors in [17] presented a thermal-aware routing protocol for WBANs. The nodes are assigned some priority levels where high priority packets are forwarded immediately as compared to normal data packets. The cost metric is based on neighboring node's temperature, distance from the sink, packet priority and remaining energy of the node. To avoid temperature rise, each node in the network is required to estimate the temperature of their neighboring nodes. If the temperature of a certain node reaches the pre-defined threshold, then that node will be marked as hotspot node and will be refrained from packet forwarding. The proposed routing scheme works fine at low arrival of packets but at high packet arrival rate, most of the packets are kept into the buffer which unnecessary increases packet delivery delay. Moreover, due to assigning preference to high priority packets it is possible that low priority packets could not reach at the destination node at all or could be dropped due to the buffer expiration time.

An Adaptive Thermal-Aware Routing (ATAR) algorithm [18] is proposed with the aim to reduce the temperature rise in implanted sensor nodes. A multi-ring routing approach is proposed that selects alternate end to end routes if the temperature of node at any specific route exceeds a threshold value. The partitioning of the network into multiple rings and maintaining ring information along with temperature and hop count across the network results in increased overhead which is not a preferable choice for resource-limited networks such as WBANs.

In [19] authors propose Hotspot Preventing Routing (HPR) to reduce packet delivery delay and minimize the formation of hotspots. HPR routes packets to its destination node using shortest path until any of the hotspot nodes detected on an active path. However, packets are dropped in a case if it surpasses its max-hop-count. Temperature change is estimated by overhearing transmission of neighbors. HPR significantly reduced the max temperature rise and packet delay. In [20] authors propose a thermal-aware shortest hop routing (TSHR) algorithm for priority based WBSNs. TSHR is designed in a way that if any packet drops during its transmission will be retransmitted. TSHR algorithm is comprised of setup and routing phase: in the setup phase, each node is responsible for building its routing table while in routing phase a route to the destination node is established using shortest path. Furthermore, this scheme defines two separate temperature threshold values. One dynamic threshold value which is comprised of the node's own temperature and temperature of its neighboring node and second fixed threshold value which is used to make sure that every node must satisfy a certain threshold value. The simulation result shows that the packet loss ratio of TSHR is almost zero and the maximum temperature rise is low. However, packet delay is also high. Authors in [21] propose Link-aware and Energy Efficient scheme for Body Sensor Networks (LAEEBA) which is comprised of 4 phases. Initialization Phase, Next Hop Selection Phase, Routing Phase and Path-Loss Selection Phase. This scheme makes use of a cost function which depends upon the distance between the sink and source node and residual energy. A node with minim cost value will be elected as forwarder node; all other nodes pass their data to this forwarder node, forwarder after aggregating forwards this data to the sink node. The path loss model of this scheme is based on distance and frequency. The simulation results show that this scheme successfully reduced the path-loss and enhanced network stability time. However, due to the selection of a new forwarder at each round increases overhead which ultimately puts a negative effect on energy consumption. In [22] authors propose Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol (M-ATTEMPT) for WBASNs. The scheme makes use of single and multi-hop communication for data transmission. For real-time or on-demand data single-hop communication is advised while as for normal data multi-hop communication is preferred to save precious energy. Hotspot avoidance mechanism is adapted to lower the temperature rise. Data packets are re-routed on alternate routes if any hotspot node exists on the active route. Sink node assigns time slots to each root node for communicating with it while transmitting normal data packets. In multi-hop communication M-ATTEMP only consider hop count as a routing matric to minimize energy consumption. However, doing this load of the network is not evenly distributed; therefore, it is possible that some node may die earlier which will undermine network lifetime.

In [23] authors propose iM-SIMPE a mobility based routing protocol for WBANs that elects a new forwarder node in each round on the basis of the cost function. The cost function depends upon residual energy and distance of forwarder node from the sink node. All remaining nodes in the network pass their data to the elected forwarder node which at the end transmits data to the sink node. A linear programming based mathematical model is implemented for minimizing energy consumption and maximizing throughput. Authors in [24] propose an Even Energy Consumption and Backside Routing for WBANs with the aim to improve the lifetime of the network, probability of successful transmission, and to support postural body movements. This scheme proposes two routing algorithms one for backside node and other for even energy consumption. *Algorithm for Backside Node:* Selects an optimal route using *Selection-Optimal-Route* procedure and routes data in a multi-hop fashion. In case of emergency, data is routed in single-hop to the sink. *Algorithm for even energy consumption:*Computes residual energy and standard deviation respectively for all nodes and chose a forwarder node with a minimum value of standard deviation. The scheme achieves significant performance improvement against the compared schemes. However, the overhead of the scheme is high due to selecting a forwarder node in each turn. Authors in [25] propose a novel algorithm for BANs named as Energy Efficient Thermal and Power-Aware (ETPA) routing algorithm for BANs. A cost function is designed for route selection that is based on the node's temperature, its energy level and received power strength of the adjacent nodes.

Moreover, an optimization problem is defined for minimizing the average temperature rise in the network. EPTA defines time slots for each of the nodes to transmit its data. Each node during its cycle broadcast their temperature and energy via hello packet. Each neighbor node upon receiving hello packets estimates the received power to compute the cost function. In the next subsequent frame, each node forwards its data packets to the node with a minimum value of the cost. A max-hop-count field is associated with each packet. The packet is dropped when it exceeds its max-hop field.

From the literature review, it can be concluded that majority of WBSNs routing protocols addresses the temperature rise and efficient energy utilization. However, link status has been overlooked which could play a significant role in achieving desired results. In addition, it is found that weight factor also plays a significant role in the performance of WBSNs by equally distributing traffic load across the network. Therefore, we proposed weighted QoS-based energy and thermal-aware routing protocol for WBSNs with the aim to enhance network lifetime and minimize packet delivery delay, and frequent hotspot formation. Moreover, an efficient route maintenance scheme is also defined for finding an alternative route if existing route encounters any hotspot or energy deficit node or experience too much congestion in the network.

III. PROPOSED WETRP SCHEME

WETRP is an extension of our previous work [26] which deals with the reliable delivery of data packets by introducing an interference-aware routing for WBSNs. However, this work enhances the network lifetime by incorporating relay nodes for multi-hop communication in WBSNs. The network model of proposed WETRP scheme is comprised of sensor nodes, relay nodes, and a gateway node. The connectivity graph of the WETRP is given in equation 3:

$$G = (V, E, W) \tag{3}$$

where V describes the sum of all biomedical sensor and relay nodes such that $V = \{B_s\}\, U\, \{R_n\}$ .B_s represents the set of all biomedical sensor nodes (i.e. source node and the sink node) such that $B_s = \{b_{s1}, b_{s2}, b_{s3,\ldots,} b_{sn}\}$, and R_n represents the set of relay nodes such that $R_n = \{r_1, r_2, r_3, \ldots, r_n\}$. Whereas, E represent links between relay, biomedical and gateway node such that $E = \{e_1, e_2, e_3, \ldots, e_n\}$ and W represents link metrics.

A relay node estimates the temperature rise of its nearby nodes by counting the total number of forwarded/received packets. We believe that each packet forwarded by a relay node results in its temperature rise by one unit as discussed in [25]. We incorporated a composite routing metric comprised of temperature, residual energy and link-delay for the selection of optimized route as shown in equation 4. A forwarder relay node is selected on the basis of the minimum value of the cost function.

$$CF = w1 \times T + w2 \times RE + w3 \times LDE \tag{4}$$

The composite function is a weight based function where weights are assigned to temperature T, residual energy RE and link-delay estimation, LDE respectively. The proportion of weight is equally distributed among temperature, energy, and link-delay such that $(w1 + w2 + w3 = 1)$. Assigning equal weights make sure that the traffic load is equally distributed among all the relay nodes in the entire network. The proportion of these weights can also be adjusted as per the application's requirements.

The structure of proposed scheme is comprised of a route discovery phase that determines hotspot free, energy efficient route with minimum link delay between source and the destination node and a route maintenance phase that determine alternative routes if active route encounters any hotspot or energy deficit node while routing packets.

A. ROUTE DISCOVERY PHASE (RDP)

In the RDP phase, a biomedical sensor node looks for a route entry in its routing table. If any route to the sink node exists, it must satisfy temperature and energy thresholds. Otherwise, source node broadcasts a route request (RREQ) to its immediate neighbors as shown in the figure. 1.

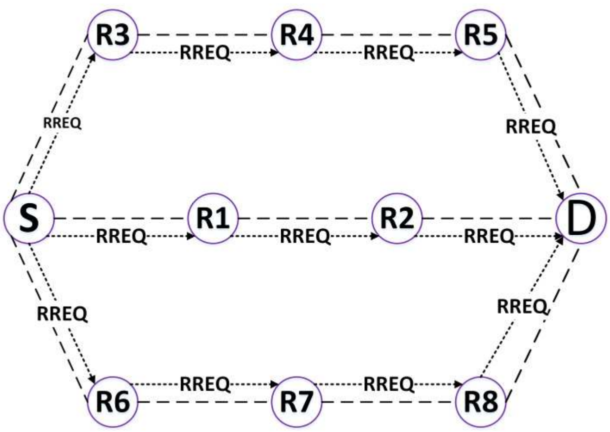

FIGURE 1. Route Request (RREQ).

Upon receiving RREQ a relay node compares it with its routing table (RT) and acknowledges the request if route to the sink node already exists, otherwise RREQ is broadcasted to downstream nodes. Eventually, the request reaches the sink node that unicast route reply (RREP) along the reverse route, as shown in the figure. 2.

Finally, each intermediate relay node along the reverse route, update RREP packet by embedding information regarding temperature, residual energy and LDE. However high temperature (hotspot) and low energy nodes are excluded in reverse route formation as these nodes do not satisfy temperature and energy thresholds respectively. In the end, the source node will have multiple routes; however, a route with a minimum value of the cost metric will be considered for forwarding data packets, as shown in the figure. 3.

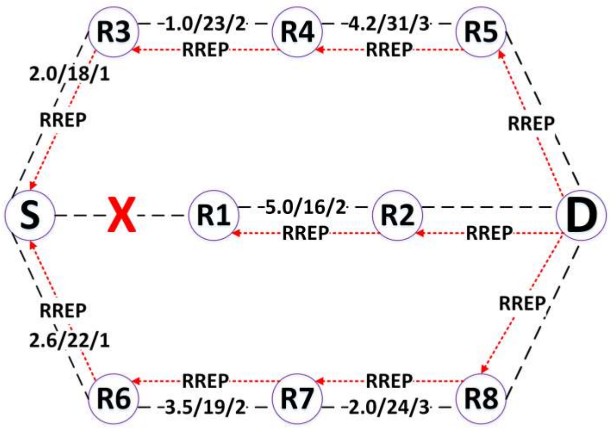

FIGURE 2. Route Reply (RREP).

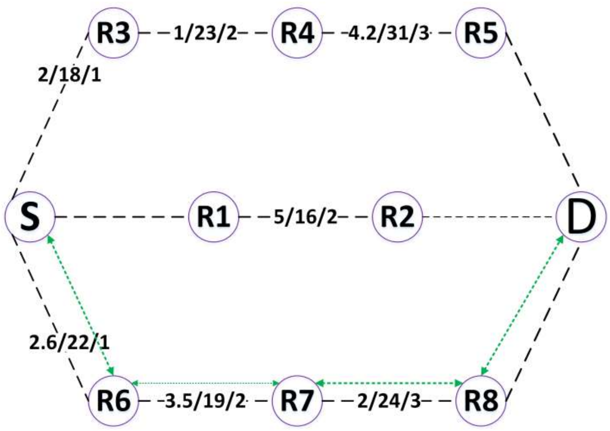

FIGURE 3. Active Route.

Algorithm-1 further elaborates and justify the route discovery phase.

B. ROUTE MAINTENANCE PHASE (RDP)

Figure. 4 describes the route maintenance process of the proposed scheme where an active route at any time during packet transmission might be inactive due to varying reasons such as the existence of hotspot node, energy deficit node. In such a case, a route error (RERR) packet is broadcasted to inform upstream nodes. However, the source node upon receiving RERR packet, broadcast RREQ packet for finding an alternative route.

IV. SIMULATION AND RESULTS DISCUSSION

We used network simulator NS-2 to simulate our proposed scheme. The Proposed scheme is compared with two well-known protocols of WBSNs, TARA and HPR. Simulation results of the proposed and compared schemes are based on the metrics of packet delivery ratio, average end-to-end delay, throughput, average temperature rise, network lifetime, and normalized routing load. Simulation parameters are mentioned in table-1.

Algorithm 1 Thermal and Energy Aware Route Discovery

BEGIN
Initialize Route Discovery
// Whether this is the route (meeting requirements) to destination
If (such route exist) **then**
  forward data packets
else
  call procedure RREQ_PROC
end if
____
procedure RREQ_PROC
  Initialize RREQ Packets $\{RREQ_{\text{Energy}}\}$
  RREQ ← Network Diameter
  Set E_{thresh} ← Energy threshold
  Set $Node_{curr}$ ← This_Node
  Set $Node_{prev}$ ← ∅
  Broadcast RREQ packets to downstream nodes
  $Node_{prev} \leftarrow Node_{curr}$
  $Node_{curr}$ ← This_Node
  Evaluate Current Status of this_node energy level
  if $Energy_{this-node} < E_{thresh}$ **then**
    Discard RREQ Packet
    Terminate
  end if
  if $Node_{this-node} = DestinationNode$ **then**
    call procedure RREP_PROC
  end if
end proc
____
procedure RREP_PROC
  Initialize RREP Packet
  $RREP_{\text{Temp}} \leftarrow \emptyset$, $RREP_{\text{Energy}} \leftarrow \emptyset$, $RREP_{\text{LDE}} \leftarrow \emptyset$,
  Unicast RREP packet to upstream nodes
  $Node_{prev} \leftarrow Node_{curr}$
  $Node_{curr}$ ← This_Node
  Evaluate Temperature of Nodes in Network Diameter at time t

$$T^{t}(x,y) = \left(1 - \frac{\Delta_t b}{\rho Cp} - \frac{4\Delta_t K}{\rho C_p \Delta^2}\right) T^{t-1}(x,y) + \frac{\nabla^t}{C_p} SAR + \frac{\Delta_t b}{\rho Cp} T_b + \frac{\Delta}{\rho C_p} P_c + \frac{\Delta_t K}{\rho C_p \Delta^2} (T^{t-1}(x+1,y) + T^{t-1}(x,y+1) + T^{t-1}(x-1,y) + T^{t-1}(x,y-1))$$

  Where x, y are neighboring nodes
  if $T(x,y)_{Node-prev} > T_{thresh}$ **then**
    $T(x,y)_{Node-prev} \leftarrow Hotspot\_Node$
    Suspend this node for predetermined time period
    Discard $RREP_{node-prev}$
  end if
  if $Node_{curr} = SourceNode$ **then**
    Compute Route Cost from the Received RREP Packets
  Route_Cost $= w1\,x\,RREP_{T(x,y)} + w2\,x\,RREP_{Energ} + w3\,x\,RREP_{LDE}$
    if $Route\_Cost_{curr} < Route\_Cost_{prev}$ **then**
    Update $Route\_Cost_{curr}$ for the route in cache
  end if
    Update $RREP_{T(x,y)}, RREP_{energy}, RREP_{LDE}$
end procedure RREP_PROC
END

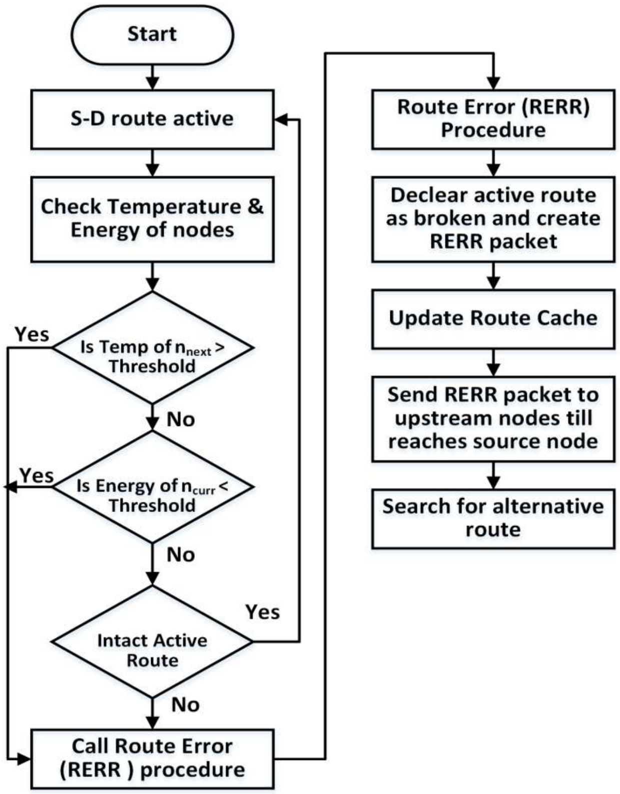

FIGURE 4. Route Maintenance Scheme.

TABLE 1. Simulation parameters.

Parameters	Values
Area	2m x 2m
No: of Relay nodes	12
No: of Sensor nodes	3
No: of Sink node	1
Transmission range of relay nodes	50 cm
Propagation model	TwoRayGround
Network interface type	WirelessPhy
Traffic type	CBR
IEEE 802.15.4 standard	Default values
Simulation time	1000 seconds
Temperature threshold	5 °C
Initial energy	50 J
Energy threshold	20% of initial energy

Figure 5 describes the packet delivery ratio against varying data rate. Although packet delivery ratio of proposed and compared scheme decreases with increasing data rate but WETRP delivers packets at higher rate as TARA's withdrawn policy keep packets in buffer most of the time unless temperature of node drops down or buffered packet exceeds its time constraints, while HPR remain busy in finding coolest neighbors in the network to route packets, moreover every node in HPR maintains a small list of most recently visited node in order to forward packets towards coolest and unvisited node, therefore, results in a decrease packet delivery ratio.

Fig. 6 shows the average end-to-end delay at various loads. End-to-end delay is an average time taken by all the packets

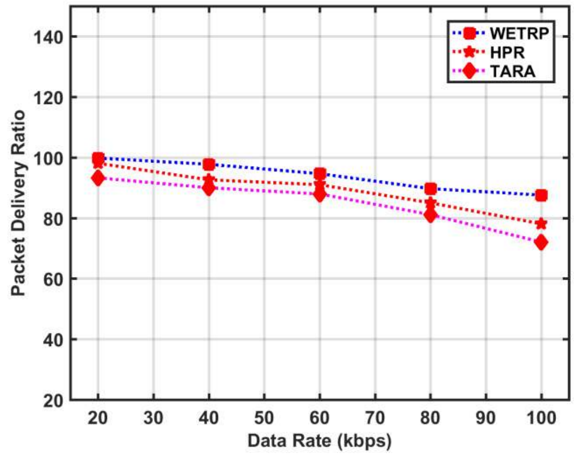

FIGURE 5. Data rate vs Packet Delivery Ratio (PDR) analysis.

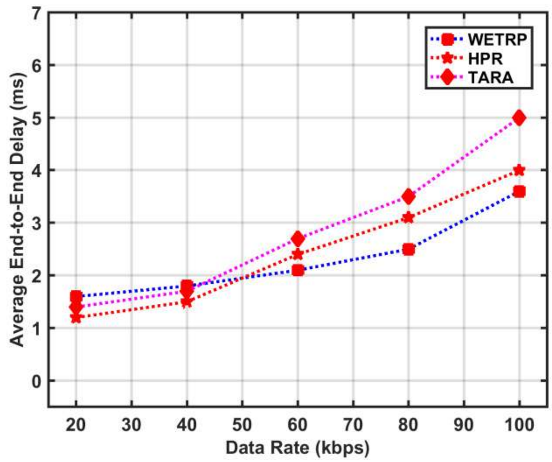

FIGURE 6. Data rate vs Average End-to-End delay analysis.

to reach the destination node. WETRP's average delay is significantly lower than TARA and HPR as proposed scheme considers the least delay routes in contrast to shortest hop routing.

Fig. 7 describes the result in terms of throughput at varying network loads. It is observed that when the data rate is increased throughput also increases because more data packets are provided to the network, however, when data rate reaches at (100 Kbps) throughput starts declining as network load strains wireless links.

Fig. 8 demonstrates the average temperature rise of the relay nodes at various data rates. It is observed that the temperature of relay nodes increases with the increasing data rate, this is due to the fact that each forwarded packet results in temperature rise, and ultimately it results in the creation of frequent hotspot nodes. WETRP being energy and temperature aware exhibits less temperature rise even at high data rate compared to TARA and HPR. The temperature rise in TARA is very high due to a large number of retransmissions. HPR, on the other hand, consume most of its energy in finding coolest nodes. Hence packet distribution is not even across the

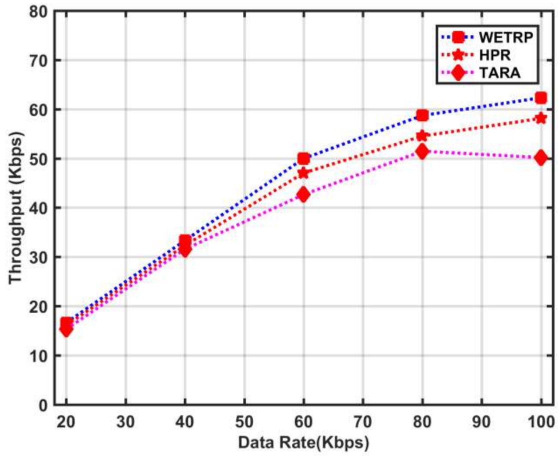

FIGURE 7. Data rate vs Average Throughput (kbps) analysis.

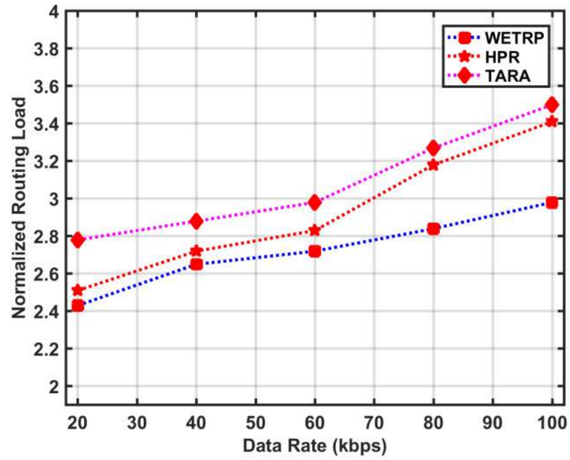

FIGURE 9. Data rate vs Normalized Routing Load analysis.

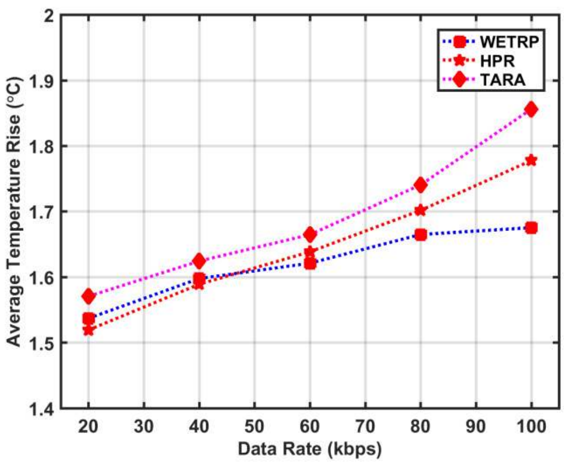

FIGURE 8. Data rate vs Average temperature rise analysis.

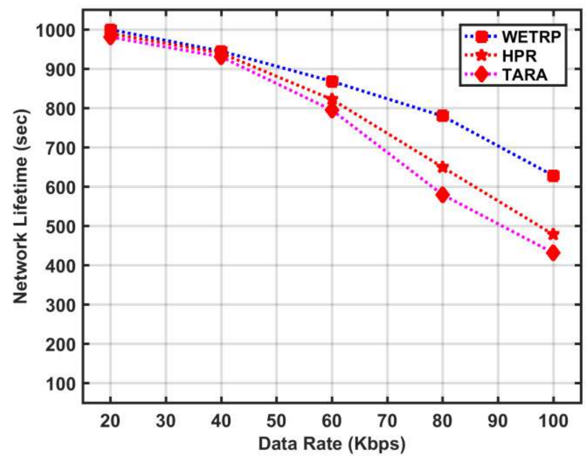

FIGURE 10. Data rate vs Network Lifetime analysis.

network. Therefore, nodes deplete their energy more quickly, consequently leading to an average temperature rise across the network.

Fig. 9 shows the routing load between WETRP and other compared schemes. Normalized routing load is basically a ratio between transmitted control packets and received data packets. The result demonstrates that the routing load of WETRP is significantly low as compared to other schemes as routes are more stable.

Fig. 10 depicts the network's lifetime performance of WETRP and existing schemes. Network lifetime depends on the network resource. Better utilization of resource maximizes the network lifetime. WETRP outperforms other schemes in term of network lifetime as TARA and HPR focus on avoiding hotspot node and finding coolest neighbor respectively, which results in inefficient utilization of precious resources, hence network node depletes their energy more quickly. On the other hand, WETRP is thermal and energy-aware scheme which makes an informed decision regarding temperature and energy, therefore, assigns equal weight to both temperature and energy, therefore, maximizes network lifetime.

V. CONCLUSION

In this work, we proposed a thermal and energy aware routing protocol (WETRP) which addresses the problems faced by the existing thermal-aware routing protocols for wireless body Sensor networks (WBSNs), in pursuit of efficient network resource utilization, which is essential for network lifetime, overall throughput and route stability. Incorporating energy awareness and link-delay estimation with thermal-aware protocol exhibits a reduced number of hotspots in the network and improved network lifetime against state of the art schemes. Furthermore, assigning equal weights to temperature, energy and LDE distributes network load equally among the nodes. We compared the proposed WETRP protocol with two famous body Sensor network routing protocols TARA and HPR by varying data rate between 20 Kbps to 100 Kbps. It is observed from the results that WETRP evenly distributes network load among all the relay nodes even at high traffic load which results in a reduced number of hotspots as compared to TARA and HPR. We observed significant improvement in terms of network lifetime, throughput, normalized routing load, packet delivery ratio and average temperature rise. In the future, this work can be customized to deal with the issues raised due to postural body movement. Moreover, packet-level priority can be integrated in the proposed scheme so that critical data packets may be differentiated from the normal data packets, so that critical data packets may be routed on priority basis.

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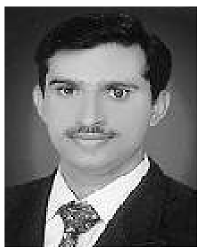

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