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A guide for the selection of routing protocols in WBAN for healthcare applications

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Abstract

In the present scenario, the term wireless body area network (WBAN) is becoming an integral part of human day to day life due its wide variety of applications, especially in the field of healthcare systems. To design such a reliable body area network system, there are a number of factors to be considered both in hardware and software levels. One of such factors still developing is the design and the analysis of routing protocols in the network layer. Routing protocols are a set of protocols which can identify and maintain the routes in the network so that the data can be exchanged between the nodes efficiently. Hence, routing protocol plays a vital role in the wireless sensor networks for reliable communication between the sensor nodes. In this paper, different routing protocols for body area networks are surveyed and observed that they are affected by factors like energy, network topology, various quality of services (QoS) in the nodes, node temperature, transmission range of nodes, human posture, etc. An evocative taxonomy of protocols is presented such as cluster-based, cross-layered, postural movement based, QoS aware and temperature-aware routing protocols. From the survey, it is found that the selection of a routing protocol is application dependent. For example, the energy efficient protocols like reinforcement learning based routing with QoS support or wireless autonomous spanning tree protocol can be used for daily health monitoring systems due to its high packet delivery ratio. If the system is for in vivo networks, routing algorithm for network of homogeneous and Id-less biomedical sensor nodes or mobility-supporting adaptive threshold-based Thermal-aware energy-efficient multi-hop protocols are the suitable ones. For critical and emergency cases, where accuracy with little delay is the major concern, the protocols like critical data routing, reliability aware routing, data-centric multi objective QoS-aware routing protocol, etc. can be rightly chosen. This entire survey paper can be used by the researchers as a reference for studying various WBAN routing protocols, especially in the field of medical health care systems.

Keywords: Quality of service, Routing protocols, Wireless body sensor networks

Introduction

Wireless body area networks (WBANs) include a collection of body sensor nodes that are low power, invasive or non-invasive, light-weight devices which are either worn on the body or implanted inside the body. The architecture of WBAN [1] can be considered as three different tiers, namely: Tier-1 as Intra-BAN, Tier-2 as Inter-BAN and Tier-3 as Extra-BAN as shown in Fig. 1. In Tier-1, the body sensor nodes collect the data and send to the coordinator. In Tier-2, the coordinator processes the received data and sends the

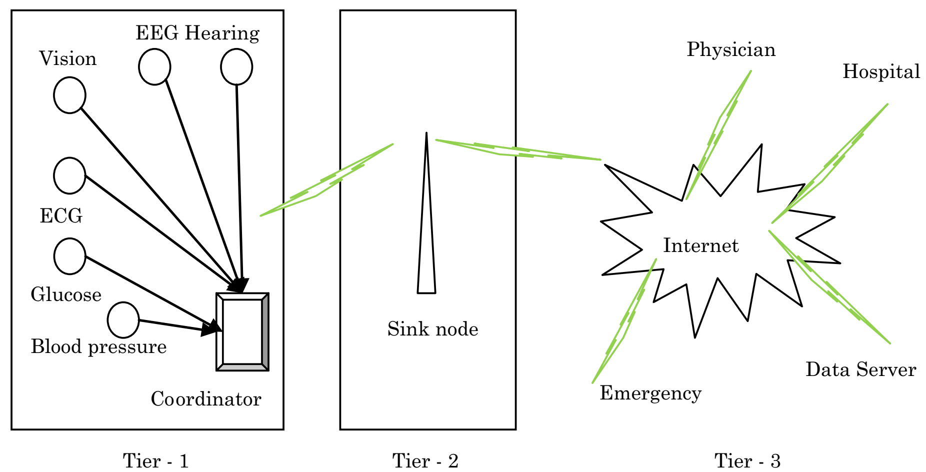

Fig. 1 Wireless body area network architecture

information towards the sink node. From the sink node the packets are transmitted to the corresponding health-center through internet or other communication techniques.

According to the survey conducted by the Economic and Social Affairs Department of United Secretariat [2], after 10 years people with age above 65 will be approximately 15% of total world population. As, older people are more exposed to medical health issues, the need for low cost health monitoring devices [3] becomes a major part human life.

WBAN is actually a subset of conventional wireless sensor networks (WSNs), which can be used for early detection of various diseases, for real-time patient monitoring of elderly people, etc. The body sensor node is either worn on the body surface or implanted inside the body. The sensed data is sent to the Base Station and is then forwarded to the sink node. The sink node is responsible for sending the information to its corresponding healthcare center.

The reliability and efficiency of WBAN depend on how the system responds quickly and accurately, to send and receive the data between the nodes, which eventually depends on the selected routing protocols or algorithms. The process of sending information from either an in-body or an on-body sensor node includes the radiation emitted from wireless transceivers which is similar to WSNs.

Although the routing protocols that are used in WSNs have been under study for past few years, these protocols cannot be used for WBANs due to its stringent requirements. For WSNs, the main focus is on minimal routing overhead and maximal throughput than reduced energy consumption [4]. Also, WSNs are mostly homogenous networks, the WBANs are heterogeneous too [5].

In this article, a comprehensive review of the existing recent routing protocols/algorithms is discussed. "The required evaluation metrics for healthcare applications" section discusses the performance metrics that should be considered for WBANs. The classification of the existing routing protocols is explained in "Classification of routing protocols" and "Future challenges and comparative analysis of routing protocols" sections gives the future challenges and a comparative analysis of different selected protocols. Finally, "Conclusions" concludes the survey.

The required evaluation metrics for healthcare applications

In order to identify the important metrics that have to be considered in WBANs during the design process, a general overview about the routing challenges in WBANs should be studied. The certain routing issues and challenges include network topology, postural body movements, limited resources, quality of service metrics, radiation and interference, global network lifetime, heterogeneous environment, etc. By analyzing all these factors we can conclude and list the important performance metrics to be considered while implementing the whole WBAN. The following section defines the metrics:

- *Network lifetime* defines the total operation time of the network until the last node is dead.
- *Path loss* is the difference between the transmitted power at the source node and received power at sink node.
- *Stability period* is the time before first node die.
- *Residual energy* is the difference between initial energy and used energy during the operation of the network.
- *End-to-end delay* is the average time taken by a data packet to reach the sink from the source node.
- *Packet delivery ratio* is determined by number packets obtained at the sink divided by the number of packets send from the source.

Classification of routing protocols

The classification of routing protocols can be done in different categories that correlate with the routing challenges of WBAN. The following section gives an overview about the existing protocols, which can be categorized as Cluster-based, Cross-layered, Postural movement based, quality of services (QoS) aware and Temperature-aware routing algorithms [6] as shown in Fig. 2.

Cluster-based routing protocols

In both WSNs and WBANs, the limited energy source is the main constraint to be analyzed. Hence, several efficient cluster based schemes are proposed for both networks to minimize the power consumption and maximize the network lifetime [7]. While comparing hybrid indirect transmission [8] to power-efficient gathering in sensor information systems [9] and low-energy adaptive clustering hierarchy (LEACH) [10], it consumes less amount of energy if the number of nodes are small. However, AnyBody [11] protocol is better than LEACH, as the numbers of clusters remain constant with an increase in the number of nodes, but LEACH does not. Also, the installation cost is also less with AnyBody. The Table 1 shows an overview of the existing cluster-based protocols.

Cross-layered routing protocols

These protocols use the concept of cross layering [13] which is already addressed in WSNs, where each layer (adjacent or non-adjacent) in the protocol stack shares their information unlike in the strict layered model. In WBANs, we can utilize the cross layering concept between network and medium access control (MAC) layers for routing and

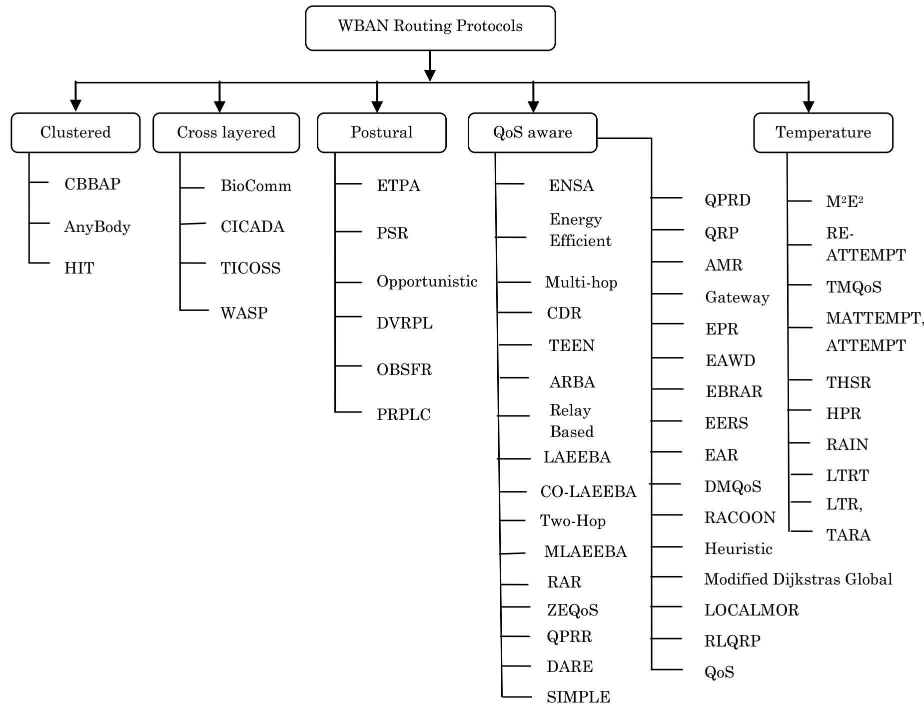

Fig. 2 Classification of routing protocols

Table 1 clustered routing protocols in body area networks

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
1	Cluster based body area protocol (CBBAP) [12]	To enhance the overall energy efficiency of WBAN	Throughput, residual energy, number of live nodes	LEACH
2	AnyBody protocol [11]	To divide the network into clusters and to efficiently send packets from source to sink	Number of clusters, average cluster size, number of transmitted messages to setup	LEACH
3	Hybrid indirect transmission (HIT) [8]	To maintain longer network life	Network longevity, network delay, average energy dissipation, average energy dissipation × average delay product	LEACH, PEGASIS, direct

thereby can upgrade the overall network performance. Table 2 shows the different cross-layered routing protocols. Considering the detailed analysis of cross layered protocols, Cascading Information retrieval by controlling access with distributed slot assignment (CICADA) [14] and time zone coordinated sleep scheduling [15] have less power consumption. Wireless autonomous spanning tree protocol (WASP) [16] has better packet delivery ratio and CICADA has less delay.

Postural movement based routing protocols

The body postural movements affect the network topology of the network, which results in link disconnection. The researchers introduced a cost function that is periodically

Table 2 Cross layered protocols in body area networks

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
1	Biocomm and Biocomm-D [17]	To optimize the overall performance of the in vivo network	Maximum temperature rise, average energy consumption, packet delivery delay, percentage of injected packets dropped, cumulative network throughput	Shortest hop routing, hotspot preventive routing
2	Cascading information retrieval by controlling access with distributed slot assignment (CICADA) [14]	To introduce less delay and low energy consumption	End to end delay	–
3	TImezone coordinated sleep scheduling (TICOSS) [15]	To improve 802.15.4 through the division of the network into time zones	Network lifetime	IEEE 802.15.4 without TICOSS
4	Wireless autonomous spanning tree protocol (WASP) [16]	To reduce power consumption, network delay and packet loss rate	End to end delay	CSMA with fixed routing

updated for choosing the best route to forward packets to the sink. The protocols listed in Table 3 are the existing postural movement based routing protocols. Among the discussed protocols, on-body store and flood routing (OBSFR) [18] has better performance in reducing the packet delivery delay, but opportunistic postural movement based routing protocol has lower energy consumption than others.

QoS aware routing protocols

Presently, there are a number of diverse QoS aware protocols available in WSNs, which cannot be as such implemented in WBANs, but by considering its unique curbs it can. In WBANs different data types require different QoS [24]. Hence the proposed protocols should be aware of different types of QoS metrics for various types of data. The various QoS aware routing protocols are shortlisted as given in Table 4.

The comparative analysis has shown that energy-aware peering routing protocol (EPR) [45], QoS-aware peering routing protocol for delay sensitive data (QPRD) [41] and QoS aware peering routing protocol for reliability sensitive data (QPRR) [38] have less power consumption when compared to other protocols. Some protocols do not consider energy consumption, while others. One of the most used QoS aware protocols is data-centric multi objective QoS-aware routing protocol (DMQoS) [50] because it can decrease the delay for delay-sensitive information, and similarly, it can provide reliable routing for reliable-sensitive information. The other QoS-aware protocols are used or selected for a particular network, according to the data type and its QoS requirements.

Temperature-aware routing protocols

The antenna radiation, its absorption and interference are the major challenges to be considered while designing a body sensor network, since the radiated fields cause a temperature rise of node's electronic circuitry. The field of radiation also has a strong

Table 3 Postural routing protocols in body area networks

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
1	Energy efficient thermal and power aware routing (ETPA) [19]	To reduce the node's temperature and to prevent the hotspot formation	Packet hop count, packet delivery ratio, packet delay, average temperature rise of nodes in the network, scalability, depletion time of the first node mobility	PRPLC
2	Prediction based secure and reliable routing framework (PSR) [20]	To provide secure and reliable routing from various data attacks	Packet dropping rate, authentication cost	Backbone protocol
3	Opportunistic routing [21]	To increase the network lifetime from the motion of body parts	Average energy consumption per bit	Single hop, multi hop
4	Distance vector routing with postural link costs (DVRPLC) [22]	To decrease end to end delay	Average delay, packet delivery ratio, packet hop count	Probabilistic protocol (PROPHET), opportunistic protocol, UTILITY
5	On-body store and flood routing (OBSFR) [18]	To provide better routing delay and hop count	End-to-end packet delay (PD), number of transmissions per packet (NTPP), packet delivery ratio (PDR)	PROPHET, on-body store and flood routing (OBSFR)
6	Probabilistic routing with postural link costs (PRPLC) [23]	To reduce end to end delay	Average delay, packet delivery ratio	PROPHET, OBSFR

impact on the human body [57] that may damage the human tissues due to its continuous exposure. The goal of all temperature-aware protocols is to decrease the temperature rise of in-body sensor nodes by avoiding routing through hotspots. Table 5 discusses the existing temperature-aware protocols. From the comparison of different protocols, it is seen that LTRT [58] performs much better than others while TARA [59] performs worst. In terms of temperature rise, HPR [60] shows less temperature rise in comparison with others. Finally, the latest M^2E^2 protocol [61] has proved that it is the best one among all thermal aware protocols, suitable for heterogeneous, multimode, energy efficient body sensor networks.

Future challenges and comparative analysis of routing protocols

The scope of this article is to open up new research areas in WBAN domain for routing protocol designs. Among all the routing protocols, the cluster based protocol HIT [8] aims at maximizing the network lifetime, but it does not consider the packet delivery ratio which is an important QoS metric. The second one, AnyBody [11] protocol considers the delivery ratio, but does not consider average delay, mobility and energy consumption. It leads to poor security measures. In order to optimize the performance of sensor networks for some specific applications, it is necessary to include the aforementioned metrics also in the design considerations.

The cross layered concept is attaining great significance and interest among researchers due to its flexibility and effectiveness in sensor networks. The future research work aims at improving the reliability of CICADA [14] which performs better in terms of energy efficiency and average delay when compared to other cross layered protocols.

Table 4 QoS aware routing protocols in body area networks

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
1	Efficient next hop selection algorithm (ENSA-BAN) [25]	To improve the overall QoS performance of the network using link cost function	Energy consumption, packets forwarded, end-to-end delay, packet delivery ratio	DMQoS
2	Energy efficient routing algorithm [26]	To maximize the working lifetime of the network	Coverage distance, residual energy, communication count node criticality	–
3	Multi-hop protocol using cost function [27]	To boost the network performance and lifetime by optimum residual energy and distance	Number of dead nodes, residual energy, data packets sent and received to sink, delay	Old energy aware multi-hop
4	Critical data routing (CDR) [28]	To forward the critical data packets with better reliability along with reduction in temperature rise of the in-body sensor nodes	Packet loss ratio, packet success ratio, on-time packet delivery ratio, energy consumption	TMQoS, LTRT
5	Threshold sensitive energy efficient sensor network protocol (TEEN) [29]	To monitor and record critical data of the patient's body parameters	Energy consumption, false acceptance rate, false rejection rate, time served	–
6	Adaptive routing and bandwidth allocation protocol (ARBA) [30]	To enhance bandwidth utilization and routing in BAN, better network lifetime	Residual energy, throughput	Optimal solution
7	Relay based routing protocol [31]	For network lifetime maximization and end-to-end-delay (E2ED) minimization	Remaining energy, no. of dead nodes, no. of dropped packets, packet arrival rate	Single-hop Multi-hop CH-rotate
8	Link-aware and energy efficient scheme for body area networks (LAEEBA) [32]	To route data with minimum path-loss over the link in WBAN	Stability period, residual energy, network lifetime, path-loss, delay spread, throughput	SIMPLE, M-ATTEMPT
9	Cooperative link-aware and energy efficient protocol for WBAN (Co-LAEEBA) [33]	To select better routing path with minimum path-loss in cooperative links in WBAN	Stability period, residual energy, path-loss, throughput	LAEEBA, SIMPLE, M-ATTEMPT
10	Two-hop transmission scheme [34]	To extend network lifetime and to improve the network stability of WBAN	Average residual energy, number of packets per priority level, total energy, number of dead nodes	Direct transmission, TPDS
11	Modified LAEEBA: link aware and energy efficient scheme for BAN (MLEEBA) [35]	To upgrade the LEEBA protocol by increasing throughput and decreasing delay	PDR, end to end delay, throughput	LEEBA
12	Reliability aware routing (RAR) [36]	To enhance reliability for reliability constraint data packets	Packet loss ratio, average PDR, average energy consumption	RAR with relay nodes, TMQoS
13	Zahoor energy and QoS-aware routing protocol (ZEQoS) [37]	To provide better QoS by selecting the best routing paths	Energy consumption, successful transmission rate, packets forwarded and received	DMQoS, NoRouting

Table 4 continued

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
14	QoS aware peering routing protocol for reliability sensitive data (QPRR) [38]	To enhance the reliable delivery of emergency BAN data for indoor hospital communication	Successful transmission rate, network traffic load, overall energy consumption, latency	DMQos, NoRouting
15	Distance aware relaying energy efficient protocol (DARE) [39]	To achieve better network lifetime for monitoring patients in multi-hop body area networks	Residual energy, PDR, number of packets sent to sink	M-ATTEMPT
16	Stable increased-throughput multi-hop protocol for link efficiency (SIMPLE) [40]	To boost the network stability period and packet delivered to sink	Network lifetime, stability period, throughput, residual energy, path loss	ATTEMPT
17	QoS-aware peering routing protocol for delay sensitive data (QPRD) [41]	To lessen the end to end delay	Traffic load, successful transmission rate, number of packets timeout	DMQoS
18	Q-learning based routing protocol (QRP) [42]	To design a power efficient and reduced hop count body sensor networks	Residual energy, average hop count	PSR, EBRAR
19	Adaptive multihop tree-based routing (AMR) protocol [43]	To assess several node and network parameters in order to enhance network performance using fuzzy logic	Network lifetime, PDR, normalized residual energy	Shortest path tree, received signal strength indicator, battery
20	Gateway selection algorithm [44]	To adaptively select the gateway node for balancing the load among the nodes	Network lifetime	No energy and independent energy harvesting device
21	Energy-aware peering routing protocol (EPR) [45]	To enhance BAN reliability and to reduce network traffic and power consumption	Traffic load, energy consumed and saved, buffer overflow, packets forwarded and received	DMQoS
22	Energy-aware topology design (EAWD) [46]	To reduce the total energy consumption and installation cost by wireless sensors and relays	Total energy consumed, installation cost	–
23	Energy-balanced rate assignment and routing protocol (EBRAR) [47]	To lessen the total energy consumed in the network at the expense of high network utility, adaptive resource allocation	Normalized residual energy, routing tree size	EBRAR-SP, EBRAR-PD, EBRAR-PE
24	Energy-efficient routing scheme (EERS) [48]	To provide adaptive transmission power for sensor nodes, establish an energy-efficient path	Packet reception ratio, average hop count, collection delay, average number of transmissions per packet, energy consumption per packet, per hop, overhead	Collection tree protocol (CTP)
25	Modified Dijkstra's global routing algorithm [49]	To yield better network lifetime in WBAN	Network lifetime ratio, energy per bit ratio	Opportunistic routing, transmit power adaptation, min. energy packet forwarding, use of dedicated relays

Table 4 continued

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
26	Data-centric multi objective QoS-aware routing protocol (DMQoS) [50]	To achieve best QoS services for different data types	Average end-to-end delay, on-PDR, average energy consumption per packet, operation energy overhead	MMSPEED LOCALMOR DARA
27	Random contention-based resource allocation protocol (RACOON) [51]	To provide better the quality of service for multi-user mobile wireless body area networks	Packet latency, power consumption, packet collision, user capacity	BodyQoS
28	Heuristic adaptive routing algorithm [52]	To make multi-hop WBAN energy efficient	Lifetime, standard deviation of remaining power, average end to end delay, packet loss	Optimal scheme
29	Environment-adaptive routing algorithm (EAR) [53]	To achieve better network lifetime and reliable communication for heterogeneous networks	Number of alive nodes, amount of collected data in the coordinator	Hop-count based method, energy-base method
30	Localized multi-objective routing protocol (LOCALMOR) [54]	To consider the traffic diversity typical for biomedical applications and to provide a differentiation routing for different quality of service (QoS) metrics	Packet reception ratio, end to end delay, packets receiving within deadline	SPEED, MMSPEED, GFW, EAGFS
31	Reinforcement learning based routing with QoS support (RL-QRP) protocol [55]	To attain desirable QoS in respect of throughput and end to end delay	Average end to end delay, average PDR, node mobility, network traffic load	QoS-AODV
32	QoS aware routing service	To provide service with prioritized routing, user specific QoS	End to end delay, packet delivery ratio	–

Table 5 Temperature aware routing protocols in body area networks

Sl. no.	Protocol [ref. no.]	Goal	Performance metrics	Compared with
1	M^2E^2 protocol [61]	To reduce energy consumption and increase life time, to reduce link hotspot network in heterogeneous WBSNs	Packets sent to BS, number of dead nodes, total energy of network, number of cluster head	M-ATTEMPT
2	Reliability enhanced-adaptive threshold based thermal unaware energy-efficient multi-hop protocol (RE-ATTEMPT) [62]	To maximize the network lifetime and to remove the deficiencies of ATTEMPT protocol	Average rate of dead nodes, number of packets sent to sink, packets dropped and throughput	ATTEMPT
3	Thermal-aware multi constrained intra body QoS routing protocol (TMQoS) [63]	To ensure the required QoS demands along with maintaining the temperature of each node to a desirable level	Energy efficiency, average temperature rise, delay reliability, maximum temperature rise, packets meeting deadline	LTRT, TARA
4	Mobility-supporting adaptive threshold-based thermal-aware energy-efficient multi-hop protocol (M-ATTEMPT), ATTEMPT [64]	To sense the link hot-spot, to forward the data away from such links	Number of dead nodes, throughput, number of cluster heads per round, total energy of network	Multi-hop
5	Thermal-aware shortest hop routing algorithm (THSR) [65]	To reduce the node's temperature and to prevent the formation of hotspot	Maximum temperature rise, average delay, packets dropped	LTR, SHR, HPR, TARA
6	Hotspot preventing routing (HPR) algorithm [60]	To prevent the formation of hotspots and to reduce the average packet delivery delay	Maximum temperature rise of any node, average packet delivery delay, total number of packets dropped	TARA, SHR
7	Routing algorithm for network of homogeneous and Id-less biomedical sensor nodes (RAIN) [66]	To be used in an in vivo network of homogeneous and id-less biomedical sensor nodes	Maximum temperature rise of nodes, average energy consumption per node, percentage packet delivery, average packet delivery delay	Controlled-FLOOD
8	Least total-route temperature routing protocol (LTRT) [58]	To reduce temperature caused by biomedical sensors implanted in human bodies	Average temperature rise and hop count per arrival packet	LTR, ALTR
9	Least temperature routing protocol (LTR), adaptive least temperature routing protocol (ALTR) [67]	To reduce the amount of heat produced in the network	Average temperature rise, delay, power consumption, packets dropped, lifetime of networks	TARA, SHR
10	Thermal-aware routing algorithm (TARA) [59]	To estimate the temperature variation of neighbor nodes and direct packets nearby the hotspot region	Maximum temperature rise, average temperature rise, delay performance	Shortest hop

When IEEE 802.15.4 standard networks are used, it will be good if the TICOSS [15] protocol is redesigned for reducing the average delay which is not considered in the existing one. If the entire network performance is to be optimized, the choice will be the Biocomm protocols along with new techniques to reduce the node temperature. Hence, the scope for research in this area is very much wide enough to work with. The comparative analysis of postural movement protocols has shown that, none of them considered the thermal effects of nodes and QoS issues together. Therefore, the future protocols could be proposed in such a way that, it could achieve better QoS parameters along with techniques to reduce the node temperature rise and methods to counter security attacks. The survey on QoS aware protocols unveils various research areas for future work because of its importance. Every new protocol, which has been designed, is meant for addressing the limitation of the previous one. For example, in routing service framework [56] and reinforcement learning based routing with QoS support [55] the energy consumption is not considered, but it is taken into account in the remaining protocols.

In almost, all the existing QoS aware protocols, only the QoS metrics are examined, without concentrating on the human body movements and temperature rise of implanted devices. The proposed temperature aware protocols perform better by reducing the temperature rise due to radiation from antenna and other node circuitry. Along with the thermal issue and power consumption, it will be better if these protocols can also address the routing issues like shortest path as in QoS aware.

Table 6 summarizes the comparison between some of the routing protocols used in WBAN. From the analysis, it is seen that almost all the protocols have considered different QoS metrics for their performance analysis. Hence, choosing the protocol for a WBAN system depends on the particular application of the system; whether it should be energy efficient, good reliable one or it should reduce the temperature of the node circuitry. Table 7 lists the pros and cons and the application domain of each protocols used in body area networks. This table helps to choose a particular protocol based on the QoS requirements. For example, if the application of the proposed system is patient monitoring in hospitals, then the protocols like WASP [16] or TICOSS [15] can be selected due to its high packet delivery ratio and low average delay. If the sensors are implanted within the body, then the protocols like Co-LEEBA [33], TARA [59], or routing algorithm for network of homogeneous and Id-less biomedical sensor nodes (RAIN) [66] can be chosen. If the network is heterogeneous one, then M-ATTEMPT or M^2E^2 can be used.

Conclusions

Wireless body area network is a part of wireless sensor network, with a number of nodes deployed within and on the surface of human body to measure different biological parameters for a particular application. In this survey article, various existing routing protocols that are used in WBANs are categorized and briefly analyzed from the available articles between the years 2002–2016. It is seen that the routing protocol plays a vital role in the design process of every efficient, reliable, low cost wireless

Table 6 Comparative analysis of routing protocols

Sl. no.	Routing protocol	Type of protocol	Average delay	Energy consumption	Packet delivery ratio	Average temperature rise
1	HIT [8]	Clustered	Very Low	Low	*	*
2	AnyBody [11]	Clustered	*	*	Very high	*
3	WASP [16]	Cross-layered	Low	Low	Very high	*
4	CICADA [14]	Cross-layered	Low	Low	*	*
5	TICOSS [15]	Cross-layered	*	Low	High	*
6	Routing service framework [56]	QoS-aware	*	*	Moderate	*
7	RL-QRP [55]	QoS-aware	High	*	High	*
8	ZEQoS [37]	QoS-aware	*	High	High	*
9	RL-QRP [55]	QoS-aware	Low	Low	High	*
10	ENSA-BAN [25]	QoS-aware	Very low	Low	Very high	*
11	Co-LEEBA [33]	QoS-aware	*	Low	High	*
12	DMQoS [50]	QoS-aware	Low	Moderate	High	*
13	LOCALMOR [54]	QoS-aware	Low	Low	High	*
14	TARA [59]	Temperature-aware	Very High	High	Low	Low
15	LTRT [58]	Temperature-aware	*	*	Very high	Low
16	RAIN [66]	Temperature-aware	Moderate	Low	High	Low
17	M-ATTEMPT [64]	Temperature-aware	Low	Low	High	Low
18	M^2E^2 [61]	Temperature-aware	Low	Very low	Very high	Low
19	TMQoS [63]	Temperature-aware	Very low	Very low	High	Moderate
20	ETPA [19]	Postural	High	Low	High	Low
21	PSR [20]	Postural	Low	High	Moderate	*

* Not applicable

body sensor networks. Based on the structure and nature of networks, the routing protocols for WBANs are categorized as cluster-based, cross-layered, postural movement based QoS aware and temperature-aware protocols. It is observed that there is no strict classification of protocols is possible since most of them aims or results in achieving the challenges of sensor networks. It is also concluded that each protocol is application dependent, i.e., the protocols used for daily monitoring and the critical medical cases are different. The future directions for each group of protocols are also presented which helps the researchers to focus on their interested area. Also, a comparative study of different protocols has been examined so that an appropriate protocol can be selected according to the targeted application. This survey will benefit the researchers to study the existing routing protocols for WBANs in the field of healthcare systems.

The Future work includes the design and implementation of a body sensor prototype with a newly designed routing protocol, which will be highly energy efficient and reliable one for rehabilitation of old age people using a microcontroller based system with suitable sensors.

Table 7 Pros and cons and the application domain of routing protocols

Sl. no.	Routing protocol	Pros	Cons	Application domain
1	HIT [8]	Requires only 25% of the time required by PEGASIS and LEACH for data collection, network longevity is 1.05 and 1.44 times that of PEGASIS and LEACH respectively	Not mentioned for a specific medical application, the terms security, fault-tolerance and reliability of the network need to be addressed	Micro sensor networks, bio medical sensing like EEG and EMG signals, bio electric computer interfaces
2	AnyBody [11]	A self-organizing protocol, maintains constant number of clusters with increasing number of nodes. PDR is approximately 100%	The metrics like network delay and energy consumption are not analyzed. Hence cannot considered for critical medical applications	Periodic patient monitoring in hospitals
3	WASP [16]	Minimizes the coordination overhead, throughput obtained is 94%. It can minimize the delay by reducing the number of levels in the spanning tree and also the energy consumption	Mobility is not supported, hence cannot be used for dynamic sensor network applications	For indoor hospital patient monitoring
4	CICADA [14]	Enhanced mobility is supported, generation of the scheme is easier, end to end delay is about 110 ms, nodes wake up only to transmit and receive data, hence dissipation of energy is minimized	It does not support traffic from the sink to the nodes	For sensors where computational resources are scarce
5	TICOSS [15]	Doubles the network lifetime for high traffic scenarios, PDR is higher than 92%. Lifetime of 4 min per Joule for TICOSS with 802.15.4 and 2 min per Joule with 802.15.4 alone, saves energy due to timezone coordinated sleeping mechanism	Not suitable for delay tolerant networks and also it is not an application specific protocol	Continuous vital sign monitoring, for ambient sensor nodes placed throughout a site
6	Routing service FRAMEWORK [56]	Provides prioritized routing service, user specific QoS support for small scale networks	Not considered energy consumption, which is one of the major constraints of sensor networks	Dynamic, small scale wireless body area networks
7	RL-QRP [55]	Uses independent distributed reinforcement learning approach for QoS route calculation, PDR above 90%	Average delay is higher (above 200 ms), energy consumption is not considered, not sufficient for global optimization in large scale networks	Dynamic, small scale wireless body area networks
8	ZEQoS [37]	Suitable and effective for all data types like ordinary, delay and reliability sensitive packets, 84% consistent throughput	No considerable improvement in terms of energy consumption	Hospital BAN communication
9	RL-QRP [55]	Fits well in dynamic environments using optimal routing policy. Good performance during heavy traffic conditions, average delay is less than 200 ms	Not suitable for large scale networks like multi agent systems	Dynamic bio-medical sensor networks

Table 7 continued

Sl. no.	Routing protocol	Pros	Cons	Application domain
10	ENSA-BAN [25]	Along with all QoS requirements, it considers the energy consumption of nodes to improve the network performance. Approx. 96% PDR compared to DMQoS can be achieved, average delay is less than 16 ms	Although it is a QoS aware routing protocol, the body movement is not considered	Continuous patient monitoring sensor networks
11	Co-LEEBA [33]	It is a link aware routing protocol. Path loss is reduced due to the use of different path loss models. With the discontinuous data transmission, it provides better life time. It maximizes the throughput to 36 Mbps compared to other protocols with a throughput of average 2 Mbps	Maximizes the throughput at the cost of increased delay	Implanted sensors, monitoring of aged people
12	DMQoS [50]	Uses modular architecture for delay critical and reliability critical packets, end to end delay is less than 120 ms when compared to other QoS aware protocols of 260 ms. PDR is above 92% for varying traffic flows	The estimation of several tuning parameters is not analytical. They are fixed through different simulation experiments	Resource-constrained body area networks
13	LOCALMOR [54]	This routing algorithm can be used along with any MAC protocol with ACK mechanism, considered the diversity of data traffic like regular, delay- sensitive, reliability-sensitive and critical traffic, end to end delay is less than 200 ms, Packet reception ration is above 85%	Scalability of the protocol with higher number of sensor nodes should be investigated	Diverse traffic biomedical applications
14	TARA [59]	Handles data transmission in the presence of temperature hot spots, routes packets through low temperature area, has load balancing capability, smaller average temperature rise	Higher packet loss due to larger delay (greater than 400 ms), unique hardware ids for nodes hence this algorithm fails to operate in id-less sensor nodes, homogeneous and not emergency supported	Implanted sensor networks and applications like retinal prosthesis and cancer detection
15	LTRT [58]	Optimization of routing is accomplished, very high packet delivery ratio, which is close to 100%, Smaller average temperature rise	The analysis is done only on the average temperature rise and packet loss rate	Implanted bio -medical networks, cardiac patient monitoring applications

Table 7 continued

Sl. no.	Routing protocol	Pros	Cons	Application domain
16	RAIN [66]	Routes the data efficiently towards the sink in an id-less biomedical sensor networks, prevents the formation of high temperature zones in the network, maximum temperature rise increases slowly than CFLOOD protocol, PDR is greater than 90%, the average energy consumption is less than 1000 energy units compared to 3000 units of CFLOOD	Average packet delivery delay is slightly higher than CFLOOD protocol, PDR is slightly lower than CFLOOD protocol	In-vivo network of homogeneous and id-less biomedical sensor nodes
17	M-ATTEMPT [64]	Mobility supported, greater network lifetime (29.5%), better stability period (greater than 20%) and 29% better results for successfully received packets when compared to multihop communication, energy efficient and emergency supported	A moving node needs a new parent and the new parent may refuse this request, analysis of average/maximum temperature rise is not included	Heterogeneous and homogeneous wireless body area networks
18	M^2E^2 [61]	Mobility and multi-mode supported, energy efficient and emergency supported, throughput is above 100Mbps when compared to 50 Mbps of M-ATTEMPT	Requires more hardware than the other protocols	Heterogeneous wireless body sensor networks
19	TMQoS [63]	Table-driven protocol with high network lifetime, low end to end delay which is less than 130 ms, above 85% reliability, can meet the QoS demands along with maintaining the temperature of the nodes to an acceptable level, uses a hotspot avoidance mechanism	Average temperature rise is higher in order to meet the desired QoS demands	In-vivo wireless body area networks
20	ETPA [19]	Mobility supported, It solves the link disconnection problem due to body movements along with a reduction in temperature rise, PDR is up to 95%	The average delay is slightly higher than PRPLC in order to balance the temperature rise in the network	Wireless body area network with long lasting communication and scarce resources
21	PSR [20]	It provides reliable and secure communication against data injection attacks, PDR up to 80%, shorter routing delay	Uses ACK techniques for measuring link quality and if the number of ACKs is large, it may consume a lot of network resources, as a whole, network lifetime is less	Reliable and secure wireless body area networks

Abbreviations

WBAN: wireless body area network; QoS: quality of services; RL-QRP: reinforcement learning based routing with Qos support; WASP: wireless autonomous spanning tree protocol; RAIN: routing algorithm for network of homogeneous and Id-less biomedical sensor nodes; M-ATTEMPT: mobility-supporting adaptive threshold-based thermal-aware energy-efficient multi-hop protocols; CDR: critical data routing; RAR: reliability aware routing; DMQoS: data-centric multi objective QoS-aware routing protocol; LEACH: low-energy adaptive clustering hierarchy; CBBAP: cluster based body area protocol; HIT: hybrid indirect transmission; PEGASIS: power-efficient gathering in sensor information systems; MAC: medium access control; CICADA: cascading information retrieval by controlling access with distributed slot assignment; TICOSS: time zone coordinated sleep scheduling; OBSFR: on-body store and flood routing; ETPA: energy efficient thermal and power aware routing; PSR: prediction based secure and reliable routing framework; DVRPLC: distance vector routing with postural link costs; PRPLC: probabilistic routing with postural link costs; ENSA-BAN: efficient next hop selection algorithm; TEEN: threshold sensitive energy efficient sensor network protocol; ARBA: adaptive routing and bandwidth allocation protocol; LAEEBA: link-aware and energy efficient scheme for body area networks; Co-LAEEBA: cooperative link-aware and energy efficient protocol for WBAN; MLEEBA: modified LAEEBA: link aware and energy efficient scheme for BAN; ZEQoS: Zahoor energy and QoS-aware routing protocol; QPRR: QoS aware peering routing protocol for reliability sensitive data; DARE: distance aware relaying energy efficient protocol; SIMPLE: stable increased-throughput multi-hop protocol for link efficiency; QPRD: QoS-aware peering routing protocol for delay sensitive data; QRP: Q-learning based routing protocol; AMR: adaptive multihop tree-based routing; EPR: energy-aware peering routing protocol; EAWD: energy-aware topology design; EBRAR: energy-balanced rate assignment and routing protocol; EERS: energy-efficient routing scheme; MDGRA: modified Dijkstra's global routing algorithm [49]; RACOON: random contention-based resource allocation protocol; EAR: environment-adaptive routing algorithm; LOCALMOR: localized multi-objective routing protocol; RE-ATTEMPT: reliability enhanced-adaptive threshold based thermal unaware energy-efficient multi-hop protocol; TMQoS: thermal-aware multi constrained intra body QoS routing protocol; M-ATTEMPT: mobility-supporting adaptive threshold-based thermal-aware energy-efficient multi-hop protocol; THSR: thermal-aware shortest hop routing algorithm; HPR: hotspot preventing routing; LTRT: least total-route temperature routing protocol; LTR: least temperature routing protocol; ALTR: adaptive least temperature routing protocol; TARA: thermal-aware routing algorithm.

Authors' contributions

VB conducted the survey work, analyzed the schemes and drafted the manuscript. CPS participated in literature review and helped to draft the manuscript. Both authors read and approved the final manuscript.

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References

1. Movassaghi S, Abolhasan M, Lipman J, Smith D, Jamalipour A (2014) Wireless body area networks: a survey. IEEE Commun Surv Tutor 16(3):1658–1686. doi:10.1109/SURV.2013.121313.00064
2. United Nations (2013) World population prospects: the (2012) revision. https://esa.un.org/unpd/wpp/Publications/Files/WPP2012_Methodology.pdf. Accessed 13 June 2013
3. Chen C, Knoll A, Wichmann HE, Horsch A (2013) A review of three-layer wireless body sensor network systems in healthcare for continuous monitoring. J Mod Internet Things 2(3):24–34
4. Ullah S, Higgins H, Braem B, Latre B, Blondia C, Moerman I, Saleem S, Rahman Z, Kwak KS (2012) A comprehensive survey of wireless body area networks. J Med Syst 36:1065–1094. doi:10.1007/s10916-010-9571-3
5. Latre B, Braem B, Moerman I, Blondia C, Demeester P (2011) A survey on wireless body area networks. Wirel Netw 17(1):1–18. doi:10.1007/s11276-010-0252-4

6. Bangash J, Abdullah AH, Anisi MH, Khan AW (2014) A survey of routing protocols in wireless body sensor networks. Sensors 14(1):1322–1357. doi:10.3390/s140101322
7. Heinzelman WB, Chandrakasan AP, Balakrishnan H (2002) An application-specific protocol architecture for wireless microsensor networks. IEEE Trans Wirel Commun 1(4):660–670. doi:10.1109/TWC.2002.804190
8. Culpepper BJ, Dung L, Moh M (2004) Design and analysis of hybrid indirect transmissions (HIT) for data gathering in wireless micro sensor networks. ACM SIGMOBILE Mob Comput Commun Rev 8(1):61–83. doi:10.1145/980159.980169
9. Lindsey S, Raghavendra CS (2002) PEGASIS: power-efficient gathering in sensor information systems. Proceedings of the IEEE aerospace conference proceedings. Big Sky, Montana, pp 1125–1130
10. Heinzelman WR, Chandrakasan A, Balakrishnan H (2000) Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the IEEE proc. Hawaii int'l. conf. sys. sci, pp 1–10
11. Watteyne T, Augé-Blum I, Dohler M, Barthel D (2007) Anybody: a self-organization protocol for body area networks. In: Proceedings of the ICST 2nd international conference on body area networks (BodyNets '07), Brussels, ICST Belgium, pp 6:1–6:7
12. Alghamdi TA (2016) Cluster based energy efficient routing protocol for wireless body area networks. Trends Appl Sci Res 11(1):12–16. doi:10.3923/tasr.2016.12.18
13. Mendes LDP, Rodrigues JJPC (2011) A survey on cross-layer solutions for wireless sensor networks. J Netw Comput Appl 34(2):523–534. doi:10.1016/j.jnca.2010.11.009
14. Latre B, Braem B, Moerman I, Blondia C, Reusens E, Joseph W, Demeester P (2007) A low-delay protocol for multihop wireless body area networks. In: Proceedings of the 4th annual international conference mobile and ubiquitous systems: networking and services. Philadelphia, PA, USA, pp 1–8. doi:10.1109/MOBIQ.2007.4451060
15. Ruzzelli AG, Jurdak R, O'Hare GM, Van Der Stok P (2007) Energy-efficient multi-hop medical sensor networking. In: Proceedings of the 1st ACM SIGMOBILE international workshop on systems and networking support for healthcare and assisted living environments. San Juan, Puerto Rico, ACM New York, USA, pp 37–42. doi:10.1145/1248054.1248064
16. Braem B, Latre B, Moerman I, Blondia C, Demeester P (2006) The wireless autonomous spanning tree protocol for multihop wireless body area networks. In: Proceedings of the 3rd annual international IEEE conference on mobile and ubiquitous systems: networking and services. San Jose, CA, USA, pp 1–8. doi:10.1109/MOBIQ.2006.340421
17. Anirban B, Bassiouni MA (2009) Biocomm—a cross-layer medium access control (MAC) and routing protocol co-design for biomedical sensor networks. Int J Parallel Emergent Distrib Syst 24(1):85–103. doi:10.1080/17445760802335345
18. Quwaider M, Biswas S (2009) On-body packet routing algorithms for body sensor networks. In: Proceedings of 1st international conference on networks and communications, Chennai, India, pp 171–177. doi:10.1109/NetCoM.2009.54
19. Movassaghi S, Abolhasan M, Lipman J (2007) Energy efficient thermal and power aware (ETPA) routing in body area networks. In: Proceedings of the IEEE 23rd international symposium on personal, indoor and mobile radio communications, Sydney, NSW, pp 1108–113. doi:10.1109/PIMRC20126362511
20. Liang X, Shen Q, Lu R, Lin X, Shen X, Zhuang W (2012) Exploiting prediction to enable secure and reliable routing in wireless body area networks. In: Proceedings of the 31st annual IEEE international conference on computer communications, Orlando, FL, USA, pp 388–396. doi:10.1109/INFCOM20126195777
21. Maskooki A, Soh CB, Gunawan E, Low KS (2011) Opportunistic routing for body area networks. In: Proceedings of the IEEE consumer communications and networking conference (CCNC'11) Las Vegas, NV, USA, pp 237–241. doi:10.1109/CCNC20115766463
22. Quwaider M, Biswas S (2010) DTN routing in body sensor networks with dynamic postural partitioning. Ad Hoc Netw 8(8):824–841. doi:10.1016/j.adhoc201003.002
23. Quwaider M, Biswas S (2009) Probabilistic routing in on-body sensor networks with postural disconnections. In: Proceedings of the 7th ACM international symposium on mobility management and wireless access. Tenerife, Canary Islands, Spain, pp 149–158. doi:10.1145/1641776.1641803
24. Uthra RA, Raja SV (2012) QoS routing in wireless sensor networks—a survey. ACM Comput Surv 45(1):9. doi:10.1145/2379776.2379785
25. Ayatollahitafti V, Ngadi MA, bin Mohamad Sharif J (2016) An efficient next hop selection algorithm for multi-hop body area networks. PLoS ONE 11(1):1–14. doi:10.1371/journal.pone.0146464
26. Kumaria J, Prachia (2015) An energy efficient routing algorithm for wireless body area network. Int J Wirel Microw Technol 5:56–62
27. Kaur HP, Goyal K (2015) Cost based efficient routing for wireless body area networks. Int J Comput Sci Mob Comput 4(8):295–300
28. Bangash JI, Abdullah AH, Razzaque MA, Khan AW (2015) Critical data routing (CDR) for intra-wireless body sensor networks. TELKOMNIKA 13(1):181–192. doi:10.12928/telkomnika.v13i1.365
29. Gupta S, Kaur P (2015) WBAN health monitoring system using TEEN protocol: threshold sensitive energy efficient network protocol. Int J Innov Sci Eng Technol 2(10):20–25
30. Nedal A, Timmons N, Morrison J (2015) A cross-layer QoS-aware optimization protocol for guaranteed data streaming over wireless body area networks. Telecommun Syst 58(2):179–191. doi:10.1007/s11235-014-9901-8
31. Javaid N, Ahmad A, Khan Y, Khan ZA, Alghamdi TA (2015) A relay based routing protocol for wireless in-body sensor networks. Wirel Pers Commun 80(3):1063–1078. doi:10.1007/s11277-014-2071-x
32. Ahmed S, Javaid N, Akbar M, Iqbal A, Khan ZA, Qasim U (2014) LAEEBA: link aware and energy efficient scheme for body area networks. In: Proceedings of the 28th IEEE international conference on advanced information networking and applications (AINA'14), Victoria, BC, pp 435–440. doi:10.1109/AINA201454
33. Ahmed S, Javaid N, Yousaf S, Ahmad A, Sandhu MM, Imran M, Khan ZA, Alrajeh N (2015) Co-laeeba: cooperative link aware and energy efficient protocol for wireless body area networks. Comput Hum Behav 51(Part B):1205–1215. doi:10.1016/j.chb201412.051

34. Cabacas R, Yang H, Ra IH (2014) Energy-efficient two-hop transmission prioritization scheme for wireless body area networks. In: Proceedings of the 15th IEEE international symposium on soft computing and intelligent systems (SCIS'14), Kitakyushu, pp 1213–1218. doi:10.1109/SCIS-ISIS20147044860
35. Sheth Mahammed Ovesh I, Sharma AK (2014) Modified LAEEBA routing in WBAN. Int J Sci Res Dev 2(8):348–351
36. Bangash JI, Abdullah AH, Razzaque MA, Khanv AW (2014) Reliability aware routing for intra-wireless body sensor networks. Int J Distrib Sens Netw. doi:10.1155/2014/786537
37. Khan ZA, Sivakumar S, Phillips W, Robertson B (2014) ZEQoS: a new energy and QoS-aware routing protocol for communication of sensor devices in healthcare system. Int J Distrib Sens Netw. doi:10.1155/2014/627689
38. Khan ZA, Sivakumar S, Phillips W, Robertson B (2013) A QoS-aware routing protocol for reliability sensitive data in hospital body area networks. Procedia Comput Sci 19:171–179. doi:10.1016/j.procs201306.027
39. auqir A, Javaid N, Akram S, Rao A, Mohammad SN (2013) Distance aware relaying energy-efficient: DARE to monitor patients in multi-hop body area sensor networks. In: Proceedings of the IEEE 8th international conference on broadband and wireless computing, communication and applications (BWCCA'13), Compiegne, France, pp 206–213. doi:10.1109/BWCCA201340
40. Nadeem Q, Javaid N, Mohammad SN, Khan MY, Sarfraz S, Gull M (2013) Simple: stable increased-throughput multi-hop protocol for link efficiency in wireless body area networks. In: proceedings of the eighth international conference on broadband and wireless computing, communication and applications (BWCCA'13) Compiegne, pp 221–226. doi:10.1109/BWCC201342
41. Khan ZA, Sivakumar S, Phillips W, Robertson B, Javaid N (2012) QPRD: QoS-aware peering routing protocol for delay sensitive data in hospital body area network communication. In: Proceedings of the 7th international IEEE conference on broadband, wireless computing, communication and applications (BWCCA'12) Victoria, BC, Canada, pp 178–185. doi:10.1155/2015/153232
42. Alam MG, Hong CS (2012) A Q-learning based routing protocol for body area networks. DBPIA Korean Sch J 39(2):132–134
43. Ortiz AM, Ababneh N, Timmons N, Morrison J (2012) Adaptive routing for multihop IEEE 802.15.6 wireless body area networks. In: Proceedings of the 20th international conference on software, telecommunications and computer networks (softCOM'12) Split, Croatia, pp 1–5
44. Bayilmis C, Younis M (2012) Energy-aware gateway selection for increasing the lifetime of wireless body area sensor networks. J Med Syst 36(3):1593–1601. doi:10.1007/s10916-010-9620-y
45. Khan Z, Aslam N, Sivakumar S, Phillips W (2012) Energy-aware peering routing protocol for indoor hospital body area network communication. Procedia Comput Sci 10:188–196. doi:10.1016/j.procs201206.027
46. Elias J, Mehaoua A (2012) Energy-aware topology design for wireless body area networks. In: Proceedings of the IEEE international conference on communications, Ottawa, ON, pp 3409–3413. doi:10.1109/ICC20126363949
47. Ababneh N, Timmons N, Morrison J, Tracey D (2012) Energy-balanced rate assignment and routing protocol for body area networks. In: Proceedings of the 26th IEEE international conference on advanced information networking and applications workshops. Fukuoka, pp 466–471. doi:10.1109/WAINA201234
48. Liang L, Ge Y, Feng G, Ni W, Wai AAP (2012) Experimental study on adaptive power control based routing in multi-hop wireless body area networks. In: Proceedings of the global communications conference. Anaheim, CA, pp 572–577. doi:10.1109/GLOCOM20126503174
49. Tsouri GR, Prieto A, Argade N (2012) On increasing network lifetime in body area networks using global routing with energy consumption balancing. Sensors 12(10):13088–13108. doi:10.3390/s121013088
50. Razzaque MA, Hong CS, Lee S (2011) Data-centric multi objective QoS-aware routing protocol for body sensor networks. Sensors 11(1):917–937. doi:10.3390/s110100917
51. Cheng S, Huang C, Tu CC (2011) RACOON: a multiuser QoS design for mobile wireless body area networks. J Med Syst 35(5):1277–1287. doi:10.1007/s10916-011-9676-3
52. Seo SH, Gopalan SA, Chun SM, Seok KJ, Nah JW, Park JT (2010) An energy-efficient configuration management for multihop wireless body area networks. In: Proceedings of the 3rd IEEE international conference on broadband network and multimedia technology (IC-BNMT'10) Beijing, pp 1235–1239. doi:10.1109/ICBNMT20105705287
53. Kim DY, Kim WY, Cho JS, Lee B (2010) EAR: an environment-adaptive routing algorithm for WBANs. In: Proceedings of the international symposium on medical information and communication technology (ISMICT'10)
54. Djenouri D, Balasingham I (2009) New QoS and geographical routing in wireless biomedical sensor networks. In: Proceedings of the 6th international conference on broadband communications, networks, and systems. Madrid, Spain, pp 1–8. doi:10.4108/ICST.BROADNETS20097188
55. Liang X, Balasingham I, Byun SS (2008) A reinforcement learning based routing protocol with QoS support for biomedical sensor networks. In: Proceedings of the 1st international symposium on applied sciences on biomedical and communication technologies. Aalborg, Denmark, pp 1–5. doi:10.1109/ISABEL20084712578
56. Liang X, Balasingham I (2007) A QoS-aware routing service framework for biomedical sensor networks. In: Proceedings of the 4th IEEE international symposium on wireless communication systems. Trondheim, pp 342–345. doi:10.1109/ISWCS20074392358
57. Lazzi G (2005) Thermal effects of bioimplants. IEEE Eng Med Biol Mag 24(5):75–81
58. Takahashi D, Xiao Y, Hu F (2007) LTRT: least total-route temperature routing for embedded biomedical sensor networks. In: Proceedings of the IEEE global telecommunications conference. Washington, DC, USA, pp 641–645. doi:10.1109/GLOCOM2007125
59. Tang Q, Tummala N, Gupta SK, Schwiebert L (2005) TARA: thermal-aware routing algorithm for implanted sensor networks. In: Proceedings of the 1st IEEE international conference distributed computing in sensor systems. Marina del Rey, CA, USA, pp 206–217. doi:10.1007/11502593_17
60. Bag A, Bassiouni MA (2007) Hotspot preventing routing algorithm for delay sensitive biomedical sensor networks. In: Proceedings of the IEEE international conference on portable information devices, Orlando, FL, pp 1–5. doi:10.1016/j.inffus200702.001
61. Rafatkhah O, Lighvan MZ (2014) M^2E^2: a novel multi-hop routing protocol for wireless body sensor networks. Int J Comput Netw Commun Secur 2(8):260–267

62. Ahmed A, Javaid N (2014) RE-ATTEMPT: energy-efficient routing protocol for wireless body area sensor networks. Int J Distrib Sens Netw. doi:10.1155/2014/464010
63. Monowar MM, Mehedi Hassan M, Bajaber F, Hamid MA, Alamri A (2014) Thermal-aware multiconstrained intrabody QoS routing for wireless body area networks. Int J Distrib Sens Netw. doi:10.1155/2014/676312
64. Ahmed A, Javaid N (2014) RE-ATTEMPT: energy-efficient routing protocol for wireless body area sensor networks. Int J Distrib Sens Netw. doi:10.1155/2014/464010
65. Tabandeh M, Ahourai F, Moradi S, Jahed M (2009) A thermal-aware shortest hop routing algorithm for in vivo biomedical sensor networks. In: Proceedings of the IEEE sixth international conference on information technology: new generations, Las Vegas Naveda, pp 1612–1613. doi:10.1109/ITNG2009274
66. Anirban B, Bassiouni MA (2008) Routing algorithm for network of homogeneous and id-less biomedical sensor nodes (RAIN). In: Proceedings of the IEEE sensors applications symposium, Atlanta, GA, USA, pp 68–73
67. Anirban B, Bassiouni MA (2006) Energy efficient thermal aware routing algorithms for embedded biomedical sensor networks. In: Proceedings of the IEEE international conference mobile ad hoc and sensor systems (MASS'06) Vancouver, BC, Canada, pp 604–609. doi:10.1109/MOBHOC2006278619