

## Energy efficient routing protocols in wireless body area networks for health monitoring: a review

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### ABSTRACT

Technology nowadays is developing at an unprecedented pace in the field of wireless sensor networks (WSN). Especially in the aftermath of the pandemic, wireless body area networks (WBAN), which is a sub-category of WSN, experiences huge prominence, due to its functionality to enable remote diagnosis, treatment, and constant monitoring for patients. This functionality is a great advantage, since it allows elderly people, people with chronic diseases and even emergency cases to be monitored in real-time and, if needed, also enabling timely interventions. Furthermore, it is very cost-efficient since it reduces the occupation of hospital beds, whilst also keeping patients safer. This is possible by deploying small sensors within or around the body, where they can gather physiological data, which then at the end is sent to medical terminals, where medical staff have access to them. However, a WBAN, due to its small size, is constricted by several factors. Energy consumption, security, data transmission, as well as heat generation are only a few to be named. To deal with these challenges, whilst enabling a stable communication between the components, routing protocols are required. There are many different routing protocols which are used depending on the application being used.

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## 1. INTRODUCTION

The outbreak of COVID-19 caused, according to the JHU CSSE COVID-19 data, 673 million cases of infection, as well as the death of approx. 7 million people worldwide [1]. In the aftermath of this pandemic, health-care systems, especially real-time patient health monitoring systems are becoming more and more paramount [2], [3]. In recent time, wireless sensor networks (WSN) and in particular the wireless body area network (WBAN), which is considered a sub-category of the WSN, is gaining prominence due to its functionalities in the health care environment [4].

Whether for people with chronic diseases or elderly people who require constant monitoring, the WBAN has the possibility to cover all these areas [5]–[7]. Consisting of several sensors, which can be implanted either within the body, directly on or near the body, WBANs are capable of real-time monitoring for an extended time of several years [8], [9]. However, these systems do also have their own challenges, such as the resilience of sensors, meaning implanted sensors ability to function even within a moving body. Furthermore, its batteries, which directly effects the systems total life span.

Especially medical applications, such as glucose monitors and even pacemakers are highly dependent on a long-life span of the network, approximately 5 years, since it would mean to conduct operations in order

to remove and exchange expired sensors, which increases not just the cost and time but also, to a certain amount, the risk by operating patients [10]. Also, the quality of service has to be considered appropriately, by in large the subject of latency and packet loss for example, which is a huge topic on its own. Then, the security of the system itself to prevent outside malicious attacks.

This is especially important, since not much effort can be made on the small sensors with limited data storage and thus not allowing for sophisticated security mechanisms. And lastly its energy efficiency, which correlates with the sensor's temperature generation caused by high emission due to non-optimized routing of data. Thus, the main challenge here will be the energy efficiency since it effects the systems consumption, which, as mentioned above, does severely impact its batteries and therefore, its total life span, and the signal transmission rate or data throughput which causes hot spots and thus might harm the body [4], [9], [11].

In order to tackle this issue, a proper routing protocol must be therefore determined, since a careful selection of the correct sensors or nodes are essential for finding the path. Otherwise, a wrong decision could lead to an expiration of these nodes and worst case even to a total disconnect with the coordinator [12]–[14]. Additional factors such as the processing power the data size or even the network architecture, such as the topology, are directly affected by its correspondent routing protocol [15].

Depending on the chosen network topology, the implanted sensors are either in communication with each other and their coordinator or only directly with the coordinator. This communication, known as signal transmission rate or data throughout, is constantly emitting electromagnetic energy in form of radiation during the span of the communication process which causes heat within the human tissue. The issue is that the electromagnetic energy within the body is able to exceed the limit of the tissue's absorption rate, which then, aside from generating high heat, can also cause damage to the body [5].

## 2. ARCHITECTURE AND APPLICATIONS OF WBAN

The wireless body area network consists of several sensors (nodes) which are either directly implanted within the body, deployed on the body or as wearable nodes near the body. These nodes are tasked with gathering the physiological data of the patient, which can vary, depending on the patient's diagnosis [6], [16], [17]. The architecture itself comprises of several tiers, in most cases 3 tiers are used, which is the Intra-WBAN communication tier, the Inter-WBAN communication tier and the Beyond-WBAN communication tier [15], [18], [19].

In the first tier, the Intra-WBAN communication tier, the nodes are, depending on its topology, implanted and/or deployed accordingly. It is important to mention that there are three types of sensors: The first type are the sensors themselves, which are monitoring and measuring the patient's physiological data, such as electrocardiogram (ECG), electromyography (EMG) and electro-encephalograph (EEG), as well as glucose levels, blood pressure (BP), and body temperature [19], [20]. The second type are the actuators, which function is to execute conditional tasks, for example, regulating the insulin level by releasing specific medicine if the monitored and measured data of the sensors see a need for it [21].

The third type is the main node or coordinator, which functions as a nexus by receiving the data send by the sensors. The sensors are either in direct communication with each other, or sending the data to a coordinator, by means of ultra-short communication transmission distance (up to 2 m), which can then send the gathered data to a personal device (PD) which function as an interface between tier 1 and 2.

Some strategies implement the optionality to directly establish a communication between sensors and PD for critical and sensitive, emergency-based information. This is known as single hop, which does use more energy but is faster instead. Whereas the method prior to that is known as multi-hop, which is normally used for the general transmission of physiological data, which is not critical, however slower but consumes lesser energy instead. It is for the right routing protocol to determine a fast path which uses as little energy consumption as possible. The second tier is in charge to receive the PD's data via access point, such as ZigBee, Bluetooth or Wi-Fi and then distribute it to tier 3, which are normally the servers or terminals in the medical institutions, via 4G-6G or Wi-Fi as shown in Figure 1 [22]–[24].

The architecture is also heavily dependent on the type of its application. Since WBANs are represented in various fields, it is generally divided into medical and non-medical applications. Non-medical applications are within fields such as industry, military, sport, and entertainment. Within the medical field, applications are distinguished between implanted and wearable applications, as shown in Table 1 [4], [23]–[26].

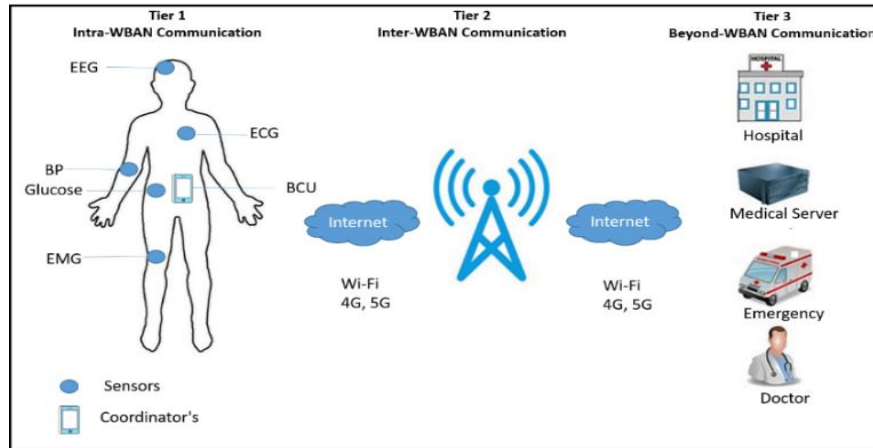


Figure 1. Wireless body area network architecture

Table 1. Wireless body area network applications

Application type		Examples
Medical	Implanted applications	Glucose sensor Pacemaker Diabetes control Cancer detection EMG ECG
	Wearable applications	Telemedicine Patient monitoring Asthma monitoring Temperature monitoring Blood pressure monitoring
Non-Medical	Military	Soldier fatigue and combat readiness
	Industry	Assisting construction
	Sports	Assisting athletic training
	Entertainment	Games

### 3. MOTIVATION AND IMPORTANCE OF WBAN

Although the wireless body area network can be used in many fields, such as military, industry and even entertainment, the field which carries the most significance is the medical field, since it is able to deliver solutions to many challenges and issues due to the pandemic, which has caused a huge change for the entire globe. The necessity for a fast diagnosis to identify possible infected people could, not just save their lives, but could also reduce or even prevent the possibility to further infect other people, which could save people from harm and in some cases, from death. It could also identify the mild cases from the severe ones, which is very important for hospitals in terms of hospitalized patients. With WBAN, medical staff could monitor patients, who are at home, remotely and only hospitalized the ones who are in need to. This does not just reduce the load hospitalized patients, but also reduces hospital and transportation cost. Additionally, work overload for medical staff will also be reduced, which is an overall improvement of the health-care efficiency. Furthermore, elderly people, disabled people or other people, who are finding it difficult to come to the hospital, could be properly treated and monitored remotely, which also reduces the risk of them being injured or infected since they stay at home most of the time [22], [23], [25], [27].

### 4. ROUTING PROTOCOLS FOR WBAN AND ITS CATEGORIES

As indicated before, WBANs are very much dependent on several conditions, such as long-life span, accurate and fast signal transmissions, proper data management, heat generation and security, while these factors impact the design and structure of the WBAN in itself, it is the routing protocol which enables a proper communication between these components, and therefore, it is imperative to the overall energy efficiency [3], [15]. Setting the right path between nodes to optimize communication and data transfer, while at the same time, reducing energy consumption is a routing protocol's main objective [28]. In this subject, there are five distinguished categorization of protocol methods which vary, depending on the strategy and purpose of a WBAN as shown in Figure 2 [20], [23], [29].

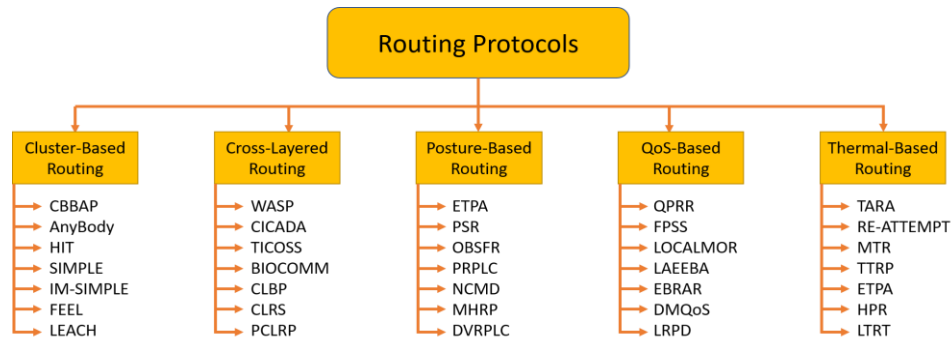


Figure 2. Categorization of routing protocols

#### 4.1. Cluster-based routing

This specific protocol originates from WSNs and it is very well tailored for WBAN as well. The protocol “low energy adaptive clustering hierarchy (LEACH)” is specifically designed to ensure a proper adaption with a dynamic structure, such as it is important for WBAN. Furthermore, this protocol enables a balanced consumption of energy whilst providing stability for the system. Its strategy is to divide the sensors into clusters, with each cluster setting one node as a cluster head. Each cluster head acts as a focal point in terms of communication and data transmission, whilst, at the same time, avoid excessive heat generation [12], [23], [30], [31].

#### 4.2. Cross-layer routing

The protocol stack of this particular method enables layer to communicate with each other, which are normally restricted on their own layers. This improves interoperability and efficiency simultaneously. Some known protocols are “cross-layer optimization based on prediction (CLBP)”, “cross-layer retransmit strategy (CLRS)” and “A priority-based cross layer routing protocol (PCLRP)” to name a few. However, even though the energy consumption is reduced, and the data transmission is increased, the downside of these protocols is, that they don’t take the movement of the body into consideration [12], [23], [30].

#### 4.3. Posture-based routing

A very important factor within a WBAN is the probability of effect due to body movement or even human tissue. If none considered appropriately, human tissue could obstruct the signal which could lead to link failure, whilst body movement could even leave to disconnection of linkages. Posture-base routing protocols are specialized to deal with these challenges by taking human physiology and movement into calculation. The idea here is to send the data packages periodically to the coordinator. Some examples are the “energy-efficient and distributed network management cost minimization (NCMD)”, “A novel mobility handling routing protocol (MHRP)” and “distance vector with postural link cost (DVRPLC) [23], [29], [32].

#### 4.4. Quality of service-based routing

To ensure safety and security for a patient who uses WBAN with implanted sensors, a set of rules and regulations are necessary. These qualities of services are upholding certain standards to ensure a patient’s well-being. Services such as data security, data authenticity, data priority, data transmission, link reliability as well as heat generation and transmission delay are a few of these factors which need to be regulated. Some examples of those protocols are “energy balanced rate assignment and routing protocol (EBRAR)”, “data-centric multi-objective QoS-based routing protocol (DMQoS)” and “designing lightweight QoS routing protocol (LRPD)” [23], [30].

#### 4.5. Temperature-based routing

The term hot spot sensors normally describe sensors with high temperature due to radiation continuously generated by processor uptime, data transmission as well as energy consumption. It is problematic since increased heat can and will damage human tissue as well as compress blood flow. In order to prevent these outcomes, several approaches were researched to create protocols to handle this issue. For example, “thermal-aware routing algorithm (TARA)”, “A new energy-efficient routing protocol (ER-ATTEMPT)”, “A mobility-based temperature-aware routing protocol (MTR)” and “trust and thermal aware routing protocol (TTRP)” [12], [23], [33].

## 5. CHALLENGES FOR ROUTING PROTOCOLS IN WBAN

Although routing protocols are means to improve energy efficiency dependence of WBANs. However, even the routing protocols have their own challenges, which may have tremendous impact on the choice of the right protocol. In order to choose the optimal routing protocol, several factors must be taken into consideration. To be aware of the constraints and limitations is paramount in the determination of a proper routing protocol especially concerning implanted sensors. To understand the difficulties, an enumeration of possible challenges is listed below [12], [15], [18], [34], [35].

### 5.1. Energy availability

Implanted sensors are very small in size, in order to avoid the discomfort of a patient. Thus, a sensor's energy availability is very limited since the entire WBAN life span is depended on the first sensor to run out of energy. If that happens, it has to be removed and exchanged via surgical intervention, which is not only cumbersome for a patient but also increases the risk of possible injuries during or after a surgery [18], [28].

### 5.2. Mobility

While in theory, the implanted sensors could be placed in optimal distance with each other to increase efficiency, the reality is that due to constraints within a body, the sensors cannot be implanted everywhere. Furthermore, body movement will directly impact the sensors. Aside from the possibility to alter the sensor's location, the signal transmission rate is not all equal within a body due to the human tissue, thus a careful choice of the correct location as well as a proper routing protocol must be considered in correspondence to these factors management [12], [34], [36].

### 5.3. Transmission range

Signal transmission within a body is reliant of its signal strength, which of course severely impacts the overall energy consumption and heat generation. The higher the range, the more energy is required. On the other hand, a stronger signal allows for a faster and more stable communication within the WBAN [12], [37], [38].

### 5.4. Data management

Due to the small size of the sensors, the possibility to store data is quite limited. In addition to that the sensors collect a high amount of data in form of physiological information. Thus, the right strategy is required for good data management [12], [34].

### 5.5. Processing power

Computing power is limited since chips with high processing power would generate too much heat. Therefore, they are not applicable for implanted sensors. The reason being is that it could potentially harm the body [12], [37].

### 5.6. Real-time synchronization

Patients who are either chronically ill or have severe diseases must be monitored constantly and in real time. Therefore, the system must ensure to provide these critical data accordingly to prevent serious injuries or even death for some patients [12], [34]. Thus, a stable and secure connectivity must be available.

### 5.7. Latency

When information, which is in packet form, arrive at its destination later, due to routing a longer path, in order to avoid congestion, or longer queues or even high traffic of transmission, then its arrival time is affected by high latency. However, in order for real-time monitoring to function properly, the latency of data transmission has to be very low. This ensures that critical data is transmitted in a timely manner [18], [39].

### 5.8. Security

Physiological data as well as personal data are very sensitive and require proper encryption and authentication. The issue with security is that the sensor's limitation and constraints do not allow for sophisticated security mechanisms for the system. Thus, it needs to be outsourced with the help of routing protocols [12], [16], [18].

## 6. RELATED WORK

The amount of research which has been done regarding routing protocols, makes it very apparent that different strategies are required to be implemented for specific solutions. This is evident, due to the fact, that there are many ways to approach a proper optimization of a wireless body area network system. Since the total life span of a network is dependent on its energy availability, it is a pivotal topic and one of the main challenges. In (Table 2

see in appendix) details and features of the following mentioned literature review are shown. This comparison of the proposed routing protocols highlights the objectives, methodology, advantages, and disadvantages.

Qureshi *et al.* [40] proposed an energy aware routing protocol (EAR), which is able to reduce the utilization of energy by selecting best next hop through the evaluation of the link quality of the existing nodes within the WBAN. It balances residual energy, as well as the link quality and the proper level of energy. Al-Obaidi and Ibarahim [41] proposed a reliable stable increased multi-hop protocol link efficiency (R-SIMPLE), which is an upgraded version of SIMPLE, with the addition of a performance factor for the cost equation. Furthermore, the nodes are divided into CS and non-critical sensors (NCS), whilst the data it self is also divided in correspondence to their sensors. Additionally, a sleep function is added, where the awakening of the sensors is depended on a specific schedule, given by the medical staff, or if critical data is collected.

Zuhra *et al.* [42] proposed a different approach by utilizing a low latency traffic prioritization scheme for QoS-ware routing (LLTP-QoS). This specific protocol is focusing on ensuring a reliable approach to improve the critical data transmission whilst also reducing end-to-end delay. The modified stable increased multi-hop protocol link efficiency (M-SIMPLE) reported by Khanna *et al.* [43], was a cluster-based routing protocol, which is capable of using both, single and multi-hop, depending on the required cost function. The cost function is calculated by considering the parent node with maximal residual energy as well as shortest path to the sink.

Whereas the protocol from Qu *et al.* [5], multiple parameters of the network nodes are put into account. Parameters, such as residual energy, the transmission efficiency, the available bandwidth, and the count of hops to the destination, for example, are included. Their proposed protocol is able to use the maximum benefit function for a dynamic hop selection. Other strategies were presented by Jamil *et al.* [44], which is to use adaptive thermal-aware routing algorithms (ATAR) to deal with the challenge regarding the temperature rise of the implanted sensors within WBAN by using a multi-ring routing approach to find alternative ways in order to avoid already heated sensor nodes. Similarly, Ahmed *et al.* [45] presented another reliable thermal and energy aware routing (TEAR), which was considering the weighted average of link quality, the heat dissipation, and the energy consumption to determine the routing path in order to avoid overheated nodes.

Abidi *et al.* [30] designed a routing protocol wireless body area network protocol (WBANP) to use multi-hop to reach its destination by using a gateway body sensor, which serves as an access point between nodes and sink. Qureshi *et al.* [46] suggested an energy and link aware routing protocol (ELA-RP), which is able to deliver well balanced energy consumption whilst minimizing delay of data transmission. On the other hand, Prasad and Bojja [27] proposed a routing protocol, which is able to tackle two known main issues in a WBAN, the energy consumption and the total life span of a WBAN by using a specific hybrid synchronization technique for the energy consumption and a specific hybrid communication between sink and nodes. Ullah *et al.* [47] presented a different strategy by proposing an efficient energy harvested-aware routing protocol (EH-RCB) which is constructed to stabilize the wireless area body network's operation through choosing the most optimal forwarder node based on the cost function calculation.

Kaur *et al.* [48] introduced adam moment estimation optimized mobility supported energy efficient routing protocol (AMERP), which is able to support multi-hop communication, the mobility of sensor nodes, as well as traffic. Furthermore, is has a very small energy consumption which enhances the life span whilst also reducing the packet drop rate. Ullah *et al.* [49] suggested an energy efficient and reliable routing scheme (ERRS) which includes two novel approaches, the forwarder node selection and the forwarder node rotation. This new strategy includes the usage of an adaptive static clustering routing technique for enhanced stability within the system.

Samarji and Salamah [50] presented an energy efficient routing and QoS supported traffic management scheme for software defined wire body area networks (ERQTM), which enhances the system's life span whilst ensuring network stability and reliability by inventing an energy efficient routing scheme, as well as a traffic management scheme by prioritizing the transmission of emergency data, which results in an outcome of high QoS. Sandhu and Malik [51] did propose a priority aware protocol (PAP) for healthcare applications in WBANS. This protocol transferred data based on their priority by associating a fixed and a dynamic priority to each node. While the fixed priority was calculated based on the tasks assigned to the nodes, the dynamic priority was computed based on the data sensed by a node.

Sagar *et al.* [52] did use the critical data routing protocol (CDR) in order to transmit all relevant emergency-based data from the inner-body nodes to the on-body medical super sensor (MSS). The MSS was then able to manage and coordinate all sensors within the body, even though it considered only the critical data, while the non-critical data was discarded. Goyal *et al.* [53] presented an optimized hybrid approach of the genetic algorithm (GA) and the BAT algorithm, taking the transmission rate adaption policy into consideration as well (GABAT-TRAP). The main purpose was to adjust the transmission rates for human posture, while improving link quality and QoS metrics at the same time. GABAT-TRAP did also include harvesting techniques to improve network lifetime and higher throughput.

The proposal by Banuselvasaraswathy and Rathinasabapathy [54] was the optimum path optimum temperature routing protocol (OPOT). It reduced the influence of the sensor nodes temperature by defining a

minimum and maximum threshold limit. This approach enabled an optimum routing path, which also equalized the heat spread between the sensors within the network.

Ahmed *et al.* [55] did develop a novel energy optimized congestion control based on temperature aware routing algorithm (EOCC-TARA) using enhanced multi-objective spider monkey optimization (EMSMO) for SDN-based WBAN. Basically, the forwarder nodes were determined by prioritizing temperature and energy, meaning that overheated nodes were avoided. The optimal path was chosen by including the link reliability, queue length, path loss and residual energy into the equation. These are only a few examples of the research which has been done in order to create a proper routing protocol to address the needs of their specific network systems.

**7. CONCLUSION**

Wireless body area network systems do not only offer great possibilities for the medical sector, but also carry a lot of conditions, restraints, and challenges as well. And some of these challenges can be addressed with a specific approach or methodology, for example, the network structure and design. However, when it comes to micromanagement in regard to energy management, data transmission, heat generation, latency, data security, to only name a few, routing protocols are the tools, which are required to deal with these matters. Since there are many applications available, different strategies are needed in order to establish a safe and well-functioning communication in a WBAN, thus there has been put a lot a time and research for the development of routing protocols. And therefore, routing protocols are an intricate and pivotal part of a wireless area body network system.

**APPENDIX**

Table 2. Comparison of the proposed routing protocols

Authors	Proposed routing protocol	Objectives	Methodology	Advantages	Disadvantages
Qureshi <i>et al.</i> [40] 2020	Energy aware routing protocol (EAR)	Link quality and energy utilization	Reduction of energy utilization by selecting best next hop through the evaluation of the link quality of the existing nodes within the WBAN. It balanced residual energy, as well as the link quality and the proper level of energy.	Improved performance in energy consumption, data delivery ratio, delay and throughput	Lacking node mobility; high complexity due to calculations
Al-Obaidi and Ibarahim [41] 2020	Reliable stable increased multi-hop protocol link efficiency (R-SIMPLE)	Decrease energy consumption and prolong network lifetime	Division of nodes into critical sensors (CS) and non-critical sensors (NCS) as well as classification of data into critical and non-critical data. Added sleep function to reduce energy consumption by awaken the sensors on a scheduled timeline or if critical data was transmitted.	Improved network lifetime, stability, throughput, residual energy, reliability and data integrity	Possible missing data could cause an issue since data is transmitted once per waking cycle and therefore could take a long period of time to wait for the next waking cycle to be transmitted.
Zuhra <i>et al.</i> [42] 2019	low latency traffic prioritization scheme for QoS-ware routing (LLTP-QoS).	Enhancement of the transmission of critical data in a privileged manner and avoidance of end-to-end delay	Enhancement of critical data transmission and avoidance of node and link level congestion. It consists of two main schemes such as traffic prioritization and route discovery schemes.	Improved network lifetime, energy consumption, critical data transmission, throughput and end-to-end delay	High complexity due to computation of routing decisions; too many sensors thus uncomfortable and limits body movement
Khanna <i>et al.</i> [43] 2018	Modified Stable Increased Multi-hop Protocol Link Efficiency (M-SIMPLE)	Increase of energy efficiency by choosing the optimal number of cluster heads.	The cost function is calculated by considering the parent node with maximal residual energy as well as shortest path to the sink	Improved stability, network lifetime and packet delivery	High complexity due to computation of routing decisions

Table 2. Comparison of the proposed routing protocols (continue)

Authors	Proposed routing protocol	Objectives	Methodology	Advantages	Disadvantages
Qu <i>et al.</i> [5] 2019	Energy-efficient routing protocol for reliable data transmission	Use the maximum benefit function for a dynamic hop selection	Multiple parameters, such as residual energy, the transmission efficiency, the available bandwidth, and the count of hops to the destination, are taken into account.	Improved reliability of data transmission and energy utilization efficiency and network lifetime	High complexity due to computation of routing decisions; QoS requirements not optimized
Jamil <i>et al.</i> [44] 2019	Adaptive thermal-aware routing algorithms (ATAR)	Avoidance of tissue damage due to increased temperatures of nodes	Using Multi-Ring routing approach to find alternative route in case of increasing temperature.	Avoidance of tissue damage, extended network lifetime, decreasing temperature of nodes	High delay due to avoidance of heated nodes; overhead
Ahmed <i>et al.</i> [45] 2019	Thermal and energy aware routing (TEAR)	Using weighted average of link quality, heat dissipation, and energy consumption to avoid heated nodes	Consideration of weighted average of three costs, link quality, heat dissipation, and energy consumption to avoid overheated nodes by determining the routing path.	Improved data transmission, energy consumption, and network lifetime	High complexity due to mathematical techniques for computing temperate rise
Abidi <i>et al.</i> [30] 2019	Wireless body area network protocol (WBANP)	Use of gateway body sensors to reduce energy consumption	Use of Multi-Hop to reach destination using gateway body sensors as access points between nodes and sink.	Improved data transmission, energy consumption, and network lifetime	Low system performance due to suboptimal cooperative characteristics of WBAN
Qureshi <i>et al.</i> [46] 2018	Energy and link aware routing protocol (ELARP)	Avoidance of QoS decrease through body movement by establishing proper path	Calculation of neighbor nodes parameters including energy level and link quality whilst balancing energy consumption and minimizing data delay as well as maximizing data delivery in the network.	Improved data routing, energy consumption, data delivery and delay	Fixed and same transmission range for sensor nodes can be very difficult to realize in certain cases through the human body.
Prasad and Bojja [27] 2020	Hybrid energy-efficient routing protocol	Use of ultra-low-power transceivers with hybrid energy-efficient routing protocol to decrease energy consumption	Use specific hybrid synchronization technique for energy consumption and specific hybrid communication between sink and nodes in regards to energy consumption and total network lifespan.	Improved network lifetime, energy consumption, and avoidance of tissue damage by overheated nodes	High complexity due to too many nested iterations for the determination of the correct routing path
Ullah <i>et al.</i> [47] 2019	Energy harvested-aware routing protocol with clustering approach in body area networks (EH-RCB)	Choosing the most optimal forwarder node based on Cost Function (CF)	Use of Energy Harvesting mechanism with clustering algorithm with dual sinks.	Improvement of end-to-end delay network stability, package delivery ratio and throughput	High complexity due to extensive calculations; high Bit Error Ratio (BER)
Kaur <i>et al.</i> [48] 2021	Adam moment estimation optimized mobility supported energy efficient routing protocol (AMERP)	Enhancement of both, homogeneous and heterogeneous network configurations	Adaptation of deep learning-based Adam optimizer to predict forwarder node for homogeneous and heterogeneous configuration of nodes to improve throughput, network lifetime and residual energy of the network.	Improvement of mobility of nodes, energy consumption, network lifetime, packet drop rate	Replacement of nodes is extremely difficult; data loss is intolerable



Table 2. Comparison of the proposed routing protocols (continue)

Authors	Proposed routing protocol	Objectives	Methodology	Advantages	Disadvantages
Ullah <i>et al.</i> [49] 2021	Energy efficient and reliable routing scheme (ERRS)	Enhancement of stability period and reliability for resource constrained WBAN	Combination of two novel solutions, the forwarder node selection and the forwarder node rotation techniques to take advantage of the adaptive static clustering routing technique.	Improved stability period, network lifetime, throughput and reliability	Requires better reliability and latency for life-critical applications; suboptimal scalability and mobility
Samarji and Salamah [50] 2021	Energy efficient routing and QoS supported traffic management scheme for software defined wire body area networks (ERQTM)	Use of QoS supported traffic management for optimized routing procedures	Prioritization of transmission of emergency data, which results in a high QoS	Improved network lifetime, stability and reliability	Not optimized energy efficiency, since it requires a lot of power
Sandhu and Malik [51] 2020	Priority aware protocol (PAP)	Routing decisions of data transmission based on assignment of high priority to emergency-based data	Transmission of data as healthcare priority data, which includes the measured sensitivity and the value observed of data. The sensing interval and transmission rate are calculated based on the healthcare priority of data.	Improved performance in terms of throughput, reliability and end-to-end delay	Missing adjustment between transmission power and receiving power after dynamically determining the transmission rates
Sagar <i>et al.</i> [52] 2020	Energy aware WBAN using critical data routing (CDR)	Prioritization of critical data transmission via an algorithm for each node	Placement of nodes in an equidistant pattern to avoid the routing of data via relay or forwarder. The routing decision is done by the critical data routing protocol (CDP). The sensors only send critical data and discard non-critical data.	Improved energy efficiency, network lifetime and throughput	Placement of nodes are not optimized since they are all in equal distance to the sink; can only send critical data and not non-critical data; high complexity due to extensive calculations; sensor nodes deplete faster since all load is concentrated on one forwarder node
Goyal <i>et al.</i> [53] 2021	Genetic algorithm (GA) with BAT algorithm with transmission rate adaption policy (GABAT-TRAP)	Adjustment of transmission rates for human posture, while improving link quality and QoS metrics	The hybrid GABAT adjusts the transmission rates at each sensor node for each posture considering both the QoS metric constraint and the dynamic link constraint.	Improved network lifetime; higher throughput	High complexity due to extensive calculations
Banuselvasaras wathy and Rathinasabapathy [54] 2020	Optimum path optimum temperature routing protocol (OPOT)	Minimization of the temperature influence on sensor nodes	The optimum routing path is determined by the temperature of sensor nodes and by defining a minimum and maximum. It also considers the critical data signals to be sent when the temperature of node exceeds the admissible threshold limit.	Improved performance in power, delay, uniform temperature, energy and network lifetime	High complexity due to extensive calculations

Table 2. Comparison of the proposed routing protocols (continue)

Authors	Proposed routing protocol	Objectives	Methodology	Advantages	Disadvantages
Ahmed <i>et al.</i> [55] 2020	Energy optimized congestion control based on temperature aware routing algorithm	Improvement of energy efficiency and a congestion free communication, as well as the reduction of adverse thermal effects in WBAN routing	By considering the temperature, caused by thermal dissipation on sensor nodes, the forwarder nodes are selected based on temperature and energy. Then the congestion avoidance concept is added with the energy-efficiency, link reliability, and path loss for modeling the cost function based on which the EMSMO provides the optimal routing.	Improved performance in energy consumption, throughput, uniform temperature and less congestion	Mobility issues; high complexity due to extensive calculations

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