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REVIEW

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Energy efficiency considerations in software-defined wireless body area networks

Fahad Masood[1,2] | **Wajid Ullah Khan**[1] | **Mohammed S. Alshehri**[3] | **Albandari Alsumayt**[4] | **Jawad Ahmad**[5]

[1]Department of Computing, Abasyn University, Peshawar, Pakistan

[2]Department of Electronics, Quaid i Azam University, Islamabad, Pakistan

[3]Department of Computer Science, College of Computer Science and Information Systems, Najran University, Najran, Saudi Arabia

[4]Computer Science Department, Applied College, Imam Abdul Rahman Bin Faisal University, Dammam, Saudi Arabia

[5]School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh, UK

Correspondence
Jawad Ahmad, School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh, EH10 5DT, UK.
Email: j.ahmad@napier.ac.uk

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Abstract

Wireless body area networks (WBAN) provide remote services for patient monitoring which allows healthcare practitioners to diagnose, monitor, and prescribe them without their physical presence. To address the shortcomings of WBAN, software-defined networking (SDN) is regarded as an effective approach in this prototype. However, integrating SDN into WBAN presents several challenges in terms of safe data exchange, architectural framework, and resource efficiency. Because energy expenses account for a considerable portion of network expenditures, energy efficiency has to turn out to be a crucial design criterion for modern networking methods. However, creating energy-efficient systems is difficult because they must balance energy efficiency with network performance. In this article, the energy efficiency features are discussed that can widely be used in the software-defined wireless body area network (SDWBAN). A comprehensive survey has been carried out for various modern energy efficiency models based on routing algorithms, optimization models, secure data delivery, and traffic management. A comparative assessment of all the models has also been carried out for various parameters. Furthermore, we explore important concerns and future work in SDWBAN energy efficiency.

KEYWORDS

body area network, energy efficiency, SDWBAN, software-defined network

1 | INTRODUCTION

Recent technology developments and novel technologies, like wireless body area network (WBAN) and minimal wireless communications, are increasingly popularizing new services like remote monitoring of health and management.[1–5] The improvements and novel approaches for enhancing healthcare processes have greatly aided the healthcare sector.[6–9] Wireless sensor nodes, which are intelligent, low-power, small, inexpensive, wearable, and lightweight individual networking devices, make up WBANs as shown in Figure 1. These sensor nodes may diagnose physiological/non-physiological factors of a human body before sending the data to a predetermined target through wireless communication.

WBAN is based on the 802.15.6 standard, which consists of several sensor nodes connected to a single coordinator node known as the HUB. Inter-WBAN communication refers to interactions between the sensor and coordinator nodes,

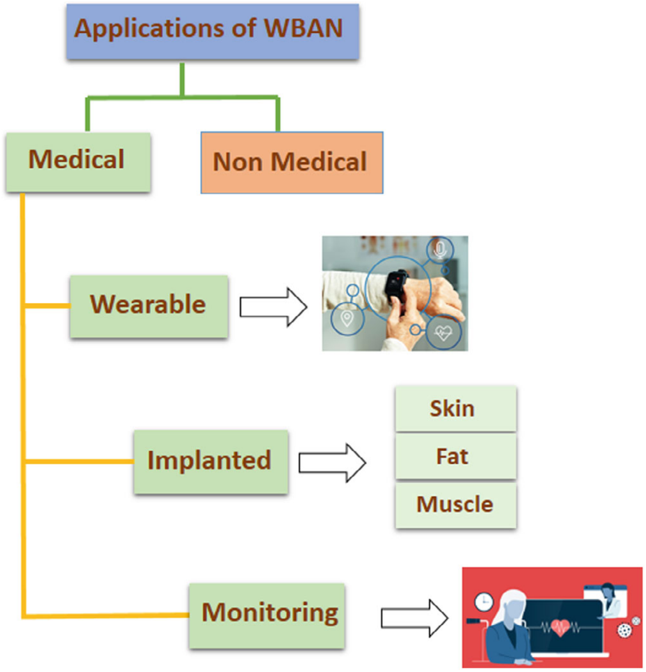

FIGURE 1 WBAN applications.

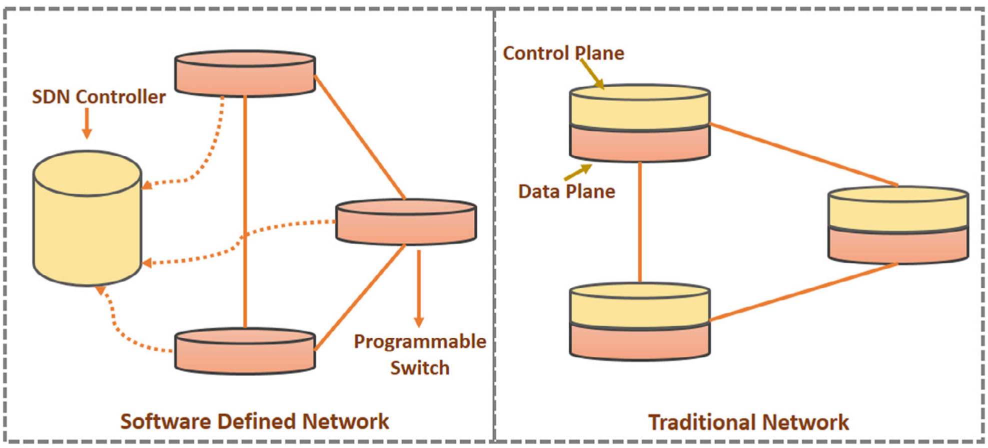

FIGURE 2 SDN versus traditional network.

the controller, and the target. In contrast, the coordinator node and the numerous sensor nodes connected to the gateway or sink, communicate with each other in Intra WBAN. The 802.15.6 standard does not produce any inter-WBAN communication solutions; it merely permits Intra-WBAN communication.[10] Contrarily, WBAN architecture is not restricted to intra-WBAN. New methods of inter-WBAN communication are necessary for this setting.

A ground-breaking network idea that has gained acceptance is the software-defined networking (SDN) concept. Its popularity has risen in recent years. The SDN simplifies by providing an abstraction of control and management procedures separation of data as well as control planes as shown in Figure 2, effectively enabling the network to be administered from a theoretically central point.[11–13] Although SDN was initially designed only for wired networks, it has lately been upgraded to work with a wide range of network topologies, including wireless networks[14] and data center clouds.[15,16]

These days, cutting-edge methods like SDN, the Internet of Things, and 5G are likely to raise the use of emerging WBAN technologies and contribute to networking solutions for industry and daily life. A heterogeneous network node with a constrained energy supply operates in a software-defined wireless body area network (SDWBAN). These sensor nodes typically cannot be recharged or changed which can also be implanted in the body. The majority of WBAN architectural research focuses on IEEE 802.15.4 and medium access control (MAC) in physical as well as data link layers. It is critical to say that the SDN technique is only integrated with WSNs and the 802.15.4 protocol is frequently addressed.[17–20] Nonetheless, the various reasons, the 802.15.4 standard is unsuitable for SDWBAN design causes, such as a low data rate and excessive energy usage in comparison to the standard 802.15.6.[21]

In SDWBAN, effective data processing via encoding and decoding operations is critical for optimizing communication and conserving energy. Data encoding includes techniques such as data compression, which decreases data size using techniques such as Huffman encryption or lossless compression, conserving energy during transmission. Furthermore, error correction codes give redundancy to the data, allowing for the identification and repair of faults during receipt and maintaining the integrity of the data in case of interference. Data aggregation is the process of combining information from several sensors into a single data packet, hence lowering network traffic. On the receiving end, data decoding includes decompression to return data to its original layout, error correction to fix any problems, and de-aggregation to split aggregated data into individual parts. The use of these technologies enables efficient and dependable communication in SDWBANs, which is critical in clinical applications as data accuracy is critical for the monitoring of patients and diagnosis.

The standard 802.15.6 is intended to satisfy various SDWBAN goals and specs as a result, all SDWBAN solutions should be based on the 802.15.6 standards such as narrowband, ultra-wideband, human body communication and so forth. The IEEE 802.15.6 standard was created to solve service inequalities in close-quarters communication between lightweight objects that surround the human body. It specifies the one-hop and two-hop star topologies as well as the physical, as well as data connection layers.[22–27] Numerous routing protocols have been created in the literature for routing ,[28–31] a process that uses a lot of energy. Low energy is a significant worry in the SDWBAN nodes, though. It lessens the appeal of using this technology. Since SDWBANs move in groups rather than nodes, they have a unique topology. SDWBAN has more stringent energy constraints than the conventional Ad Hoc and WSN networks. Battery changes for the implanted nodes put in the human body may be difficult and inconvenient while in some circumstances, a medical operation is required. As a result, the SDWBANs should have a greater network lifespan. The next node selection procedure as an intermediate or forwarding node is the most crucial phase in multi-hop routing systems. Existing routing systems propose various approaches for determining the next node. However, the majority of these protocols attempt to find the shortest way rather than the most appropriate option. As a result, the resultant route may lead to more energy usage.

The rest of the article is structured as follows. SDWBAN architecture is discussed in Section 2. Mathematical models are discussed in Section 3. Section 4 discusses a comprehensive survey of various energy-efficient SDWBAN schemes which include the routing algorithms, optimization models, secure data delivery, and traffic management. Section 5 concludes with closing remarks based on the study.

2 | SDWBAN ARCHITECTURE

SDN contains data, control, and application planes.[27] Figure 3 follows the logical design of SDN with a detailed description. The data plane is made up of base stations (BS), gateways, and SDN-enabled switches (SDES). The control plane sends control information to the switches. In the data plane, a common SDES is developed by the cluster of patients with the sensors. To reach the destination, the BSs send physiological data at fixed intervals to the linked SDES. However, if the target gateway is within the SDES's transmission range, the linked SDES can immediately transfer data to it. Otherwise, packets are routed through many SDESs in a hop-by-hop way until they reach their destination.

The control plane, on the other hand, is made up of several dispersed controllers that may operate in a network. These distributed controllers may be interconnected for east-west communication so that if one controller fails, another adjacent controller can manage the SDESs. The management coordinator can develop and install numerous WBAN apps to monitor patients on the application plane. The northbound interface (NBI) communicates between the application and the control plane, whereas the southbound interface (SBI) communicates between the control and data planes.

Figure 4 shows the basic architecture of the OpenFlow switch that works under the SDN environment. The input packet is analyzed for the header fields. If the matching is successful then the relevant action is performed and the packet is delivered at the output. If the matching is unsuccessful, it is delivered to the SDN controller to perform an appropriate action.

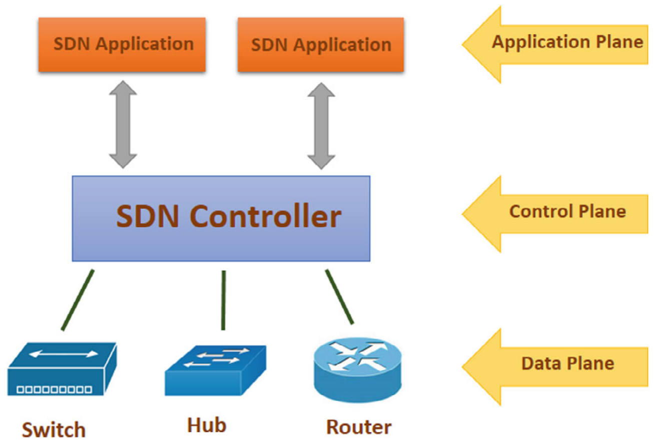

FIGURE 3 SDN architecture.

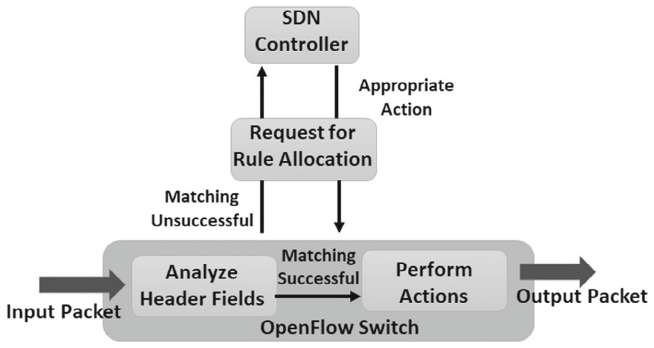

FIGURE 4 OpenFlow architecture.

Figure 5 shows the application diagram of SDWBAN. Various WBAN sensors are connected to or implanted in the human body. Assume that there are multiple sensors on the patient's body. Sensors are in charge of collecting and transmitting data to a switch. The SDN-enabled switch connects to the SDN Controller through an OpenFlow protocol-based wireless connection. The data is then sent to a gateway via an SDN-equipped switch received from the controller depending on flow information. The gateway communicates with the cloud through long-distance communication protocols such as LTE, WiMax, LTE-A, and others. In this situation, it is supposed that every patient has numerous sensor nodes and that an SDES serves as the cluster head. Several application sensors, such as temperature, heart rate, blood pressure, and glucometer might be installed on the patient's body. The SDES receives data from these sensors at varying intervals. Switches route data packets to gateways, which aggregate the data and send it to the cloud. The cloud is accessed by medical service providers to monitor their concerned patients.

3 | MATHEMATICAL MODELS

The capacity to make energy usage proportionate to traffic volume is referred to as traffic awareness. End system awareness is used to conserve energy by using virtual machine placements and transfers. Most energy-conscious routing algorithms do not rely on the restricted rule space within switches rule placement strategies address energy savings through rule meaning, and they save space by compressing them. Following are the models used to represent the mathematical expressions of the energy systems.

3.1 | Thermal model

The thermal model is constructed on two features. The first feature is the predicted increase in node temperature, which is attributable to the quantity of thermal loss from the nodes. Temperature is the second component that is affected by

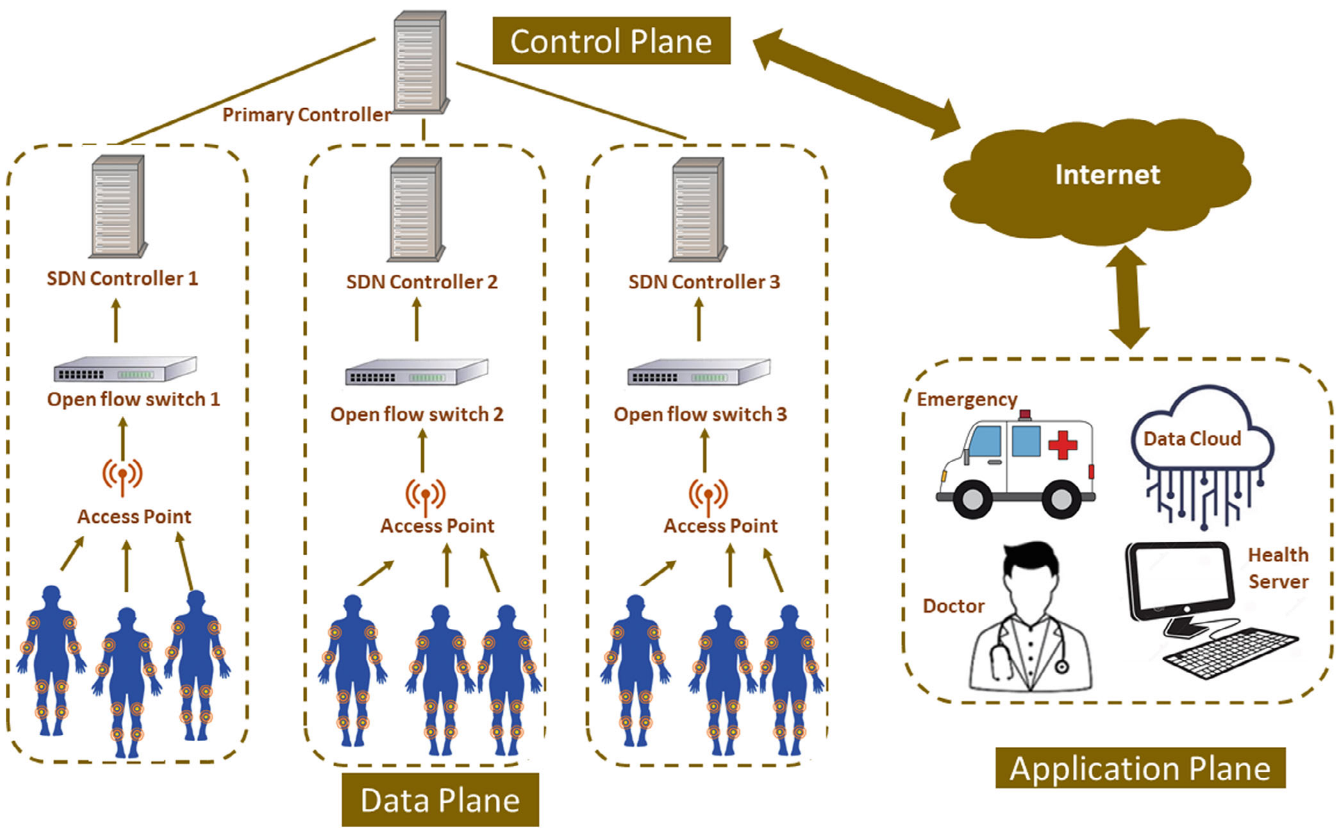

FIGURE 5 SDWBAN architecture.

the human tissues and is reliant on the first. While measuring node temperature is simple, estimating the temperature's impact on human tissues may be estimated using a few factors. The sensor provides the actual temperature of the node directly and the projected temperature. The mathematical expressions to calculate the expected temperature rise are given in Reference 32 as

$$\begin{aligned}\text{Expected temperature rise} &= \text{Total number of packets } \times \text{Average} \\ &\quad \times \text{Measured temperature rise for each packet.}\end{aligned} \tag{1}$$

The node temperature for packet transmission will be

$$T = \text{Current temperature} + \text{Exp Temp rise.} \tag{2}$$

The specific absorption rate (SAR) is given by,

$$\text{SAR} = \frac{\sigma(\text{EMF})^2}{\rho}, \tag{3}$$

where EMF is the electromagnetic field of the RF wave, ρ represents density and σ represents the conductivity rate of the concerned tissue respectively. The rise in temperature ΔT in the tissue is given by,

$$\Delta T = \frac{t(\text{SAR})}{c}, \tag{4}$$

where c denotes the specific heat capacity and t represents the time interval during which the tissue is open to electromagnetic radiation.

3.2 | Energy model

The residual energy, connection dependability, and path loss factors are employed to ensure energy efficiency in routing. Because energy resources in SDWBAN are very low, energy management is critical to increasing network longevity. Because of the limited communication range and significant route loss in WBANs, the interaction between sink and source nodes costs extra energy. The greater the energy usage, the shorter the network lifetime. As a result, to use efficient optimization algorithms, energy usage must be minimally approximated. The total energy consumption is presented as

$$E_t = E_{t,N} + E_{t,C}, \tag{5}$$

where $E_{t,N}$ is the energy consumption by the normal node and $E_{t,C}$ is the energy consumed by the coordinator. $E_{t,N}$ and $E_{t,C}$ is represented as,

$$E_{t,C} = E_{\text{sens},N} + E_{TX/RX,N} + E_{\text{proc},N} + E_{\text{tran},N}, \tag{6}$$

$$E_{t,C} = E_{\text{sens},C} + E_{TX/RX,C} + E_{\text{proc},C} + E_{\text{tran},C}, \tag{7}$$

where E_{sens} is the sensing energy, $E_{TX/RX}$ is the radio transmission and reception energy, E_{proc} is the processing energy, and E_{tran} is the transient energy as given in Reference 32.

4 | SDWBAN ENERGY EFFICIENCY SCHEMES

There are survey studies in the literature about WBAN and SDN energy efficiency as listed in Table 1. The other energy proficiency techniques for the end system are discussed in References 33–45 while the rule placement is discussed in References 46–56. Energy efficiency schemes for MAC protocols in WBAN have been discussed in References 57–73. A complete survey and analysis of recent improvements in energy efficiency optimization models for each set of solutions for SDWBAN are not available to the best of our knowledge. We discuss energy improvement strategies that may be used at various stages of SDWBAN architecture. Energy conservation in SDWBAN can be treated both algorithmically and manually through hardware advancements. Software-based solutions are available that can be used on the controller. The available energy-saving features that can be algorithmically handled are traffic awareness, end-system awareness, and rule placement.

In this section, the SDWBAN schemes for energy efficiency are discussed in detail depending on the routing algorithms, optimization methods, secure transmission, and traffic management.

4.1 | Routing algorithms

The two routing algorithms, the fuzzy-based Dijkstra algorithm, and the HUBsFlow routing protocol are discussed below.

TABLE 1 Energy efficiency in SDN.

Approach	Advantage	Disadvantage
DARE[74]	Minimized energy consumption of the nodes	Load is not uniformly distributed
MEPF[75]	Minimized energy consumption with less transmission power of the nodes	Network latency is high
SIMPLE[76]	Balanced energy consumption	Network throughput is high, packet loss is high
CoCEStat[77]	High throughput and lifetime of the network with the support of dynamic routing	Energy utilization is high
ESR[78]	Traffic load changes are handled, and patient's mobility is supported	Low network lifetime

4.1.1 | Fuzzy-based Dijkstra algorithm

SDWBAN architecture has the main concern in terms of energy efficiency. The factors considered for the energy efficiency were the remaining energy, link distance, and transmission power to determine the optimal path.[79–81] The controller, which has a complete view of the network, selects reliable and suitable paths for the coordinator nodes in SDWBAN. The suggested new measures enable better consistent network connections and less extra route discovery (reduced burden) due to the centralized and reactive routing method. ESR-W is built with 802.15.6 PHY/MAC characteristics.

Fuzzy-based Dijkstra algorithm is applied for path selection rules in SDWBAN architecture by employing new metrics such as hop count, SNR, and battery level.[82] The 802.15.6 standard specifies a generic frame organization, as well as physical and data, link layer features for communication between both the sensor nodes and the coordinator. It is also compatible with three standards of the physical layer such as human body communication band, ultra-wideband, and narrowband. The beacon mode is also supported with a superframe as the frame structure, as well as multiple access phases such as management access (MA), exclusive access (EAP1, EAP2), contention access (CA), and random access (RAP). The Slotted Aloha multiple access (MA) and the CSMA/CA approaches are also supported by this standard. Table 2 lists the various priority values established by this standard as well as the contention windows. CSMA-CA MA and MAP-RAP access phases are favored in the 2360–2400 MHz ISM band when using the superframe structure in beacon mode. Each coordinator node in the proposed technique has a neighborhood table as well as a flow table. Each coordinator node retains the node's information and battery level data in the neighborhood table. If the controller requests it, this information is delivered. SNR ranges from 10 to 30 dB, hop count from 1 hop to 15 hops whereas the battery level values range from 1 to 10 J, respectively. The controller uses fuzzy logic for the coordinator nodes to make the optimum path to translate the received information into a cost value. The Dijkstra[83] shortest route method is then used to discover the best path. As a result, no coordinator nodes with incorrect metrics are allocated as routing devices.

The controller sends the path information it has discovered using the fuzzy-based Dijkstra algorithm to the asking coordinator node and every other coordinator node along the path. The controller is responsible for setting and updating the flow tables in the coordination nodes. The simulation parameters used in Reference 82 to implement the fuzzy-based Dijkstra algorithm for energy efficiency are discussed in Table 3 while the results obtained for various performance metrics are shown in Table 4.

4.1.2 | HUBsFlow interface protocol

The HUBsFlow interface protocol is implemented which provides an energy-sensitive, manageable and flexible structure in SDWBAN.[13] In this design, HUB nodes transmit messages to their neighbors and the controller as multicast or unicast, based on the flow rule provided by the controller (not broadcast). As a result, the production of duplicate data packets may be regulated. However, in typical WBAN design, HUBs continually broadcast data packets across the network. As a result, the overhead in traditional WBAN is greater than that in the proposed SDWBAN for data packets. When a packet has to be sent to another HUB (as relay nodes) or sent to a destination (in its queue), the SDN-enabled HUB first checks

TABLE 2 User priorities for data (D) and management (M).[82]

UP	Packet type	Traffic	CSMA/CA CW (min)	CSMA/CA CW (max)
0	D	Background	16	64
1	D	Best effort	16	32
2	D	Excellent effort	8	32
3	D	Video	8	16
4	D	Voice	4	16
5	D/M	Medical data	4	8
6	D/M	Medical data with high priority	2	8
7	D	Emergency	1	4

TABLE 3 Simulation parameters for various energy efficient schemes.

	Fuzzy- based Dijkstra[82]	HUBsFlow[13]	Congestion control[32]	Traffic management[84]
Simulation time	600 s	300 s	600 s	10,000 rounds
Region	300 m × 300 m	100 m × 100 m	100 m × 100 m	2 m × 2 m
Frequency	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz
MAC protocol	IEEE 802.15.6	IEEE 802.15.6	IEEE 802.15.6	IEEE 802.15.6
Bandwidth	1 MHz	1 MHz	1 MHz	1 MHz
Data rate	971.4 kbps	971.4 kbps	8 packet/s	5 packet/s
Packet size	100 bytes	100 bytes	32 bytes	3000 bits
Initial node energy	10 J	50 J	100 J	0.5 J
No of nodes	80	24	100	15

TABLE 4 Simulation results for fuzzy-based Dijkstra algorithm.[82]

Parameters	Value
Throughput	3565.7 bps
End-to-end delay	0.01 s
Lowest delay	0.007 s
Successful transmission rate	97%
Energy consumption at different hop	0.45 J
Energy consumption at different offered load	1.3 J

TABLE 5 Simulation results for HUBsFlow interface protocol.[13]

Parameters	Value
Throughput	16 packet/s
Packet lost ratio	0.014
Lowest delay	0.006 s
Successful transmission rate	97%
Average energy consumption	3 J
Bit error rate	0.0008

the flow rules in the flow table. If no equivalent flow rule exists, the HUB node transmits a PACKET-IN message to the controller. The controller then develops a new flow rule in response to the HUB's request and delivers the message. As a result, this flow rule is added to HUB's flow table, and HUB forwards packets by this rule. All of these steps produce some sort of delay. Many inter-WBAN protocols need HUBs to continually sense the environment (to detect the condition of the idle channel) before putting packets in their queues.

In dense sensor networks, this procedure consumes more energy. Furthermore, a HUB can easily handle a large number of sensors which is one of the most significant benefits of the 802.15.6 standard. As a result, the sensors are only active during the time periods indicated by HUB, while the rest of the time they are put to sleep, decreasing energy usage. HUBs that connect with the controller regularly on each level will contact other controllers when they reach the other transmission range of both the controller and resume transmission on proper channels. Collisions, hunger, energy usage, and inter-WBAN interference issues can therefore be reduced. The packet drop ratio and rate of bit errors are also reduced, while the performance parameter is raised. The simulation parameters used in Reference 13 to implement the HUBsFlow protocol for energy efficiency are discussed in Table 3 while the results obtained for various performance metrics are shown in Table 5.

4.2 | Optimization models

The optimization models for the energy efficiency in SDWBAN are discussed below.

4.2.1 | Control plane optimization

SDWBAN gets more advanced as the number of applications and patients in the in-stalled region grows. The control plane architecture is important to the implementation and optimization of efficiency in a complex SDWBAN. The amount of controllers in the SDN control plane is critical to ensuring and performance of the network. For wired SDN implementation, several controllers reside in the control plane since the controllers have their physical resources to facilitate inter-controller communication. In the case of a wireless medium, the controllers share the same frequency band, which can cause congestion.

Because bandwidth is a precious resource in the wireless medium, employing numerous frequency ranges for the control plane is exceedingly difficult, resulting in additional issues like interference, synchronization, and so on. As a result, selecting the ideal amount of controllers to ensure service quality in SDWBANs becomes critical. Although a logically centralized controller may offer a view of the entire network, a huge deployment of an SDWBAN has significant scalability and performance restrictions.[85]

It is self-evident that having many controllers in the control plane helps alleviate the constraint of overload on the controller. The controllers, on the other hand, require regular state synchronization to keep an abstracted picture of the network.[86] Because of this synchronization, the controllers can assist the core SDESWs with requests for unidentified applications or forwarding instructions. As a result, having a large number of controllers is critical in the control plane for guaranteeing that the originating packets in SDESW requests are answered within a reasonable time limit. As a result, a perfect amount of controllers is necessary to ensure the dependability and timely supply of physiological data by SDWBAN-enabled healthcare applications. The excessive use of controllers, on the other hand, is a needless waste of resources and consequently adds redundant complexity and energy complexities.

The three main factors of SDWBAN, number of SDESWs, number of controllers, and latency are used to build a mathematical model.[87] The mathematical model establishes a link between the SDESWs, no controllers, and body sensors. The latency factor is made up of essential characteristics linked to the controller's communication with the SDESW.

Results show that the packet delivery ratio is low for a low no of controllers, and the PDR increases as the number of controllers begin to rise. The analysis is also done for the latency for several application groups. The latency is high for a low number of controllers while it is low for a high number of controllers.

4.2.2 | Congestion control optimization

The temperature dissipation of the sensors and their resulting influence on the human tissues beneath the positioned node is a critical concern in SDWBAN.[88] The nodes interact with one another through radio frequency (RF) transmissions. The heat from the RF link is received by the tissues, raising the temperature in this exact region. Another factor influencing temperature is heat generated by the nodes' internal circuitry during data processing. Temperature increases cause the creation of hot-spot nodes thus influencing the properties of human tissues.[89]

Another important element to be considered is congestion in delivery routes, which is caused by data overload in the shortest routes.[90] Other congestion issues include unequal load distribution, transmission delay, lost data retransmission, the minimal life of forwarding nodes, and so on. Congestion avoidance should be applied to save energy and enhance packet transmission.[91] The suggested approach achieves congestion management by using the congestion queue length as a consideration in the routing model. The major goal of Reference 32 is to avoid these hot-spot nodes by removing the heated node from the process of transmission till the temperature is low enough to allow safe transmission. Spider Monkey Optimization (SMO) is a universal optimization technique inspired by spider monkeys' fission-fusion social (FFS) architecture during foraging activity. SMO intimately represents two fundamental swarm intelligence theories, one is the division of labor and the second is self-organization. The spider monkey population will first be established, and they will self-organize into member monkeys, a local and a global leader. The learning and action stages are then carried out to iteratively identify the optimal options.

However, in SMO, the convergence rate is sluggish, therefore changes are proposed. The suggested EMSMO method optimizes the standard SMO method. It provided a new position update method that averages the difference between the present location and a random place. For a given issue, it creates a random place within a certain range. This recommended change promotes convergence and boosts dependability. A better-fitted solution is thought to have an ideal solution nearby.

The suggested routing method optimizes the cost model based on the parameters like connection dependability, route loss queue length, and residual energy. The connection dependability and the route loss are related to SDWBAN energy efficiency while the queue length influences congestion. Temperature control is accomplished ahead of the routing at the forwarding node selection stage. It is based on the present temperature of the nodes as well as the rise in temperature in the tissues. By using these techniques, effective routing is obtained in the SDWBAN, which aids in the stability of the applications produced with it. The simulation parameters are discussed in Table 3 while the results obtained for various performance metrics are shown in Table 6.

4.3 | Secure data delivery

As networking technology progresses, the internet steadily has become a hostile place with less intrinsic assurance of secrecy, especially for WBAN, which deals with extremely sensitive patient-related data that needs to be carefully confined to authorized users.[92] Despite advances in research and development for WBAN systems, cybercrime remains a critical barrier for WBAN to overcome. Because of the sensitive information, there is a major need for increased security in WBAN systems.[93] Any illegal entry or intrusion on the network is classified as cybercrime and therefore can result in serious and damaging con-sequences, such as the death of humans.[94,95] Thus, data confidentiality, authenticity, integrity, and safe administration, a stringent and scalable security system remain a worry for WBAN systems.

Kerberos is a network authentication protocol that provides highly powerful authentication systems. It is a method that communicates usernames/passwords in a manner that the authentication process of the parties is required before any information is transmitted, implying that passwords cannot be revealed during authentication.[96] This feature adds maturity and structural soundness to the system, allowing more secure medical data transfer. Thus a reliable and secure SDWBAN architecture is proposed for effective and energy-efficient delivery and data management.[97] For the downlink, to obtain the data, the user will submit an encrypted packet that will be reviewed by the Kerberos protocol before granting access to the authorized user to obtain the data. The SDN controller will evaluate the data format and construct the delivery route for the distribution across the software-defined platform.

4.4 | Traffic management

WBAN communication is created particularly with two topologies: one is the two-hop tree topology and the other is the star topology.[98] The two-hop tree architecture is based on the coordinated transmission of a sensor node to the sink or controller through a relay node. This method of communication uses time division multiple access (TDMA) slots, which help to save energy and extension in the lifetime of the network.[99] As a result, to achieve good QoS, a suitable relay selection is critical in the cooperative transmission technique.[100]

TABLE 6 Simulation results for congestion control optimization.[32]

Parameters	Value
Throughput	1400 b/s
End-to-end delay of different priority packets	0.06 s
Packet reception ratio at 0 dBm	0.92
Number of heated nodes at 0 dBm	6
Energy consumption for maximum nodes at 0 dBm	0.7 J
The network lifetime for optimum protocol	500 s

In Reference 84 an ERQTM system for intra-WBANs aimed at increasing network lifetime and network stability and reliability. As a result, we approached the challenge as a joint effort, devising a QoS traffic management technique (QTM) and energy-efficient routing strategy (ER). The ER scheme is based on clusters that aim to extend network lifespan. By prioritizing emergency data during transmission, the traffic management system assures network resilience and stability. Thus, good QoS is ensured. Most researchers prioritize emergency data by limiting low-energy nodes to delivering only emergency data and avoiding sending normal data. This reduces network performance and makes it impossible to achieve high network QoS.

The shortcomings are overcome by presenting an energy-efficient routing technique using meta-heuristics for selecting cluster heads. By dynamically choosing network cluster heads, this strategy avoids rapid loss of network energy. The lifetime and QoS of the network have been improved by the selection of the cluster heads dynamically among the available sensor nodes which is an NP-hard task. The proposed ER system employs a genetic algorithm[98] to optimize the selection of the cluster head.

The main factors included in the cost model are the energy consumption rate and residual energies of the node, signal-to-noise ratio, distance to the controller, and impact of the path loss. Because our approach relies on intraWBAN communication, body motions may result in route loss. The optimization process also includes path loss which has a significant impact on network throughput.

In addition to the energy-efficient method which is cluster-based, a priority-based method is discussed for traffic flow management, the emergency data (ED) is given high priority for routing, and the corresponding nodes are allocated a high transmission rate with a short sensing interval. Because high data rate transmission quickly depletes the energy for the suggested approach among sensor nodes is balanced. This is accomplished by taking into account the nodes' energy usage rates in successive periods as well as their residual energies to choose cluster heads of the network best whenever the energy level falls below a particular threshold. The best-achieved results obtained for the given performance metrics by implementing the traffic management scheme are shown in Table 7. The comparative results of various energy efficiency schemes for throughput end to end delay and transmission rate have been shown in Table 8. Results show that traffic management has the maximum throughput because it uses TDMA slots, which help to save energy and extension in the lifetime of the network. The minimum energy consumption is for fuzzy-based Dijkstra algorithm as the controller sends the path information it has discovered using the fuzzy-based Dijkstra algorithm to the asking coordinator node and every other coordinator node along the path. The HUBs flow has the maximum transmission rate as the sensors are only active during the time periods indicated by HUB, while the rest of the time they are put to sleep, decreasing energy usage as shown in Figure 6.

TABLE 7 Simulation results for traffic management.[84]

Parameters	Value
Alive nodes	2 till 9000 rounds
Throughput	10 kbps
Residual energy	2.1 J
Lowest delay	70 ms
Network stability	4900 rounds
Network lifetime	9800 rounds

TABLE 8 Comparative results for various energy efficient schemes.

	Fuzzy- based Dijkstra[82]	HUBsFlow[13]	Congestion control[32]	Traffic management[84]
Throughput	3565.7 bps	3600 bps	1400 bps	10,000 bps
Delay	0.01 s	0.006 s	0.06 s	0.07 s
Energy consumption	0.45 J	3 J	0.7 J	2.1 J
Transmission rate	97%	97%	92%	93%

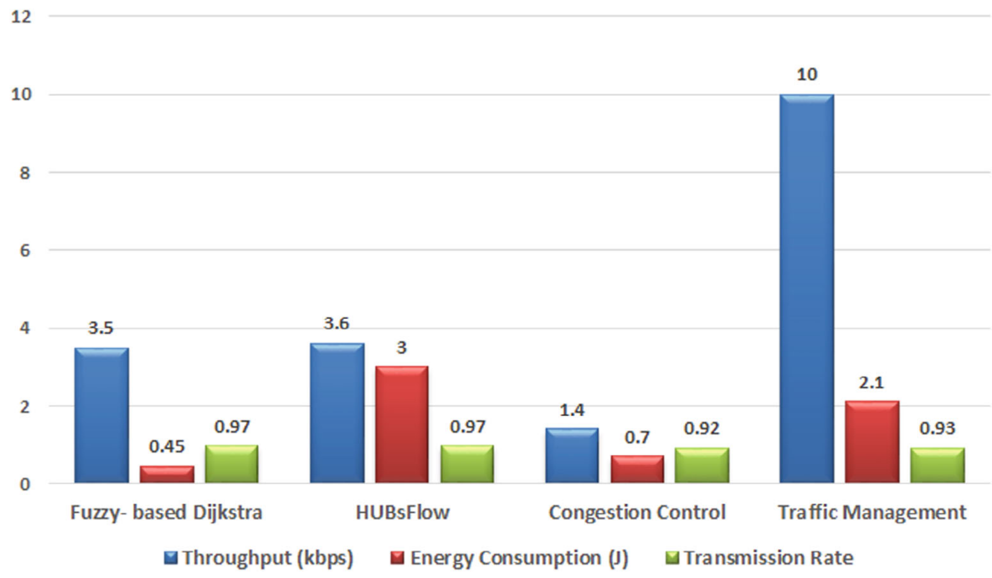

FIGURE 6 Comparative results for various energy efficient schemes.

5 | CONCLUSION

Energy awareness plays a critical role in modern networking systems design. The network performance and energy efficiency are the main features in the designing process as the QoS of the system mostly depends on them. Although the energy efficient methods have certain limitations in terms of continuous energy supply from the resources, the inefficiency of the energy systems, high energy loss and so forth yet, the researchers have made significant contributions to overcome this issue. This article discusses the energy efficiency features that may be used in SDWBAN. A comprehensive and unique classification of energy efficient solutions in SDWBAN into routing algorithms, optimization models, secure data delivery, and traffic management subcategories. For the current advances in the domain, we outline the important elements of the system and solution designs for each category. Furthermore, a detailed overview, issues, objective functions, and constraints that must be satisfied are provided for each model. Even though certain solutions for numerous aspects of energy efficiency in SDWBAN are available, there remain open research challenges, limitations, and opportunities for improvement.

Future studies will evaluate the SDWBAN framework's practicality in terms of the physiological needs of various applications. It is also critical to determine the optimal number of switches and controllers for SDWBAN in order to ensure quality of service. SDWBANs with 6G integration promise to bring wearables and healthcare into a new, revolutionary age. The ultra-high data rates, massive connectivity capabilities, and ultra-low latency of 6G will allow healthcare professionals to access and analyze high-resolution medical data in real-time, supporting fast decision-making and remote patient monitoring with unsurpassed precision. Furthermore, 6G's network slicing capabilities will let medical professionals customize network segments for certain SDWBAN applications, guaranteeing dependable, energy-efficient, and secure data transfer for a variety of healthcare situations.

AUTHOR CONTRIBUTIONS

Fahad Masood: conceptualization (equal); formal analysis (equal); investigation (equal); validation (equal); visualization (equal); writing – original draft (equal). **Wajid Ullah Khan:** conceptualization (equal); data curation (equal); methodology (equal); project administration (equal); validation (equal); writing – original draft (equal). **Mohammed S. Alshehri:** resources (equal); supervision (equal); validation (equal); visualization (equal); writing – review and editing (equal). **Albandari Alsumayt:** investigation (equal); resources (equal); supervision (equal); visualization (equal); writing – review and editing (equal). **Jawad Ahmad:** conceptualization (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal).

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No competing interests are present.

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ORCID

Jawad Ahmad https://orcid.org/0000-0001-6289-8248

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