Energy Harvesting Implementation in WBAN Routing Protocols with Multi-Relay Co-Operation

Yasir Ali Rasheed[1], Sheeraz Ahmed[1], Nazia Azim[3], Firdous Ayub[2], Muhammad Adil[1], Asif Khan[4]

[1]Department of Computer Science, Iqra National University

[2]Department of Computer Science, Women's University, Swabi, Pakistan

[3]Department of Computer Science Abdul Wali Khan University Mardan, Pakistan

[4]Government of KP Nowshera, Pakistan

*Correspondence: yasirkhan2@hotmail.com, sheerazahmed306@gmail.com, n.azim@awkum.edu.pk, firdousayub@wus.edu.pk, madil@inu.edu.pk, asif.khan43@yahoo.com

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Mostly simulations are used to evaluate the performance of Wireless Body Area Networks (WBANs). The recent researches are focused on channel modelling and energy conservation at the Network/MAC layer. Normally, collaborative learning, path loss, and energy harvesting are ignored in these schemes of studies. In this research, we will try to use an Energy Harvesting (EH) mechanism to recharge the batteries instead of replacing them time and again. In contrast with the existing studies, the proposed scheme considers collaborative learning and energy harvesting. Cost functions are used to identify the most feasible wireless route from a given node to the sink while sharing each other's distance and residual energy information. The human body temperature (thermal energy) and the pumping of the heart can be used for energy harvesting within the body, while solar energy can be used for energy harvesting of nodes on the human body.

Keywords: Cooperative, Routing, Energy Harvesting, Consumption

Introduction:

The notion of adaptive, deeply interconnected, and dynamic ubiquitous computing has existed for many years. Yet, it is only in recent times that Wireless Sensor Networks (WSNs) have been acknowledged as a crucial driving force behind the advancement of pervasive computing [1]. The combination of wireless communication and sensing technologies gave rise to Wireless Sensor Networks (WSNs). With their rapid advancement and broad adoption, WSNs are now being applied across various domains, including fire detection [2], habitat monitoring, object tracking [3], environmental monitoring [4], Vehicular Ad-hoc Networks (VANETs) [5], WBANs, etc.

The use of batteries as the only source of energy in WBANs is a significant challenge, especially in medical practice. Battery replacement can be a relatively easy task with wearable devices, but it is much more complicated and challenging in the case of implanted devices, such as surgery pain and expenses, psychological stress, and discomfort. [6].

Sensor-based networks, commonly known as sensor networks, encompass a wide range of types and applications. One notable example is the Wireless Body Area Network (WBAN), which is primarily employed for monitoring and managing an individual's health conditions. This technology gained attention only a few years or a decade ago and has been widely accepted, particularly by patients and elderly individuals, as it seamlessly integrates into their daily lives without disrupting routine activities. As per the requirements of a specific person, a WBAN is formed by placing wireless sensors on the body or embedded (implanted) inside the human body. Different sensors function self-sufficiently, capturing diverse types of information; for medical purposes or study, the captured information is transmitted wirelessly, making use of an external server.

These sensors are designed to measure and monitor various physiological parameters such as body temperature, blood pressure, heart rate, respiratory rate, glucose level, and movement-related data.

For additional analysis and processing, a wireless transmission is formed to transmit the gathered parameters that could be Low-Level being processed or raw samples, to a base station or sink [7]. The sensor nodes monitor or check the conditions of the body, and the captured data is compared for an optimal level. The installed sensors are capable of sending alert signals if one or more parameters are found out of the standard (defined) range [8].

Applications of WBAN:

WBAN has found its implementations in different fields of life, i.e., from military to sports to medical, as a result of fabulous research. For instance, the physical fitness of the players, personnel employed in various forces from the Police to the military, and astronauts can be crisscrossed by WBAN techniques. Even for a blind person, Retina Prosthesis chips [9] are implanted in the retina to support them to give a watch of the world. The asthma patients, people with heart problems or diabetics, patients with Alzheimer's or Parkinson and many others are making use of WBAN technologies [9].

Traditionally, healthcare systems required patients to remain in hospitals for continuous monitoring. However, with modern advancements, patients can now move freely while being remotely monitored, leading to a significant reduction in medical labor and infrastructure costs. To enhance the quality of life for patients and elderly individuals, WBANs enable them to carry out their daily activities without interruption. Their physical conditions are continuously monitored remotely, and potential diseases can even be diagnosed in real time through these systems [10][11]. WBANs are getting really widespread as they are equally monitoring the health of older people. Particularly in developed countries, the population of old age people is collectively growing. It is believed that in the coming forty to fifty years, their population will have a jump from 10% to 20% [12]. In developed countries, the ratio of the working to the retired is also lessening. Besides, the number of sequestered individuals is growing means there are a lot of people who don't have anyone to care for. The challenges highlighted in this proposal have inspired the design and development of modern healthcare systems. As a result, to advance beyond traditional Wireless Sensor Networks (WSNs) in areas such as mobile health (m-Health) and telemedicine, Wireless Body Area Networks (WBANs) were introduced [13]. The various applications are illustrated pictorially in Figure 1.

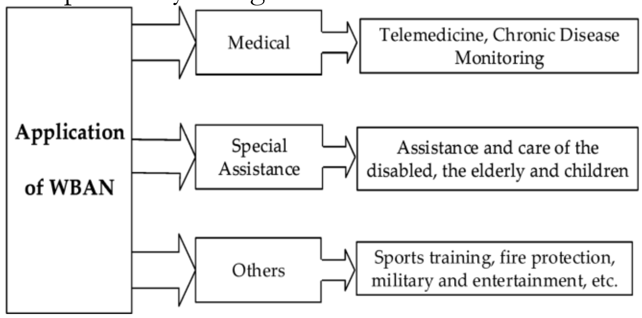

Figure 1. Applications of WBANs

Generalize the Architecture of WBAN:

A distinctive architecture of WBAN, which is categorized into four layers, is shown in Figure 2 [10]. In the initial layer, i.e., Layer 1, termed as the BAN Layer, a WSN is created using different wireless sensor nodes functioning in a small area. Depending on the design and specific requirements, the sensor nodes capable of collecting data may be positioned either on or within the human body. These nodes can be implanted inside the body, referred to as in-body sensors, or integrated into clothing or worn on the surface of the body, known as on-body sensors. The chosen parameters are sensed and captured nonstop by the sensors and are forwarded to the concerned external server, where the sent data is analysed. As per requirements, the nodes are designed to be able to perform local processing before sending. There are two possible approaches for handling the data collected by sensor nodes: it can either be processed locally within the upper layers of the node itself or transmitted to a central coordinating device, commonly referred to as the sink. While transferring data on a wireless network, the transmission power of a node might be affected by three main reasons, i.e., Signal-to-Noise Ratio (SNR), Receive-Noise-Figure (RNF), and Body Path-loss (BPL) [14]. The performance of the transmission link largely depends on the Signal-to-Noise Ratio (SNR). Each device possesses its own Receiver Noise Figure (RNF), which affects signal quality and varies across devices. Furthermore, antenna specifications and their respective radiation patterns are key factors considered in evaluating Body Path Loss (BPL) [15][16].

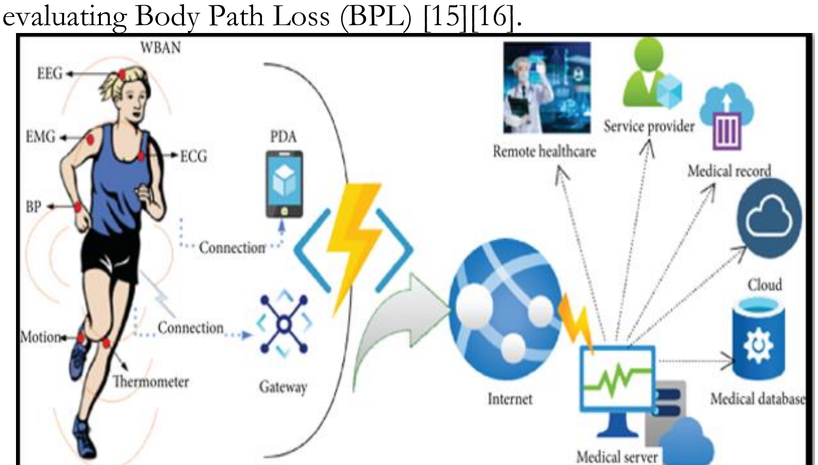

Figure 2. Architecture of WBANs

In Layer 2 transmission of data is well-thought-out. Consider if there is a medical server in a hospital, the gathered data is transmitted to it using sensor nodes. Layer 2 Technology, which comprises Access Point (AP) type of devices. Layer 2 may consist of smartphones or

PDAs with Bluetooth devices, and a suitable protocol is selected for the device being used. These devices gather the data and forward it to Layer 3, which also contains a Bluetooth device. Generally, in a house, there are different rooms and these are provided with an AP that might be connected with a wired network, for example, Wi-Fi [17].

The third layer of a WBAN, known as Layer 3, incorporates the Decision Measuring Unit (DMU). The DMU autonomously performs all processing tasks and is connected to the hospital's medical server at the backend. Its primary function is to collect and analyze data, enabling informed decision-making based on the patient's physiological information.

The final layer of WBAN architecture is Layer 4. It is actually the server placed at a remote location where the processed data is transmitted from DMU. The server then transmits this information to the designated physician, allowing them to assess the patient's health status. This final layer not only facilitates routine healthcare monitoring but also supports emergency response services when critical conditions are detected.

Routing Importance in WBAN:

Sensor node faces different constraints in supplying the energy & bandwidth due to the node's small size in nature and application type. This restriction, combined with the typical deployment of a large number of sensor nodes, poses many challenges to the design and management of the WBAN and requires an awareness of the energy at all layers of the network protocol stack. For example, at the network layer, it is highly desirable to find a method for energy-efficient route discovery and a data relay from a sensor node to a sink in order to enhance the network's lifetime to a maximum level. Routing in WBANs presents significant challenges due to their inherent constraints, including limited energy and storage capacity, transmission channel impairments, high node mobility, and the need to maintain an adequate quality of service (QoS). These issues distinguish WBAN from other wireless mobile networks like mobile ad-hoc networks (MANETs), Vehicular Ad-Hoc Networks (VANETs), Fly Ad-Hoc Networks (FANETs), etc.

Energy Issues in WBAN with reference to COVID-19:

Energy is one of the main well-known problems that are faced by all types of Wireless Sensor Networks (WSNs) [18], especially WBAN. It is nowadays the main research area in WBANs. To enhance the life span of WSNs, continuous research is being done in order to develop or enhance routing protocols, transport protocols, low-power MAC protocols, and even low-power design of sensors' operating systems.

In WSNs, most sensor nodes rely on batteries for power. When the battery energy is exhausted, the node ceases to function and disconnects from the network, unless its power source is replenished or recharged using an energy-harvesting technique [19].

Energy harvesting is termed as a technique that is used to automatically generate energy from the network's surroundings in order to offer a power supply uninterruptedly to the sensor nodes. An energy harvesting system can be categorized into two types [20]:

Generated energy is not stored in a battery; rather, it is transformed directly to electrical energy and is sent to the node.

The generated energy after conversion to electrical signals is stored in a battery and then supplied to the sensor node.

Various Energy Harvesting (EH) techniques are employed to supply alternative power to sensor nodes, as illustrated in Table 1.

Table 1. Energy Harvesting Techniques

Energy Source	Performance [21]	Nature of source	Transducer	Harvester Consideration	Efficiency	Nodes [20]
Solar energy (Ambient light)	100mW /cm^2 (Direct Sunlight)	Predictable but uncontrolled	Photovoltaic cell	Light Intensity and Wavelength	10-24%	IRN (MicaZ) BLSH (Tmotesky) LTSN (Fleck1) HydroWatch (TelosB) Helimote (Mica2)
	100µW /cm^2 (Indoor)					
Thermal (Body heat)	60µW/cm^2 at 5K gradient 135µW/cm^2 at 10K gradient	Fully controllable & unpredictable	Thermo-electric element	Thermal gradient, heat flux	~0. 1% ~3%	Flex TEG Wearable TEG
Mechanical vibration Piezoelectric	4µW/cm^2 (human motion)	Unpredictable & uncontrolled	Piezoelectric Transducer	Amplitude of vibration and resonant frequency	25~50%	AEM MEEG Piezoelectric MEEG
	250µW /cm^2 (Machine)					
Mechanical vibration Electromagnetic	50µW /cm^3 (Human)					Electronic MEEG
	2mW/cm^3(Machine)					
Ambient Radio frequency	0. 1 µW /cm^2 (Background)	Partially controllable	Antenna	Distance from the source and the resonance of the antenna	~50%	
	1 mW/cm^2 (Directed)					
Blood pressure	0. 93W at 100mmHg	Fully controllable & predictable	--	--	--	--

Objectives:

The main objectives of this research are:

Study energy harvesting effects by using a different number of forwarding/relay nodes.

Work on and feature new routing schemes for WBAN that have energy harvesting features and their practical implementation.

The possibility of minimizing energy consumption and processing calculations made by the nodes along the route.

Propose a technique to prolong battery life with minimum path-loss effects with the help of clustering.

Work on developing an efficient routing protocol that covers the path loss issue in LoS and NLoS communication.

Literature Review:

The paper [22] considers the WBANs for medical purposes and discusses the techniques for consistent data transmission. The RTT protocol utilizes a two-hop network topology, focusing on a Restricted Tree Topology (RTT) structure. In this setup, intermediate relay nodes are positioned between the sensor nodes and the sink to facilitate efficient data transmission. There are complications of high propagation loss and problems of limited energy, but these issues are tackled with the RTT techniques that make a tree topology to get evolve from a star topology with a limited number of hops that make use of relays. Received Signal Strength Indicator (RSSI) is used to find the occurrence of links amongst nodes. Opportunistic and dynamic relays enhance the reliability. In this method, the use of a huge number of relays increases human anxiety.

An improved variant of the SIMPLE protocol, termed IM-SIMPLE, has been presented in studies [23][24]. This version incorporates multi-hop communication to enhance throughput and minimize energy usage, addressing the limitations present in the original SIMPLE protocol. A node that has less distance from the sink and has high energy will be selected as a relay/forwarder node due to a better cost function. Patient's hand mobility is examined as one can move one's hands to the right or left side of one's body. This characteristic decreases the packet drop ratio, therefore deliberately affects energy consumption along with throughput. Regarding stability period, minimum energy consumption, network lifetime, and throughput, this protocol has performed better than M-Attempt [25] and SIMPLE. But no attention is given to path-loss amongst sensor nodes communicating to each other.

In [26], the authors proposed a scheme termed as tree-based energy-efficient routing scheme (EERS). The aim was to attain higher reliability and energy efficiency with low overhead to jointly address adaptive power control and routing in multi-hop WBANs. Numerous experiments have been conducted using the MicaZ WBAN testbed to assess its performance in comparison to the Collection Tree Protocol (CTP), focusing on key parameters such as packet reception ratio (PRR), collection delay, energy consumption, and energy balancing. When it is matched with CTP, it interestingly shows long network life, the least energy consumed, and better energy balancing.

Paper [27] discusses two protocols for two implementations of WBAN called LAEEBA (Link Aware Energy-Efficient Body Area) and Co-LAEEBA (Cooperative Link Aware Energy-Efficient Body Area). The primary focus here is on path loss and collaborative learning. To ensure efficient data transmission, nodes are designed to share their resources with one another, enabling cooperative communication within the network. Cost function calculation for a reasonable or feasible route from a node to any node depends upon at least two factors, i.e., node distance from the sink and residual energy. If papers [24][25] are reconsidered, it is found that through simulation that based on matrix path loss, Sink is aware of ID, distance energy, and stability period. Co-LAEEBA gave better outcomes as compared to LAEEBA, SIMPLE, and M-Attempts. However, its limitations include functionality restricted to a fixed number of nodes and design constraints that allow operation for only a single user authorization.

The authors represented in [28] the Adoptive Multi-hop tree-based Routing (AMR). AMR makes use of fuzzy logic to calculate further nodes and different network essentials. This approach aims to enhance overall network performance by optimizing key factors such as data loss, energy consumption, and packet delivery rate. Additionally, three key network metrics, such as hop count and Received Signal Strength Indicator (RSSI), are integrated using fuzzy logic techniques to optimize network performance and decision-making. In paper [29], the authors proposed the Energy-aware Peering Routing Protocol (EPR), a WBAN architecture designed for an internal hospital environment with a new mechanism of peer discovery with routing table construction. Three scenarios, including fixed and variable numbers of packets transmitted from source nodes, are considered for better analysis. In the first and second scenarios, static nodes are taken into consideration, while mobile nodes are used in the third scenario. EPR resulted in decreasing the traffic load, increasing the successful broadcast rate, and the number of packets forwarded by the node and in-between the nodes. In case of buffering, there can be an overflow, and due to this, there can be a packet drop that is avoided.

A limitation of this technique is that it involves broadcasting Hello packets, which increases network traffic and consequently raises the overall energy consumption of the body area network.

The authors of Paper [30] proposed a multi-hop routing protocol designed to enhance WBAN performance by improving energy efficiency, extending network lifetime, and increasing the Packet Delivery Ratio (PDR). The protocol employs fixed nodes that function as relay nodes. Several parameters are taken into account when calculating the cost function, which is used to select the most suitable forwarder node. For WBANs, the authors in [31] recommend the Balanced Energy Consumption (BEC) routing protocol. Node's distance from the sink is considered for the cost function for the selection of the relay node. In order to distribute an equal load, the Relay (Forwarder) nodes are nominated in every round. It works in a fashion that if the sender node is nearer to the sink, it transmits the sensed data to the sink directly, in other case closest relay node is selected for sending data. For residual energy, a threshold value is set; in case if the threshold value is met, then the node transmits the important data to the sink. Simulation results show that the new protocol is valuable for network lifetime than the On Increasing Network Lifetime (OINL) scheme.

An already designed protocol, TEEN (Threshold sensitive Energy Efficient sensor Network) for WSN, is thoroughly studied by researchers in [32]. WBANs can utilize the TEEN protocol to generate and transmit patient data. Its performance is evaluated based on factors such as the number of critical events detected per iteration, the accuracy of vital patient data computation, the total energy consumed across iterations, and the balance between false acceptance and false rejection rates. The author in [33] proposed an adaptive routing protocol that utilizes channel information to determine the most efficient data forwarding strategy. The primary objective is to minimize the energy consumption per transmitted bit. When the link quality falls below a defined threshold, the protocol employs a relay source node to maintain reliable communication. Simulation outcomes have confirmed that the proposed mathematical model outperforms earlier approaches, delivering superior efficiency and reliability. For WBAN, the Paper [34] presented a protocol that is energy efficient, stable, and reliable. Residual energy is used by this protocol to enhance the network lifetime. The suggested model selects energy-efficient stable links for transmission. Results produced by simulation show that the proposed model performs well with respect to the use of energy and routing overhead.

An adaptive protocol, which is highly energy-efficient and fuzzy, is presented in paper [35]. Clusters are formed to use the direct transmission scheme that depends on the location and situation of the sensor node. Simulation of this protocol resulted in improved network lifetime, and the stability period is enhanced.

Priority-based Energy Aware (PEA) routing protocol is proposed in this paper [36]. The parent node that is connected to the sink is chosen by child nodes using the cost function. The cost function depends upon remaining energy, priority, and the distance of the node from the sink. Distance helps to distribute packets to parent nodes and respond to bodily gestures. The remaining energy promotes load balancing, i.e., different nodes are selected for transmission. Prioritization assists in determining the most efficient routing path within a WBAN. When evaluated against cost function metrics, the PEA protocol demonstrated a 50% improvement in throughput, network lifetime, and residual energy compared to existing methods.

A new protocol named "Based on Time Slots and Sleep Scheduling DSR (BTSASS-DSR)" is discussed in the paper [37]. The basic idea behind this improved DSR over the traditional DSR is the addition of deterministic scheduling and a deep sleeping mechanism. The theory and implementation steps of BTSASS-DSR are also defined. This protocol is more energy efficient than DSR in terms of the nonlinear mathematical model of battery discharge.

In [38], the authors introduced a new algorithm for the AODV routing protocol based on Priority-Queuing. This scheme distinguishes different kinds of traffic based on the criticality of data. The NS-2 simulator is used to simulate different scenarios using this algorithm to obtain and analyse the results.

In a health care system, the authors of the paper [39] conferred the ways for the practice of WBAN. Here, the cost function calculates the path's reliability with respect to the criticality issue. Simulation results indicate that the proposed protocol achieves a longer energy stability period and demonstrates high cost-effectiveness. In paper [40], an energy-efficient and high-throughput protocol named NEW-ATTEMPT for WBAN is proposed by the researchers. Sensors of different types (heterogeneous) are used to create a network in the human body. The cost function needed to forward data between nodes is computed on the basis of remaining energy, the rate of transmission of data to be sent, and the distance between nodes.

To minimize delays, the protocol considers the distance factor by selecting the nearest node for data transmission. Additionally, the concept of residual energy is incorporated to ensure efficient energy utilization throughout the network.

Reliability Enhanced Adaptive Threshold based Thermal Unaware Energy Efficient Multi-Hop Protocol (RE-ATTEMPT) for WBAN is anticipated by the authors of the paper [25]. Nodes are positioned at fixed locations based on their energy levels. A multi-hop communication pattern is employed for regular data transmission, while emergency data is transmitted directly to the sink node for immediate response. The cost function for this protocol is the minimum hop count. Path loss estimation and problem formulation are selected as factors for designing the simulation. Additionally, the considered protocol beat the previously designed protocols in terms of net lifetime and packet drop ratio.

However, this protocol lacks a mechanism for retransmitting failed data packets and suffers from low throughput.

Contrary to previous studies, the authors proposed a novel Cognitive Radio (CR) WBAN relay model that incorporates energy harvesting (EH) and a unique system architecture. A key consideration in placing the sensors is classification based on the primary and secondary networks, where some nodes require more energy and spectral resources to transmit, which are scheduled using cognitive radio methods. It was also proposed that the relay node in a secondary network, having two secondary nodes, also had additional performance measures. In this study, the concept of cognitive radio, in which sensors are applied in medical and non-medical applications, was investigated. Nodes used for medical purposes are prioritized and referred to as primary users. This approach will aim to ensure a satisfactory quality-of-service (QoS) in these sensors [41].

Table 2. Description of Different Routing Protocols in WBAN

Protocols	**Parameters**									
	Routing Category	Network Lifetime	Stability Period	Reliability	End-to-End	Path-loss	Throughpu	Energy Conservation	Cooperation	Energy Harvesting
RTT [22]	Mobility aware, Cluster &tree based, link aware	√	x	√	x	√	√	√	x	x
IM-SIMPLE [23]	Mobility aware, Link aware.	√	√	x	x	x	√	√	x	x
EERS [26]	Mobility aware, Link aware, Cluster based.	√	x	x	√	√	√	√	x	x
Co-Laeeba [27]	Link aware	√	x	x	√	√	√	√	√	x
AMR [28]	Link-aware, Cluster-based	√	x	x	√	x	√	√	x	x
EPR [29]	Link aware	√	x	x	x	√	√	√	x	x
EnECR [30]	Link aware	√	x	x	x	x	√	√	x	x
BEC [31]	Mobility aware, Link aware.	√	√	x	x	√	√	√	x	x
TSEENP [32] *	Mobility aware	√	√	x	x	x	x	√	x	x
AdRP [33]	Link aware	√	x	x	√	x	x	√	x	x
ESR [34]	Link aware	√	√	√	x	x	x	√	x	x
EEFARP [35]	Cluster-based, link-aware	√	√	√	x	x	√	√	x	x
PEA [36]	Cluster & Tree, Mobility aware	√	x	x	√	x	√	√	x	x
ImDSR [37]	Link aware, medium access based	x	√	√	√	x	√	x	x	x
P-AODV [38] *	Cross Layer	x	x	√	√	x	√	x	x	x
CoER [39]	Link aware	√	√	x	√	x	√	√	x	x
RE-ATTEMPT [25]	Link aware	√	√	x	√	√	x	√	x	x

This work proposed a protocol called ZENMAC that combines the LPL approach with a multistage beacon approach. This protocol addresses a significant problem with the traditional IRDT protocol, where a longer intermittent period drastically increases the total power costs of the network. The ZENMAC protocol can be employed to reduce power consumption without overburdening the workload of individual devices. Further, ZENMAC fully manages the sporadic interval based on communication data of every node, thus improving the flexibility of the protocol. ZENMAC energy load control functionality provides efficient use of the power available and can tolerate a limited amount of loss in communication quality. As a result, the protocol facilitates the creation of long-lasting networks and enables autonomous, decentralized operation, even under conditions of uneven power supply [42].

Problem Definition:

After studying and having a thorough readout of several schemes for WBAN, it is found that researchers considered a variety of parameters in designing newer routing techniques. Various methods highlight the diverse parameters like increasing stability time and life-time of network, maximizing packet delivery ratio, decreasing end-to-end delay, reducing path-loss issue, and minimizing energy consumption, as shown in Table II.

Reliable, consistent, and fast transfer of data by the sensor nodes and low energy consumption are highly important in WBANs. A direct link for the transmission of data between sender and receiver nodes is always preferred. However, path-loss due to noise, channel fading, and node mobility in both Non-Line-Of-Sight (NLoS) and Line-Of-Sight (LoS) is experienced in communication links among nodes.

At any given moment, the packet drop rate may increase significantly due to high noise levels and low Signal-to-Noise Ratio (SNR). Therefore, to ensure low-energy consumption with high throughput by the sensor nodes, a reliable and efficient routing scheme is required for WBAN.

The use of small batteries in sensor networks has significantly limited their lifetime. To address this, ambient energy sources can be harnessed and stored for later use, a process known as Energy Harvesting (EH). To address these problems, such as low throughput, high path-loss, and low network life-time, this research intends to develop such a scheme that will not only help in solving these issues but also help in reducing energy utilization for increasing network life-time by means of energy-efficient routing with harvesting techniques. The focus of this research is to explore techniques for implementing energy harvesting in WBANs, an area that has not yet been thoroughly addressed. In the wave of COVID-19, where mostly people are advised to stay at their homes so how can they manage to be regularly checked up by their doctors, and how can they manage to energize the body sensors if deployed. WBAN is the answer in the wave of COVID to be checked remotely by their doctors, and Energy Harvesting will be the solution to energize the sensors if deployed and not easy to replace.

Contribution of the Research:

This research study contributes to the literature in the following ways.

A search of the literature revealed few studies that have used EH schemes using routing protocols in WSNs and Underwater Sensor Networks (UWSNs). However, there has been no research work on EH in WBANs. Therefore, this study aims to fill this gap by implementing EH to prolong network life to longer coverage of WBANs.

So far, path loss has received limited attention in research. It arises in communication links between nodes due to channel impairments—including attenuation, distortion, fading, noise, and node mobility—impacting both Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) conditions.

Therefore, the goal of this study is to contribute to this growing area of research by improving existing path loss schemes and proposing new ones.

The sensor nodes utilized in WBAN are size-wise very small, which means that these are primarily energized by non-renewable and energy-efficient batteries. Recharging or replacing the battery can cause noteworthy stress when one or more devices must be implanted (in some cases, requiring surgery) or worn by a person. Also, each node of the WBAN has its own unique characteristics that cannot be executed by other nodes. When a sensor is exhausted, WBAN will not work properly or may even stop working. Therefore, it is necessary to extend the life of each sensor node in WBAN to reduce the pressure of frequent sensors. This research will also tend to work for extending the network lifetime of WBAN, so that a WBAN may always be working smoothly.

WBAN is the answer in the wave of COVID to be checked remotely by their doctors, and Energy Harvesting will be the solution to energize the sensors if deployed and not easy to replace.

Research Methodology and Techniques:

The proposed algorithm will work as follows, shown in Figure 3:

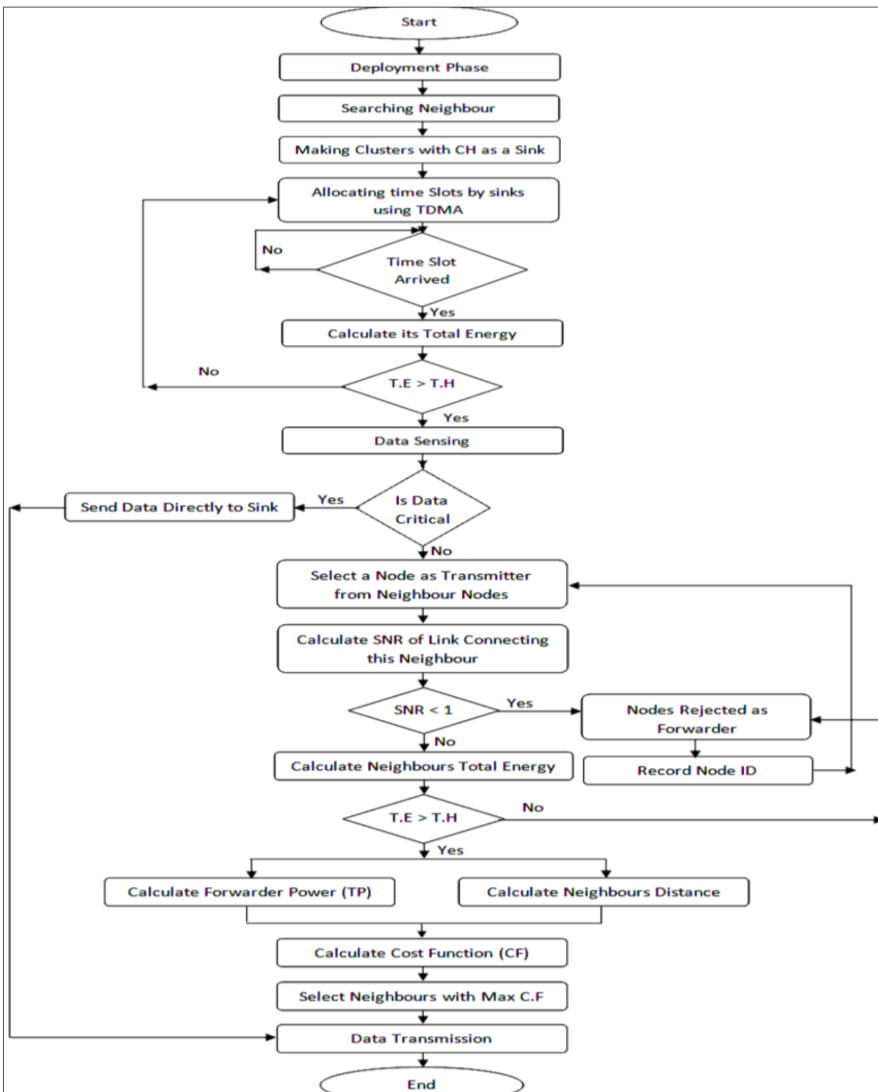

Figure 3. Flow chart of the proposed scheme

Communication Procedure of the Anticipated Protocol:

First of all, the sensor nodes will be installed/implanted in the human body.

Then, neighbouring nodes will be searched.

On the basis of information exchanged within sensor nodes, clusters are formed with sink nodes S1 and S2 as Cluster Heads (CHs).
The TDMA access method is employed by CHs to allocate time slots to every sensor node in their respective cluster.
Each node, before sensing, keeps on checking for its allocated time slot.
When the sensor node's allocated time slot arrives, it first checks its Total Energy.
If the Threshold value is less than the total energy, the data sensing phase is started; else, the node waits for enough energy.
The sensor nodes begin to sense data in the data sensing phase.
It is checked how much the sensed data is critical.
If the sensed data is critical in nature, the concern node sends it to the concerned sink directly.
Now this node (which has sensed the data) starts selecting the relay node by selecting one neighbour from its neighbour table, one after the other.
The selected neighbour is first checked that whether it has been previously rejected to become a relay/forwarder node in the same round.
The Specified Link SNR is calculated at this stage.
If (calculated value of SNR < 1) then this neighbour node is not accepted as a forwarder and its ID is stored.
If (SNR >= 1) then neighbour's Total Energy (T.E.) is calculated.
In order to calculate total energy, Residual Energy (R.E.) and its Harvesting Energy (H.E.) are calculated, and both are added and called Total Energy (T.E.).
The T. E. is compared with a defined threshold value for energy (T.H). If the (T.E<threshold value), then this neighbour node is not accepted as a forwarder node or a relay node, and its ID is recorded.
In case of (Total energy of this neighbour node >threshold value), then additional steps are taken.
The neighbour's distance and Transmission power required are calculated.
Now the Cost Function (C.F) of this link connecting this node with this neighbour is calculated by taking into account the transmission power, neighbour's distance, and T.E.
Further, the calculated value of C.F. is compared with other nodes' C.F.
The neighbour node whose C.F value is maximum is selected as the forwarder node.
After selection, the node sends its sensed data to this newly selected forwarder.

Relay Selection for Cooperation:

The Co-LAEEBA protocol selects its collaborating node in each round, unlike LAEEBA, which uses a forwarding node. This results in balanced energy consumption across sensor nodes, and it also reduces the overall network energy consumption. The sink is responsible for maintaining the information about the ID, distance, and residual energy of all the nodes in the network. The decision of sending data using the cooperative method or directly to the sink is made on the basis of calculations of the cost function of the relay node. The cost function *c(i)* of an *ith* relay node depends on its residual energy *Ere(i)* and is calculated by deducting the energy consumed by the node from its initial energy. *R* communicates that it's the data it received from the *S* and its own data, whereas *S* can have different paths to sink. Normally, data is transferred through *R,* but during an emergency, it is transferred directly to the sink. It is worth mentioning that the node with more relying responsibility consumes energy quickly as compared to other nodes. In Co-LAEEBA, *S* sends data directly to the sink if it has more energy than *R*. It is evident from the scenario that if *S* has **a** sink node in the next-hop, it will never use cooperation. In case there are multiple *R* nodes for *S,* then the *R* node with higher energy and shorter distance is selected. This requirement is fulfilled by the cooperative node [27].

Routing and Co-operation Phase:

A single source-destination pair that is separated by a certain distance is taken into consideration to describe the routing phase. There are two stages to the entire cooperative procedure. In the first phase, the relay *R* and the destination *D* receive the source *S* information. In the second phase, *R* transmits the received information from *S* to *D*. d_1 is the distance between the relay and source, while d_2 is the distance between the relay and destination. In the first phase, the information received at *R* and *D* from source *S* can be represented as [27].

$$y_{SR} = h_{SR}X_S + N_{SR}$$
$$y_{SD} = h_{SD}X_S + N_{SD}$$

Where x_S is the information symbol transmitted from *S*, h_{SR} is the characteristic of the wireless medium from *S* to *R*, and h_{SD} is the characteristic of the wireless medium from *S* to *D*. These coefficients are modelled as complex Gaussian random variables with zero mean and variance. σ^2, expressed as $CN(0, \sigma^2)$. N_{SR} and N_{SD} represent the noise components in the links from *S* to *R* and *S* to *D*, respectively, like shadowing and fading [27].

In a WBAN, direct transmission from the source to the sink can result in severe fading and strong shadowing, potentially causing link failure. Among the factors affecting signal attenuation, free-space path loss and fading have the most significant impact; therefore, both must be carefully analysed. The signal received at *D* from *S* and *R* can then be modelled for path-loss as a function of distance according to the free space formula by Friss, as given below [27].

$$y_{SR} = \left[S_{SR}.\left(PL_{0SR} + 10n.\log_{10}\frac{d_1}{d_0}\right)\right]x_S + N_{SR}$$
$$y_{SR} = \left[S_{SD}.\left(PL_{0SD} + 10n.\log_{10}\frac{d_1 + d_2}{d_0}\right)\right]x_S + N_{SD}$$

Thermal noise, shadowing, and path loss are considered in this research. PL_{0SR} and PL_{0SD} represent the path loss, while S_{SR} and S_{SD} represent the shadowing or slow fading, and all are multiplicative by nature. On the other hand, N_{SR} and N_{SD} represent the noise effect between source-to-relay and source-to-destination and are additive by nature. The basic sources of noise are components that are complex Gaussian random variables with mean zero and variance. σ^2. Total noise power is given by $N = 2\sigma^2$. PL_0 is the free-space path-loss in dB.

In the second phase, the signal received by *R* from *S* is processed and retransmitted to *D*, which can be expressed as [27].

$$y_{RD}\ (S_{RD}.PL_{RD}(d_2))x_S f(y_{SR}) + N_{RD}$$

The shadowing effects due to environment (L_{eRD}) and due to body movements (L_{bRD}), Eq. (12) can be expressed as:

$$y_{RD} = (L_{eRD} + L_{bRD})f(y_{SR}).\left[PL_{0RD} + 10n.\log_{10}\frac{d_2}{d_0}\right]x'_S + N_{RD}$$

$f(y_{SR})$ Is the function applied to the received signal from *S* at $R. x'_S$ Is the signal which is received at *D* after passing through the *S–S-S-S-R* link, which may be faded and may not be the same as x_S.

Relay Selection for Co-operation:

The source, *S*, can have multiple paths to sink. The urgent (emergency) data is transmitted directly to sink, while normal (non-emergency) data is transmitted through *R*. A node that has more relaying responsibility consumes energy quickly as compared to other nodes.

$$c(i) = \begin{cases} E_{re}(S) > E_{re}(R), & \text{direct transfer} \\ \text{else} & \\ E_{re}(S) \leq E_{re}(R), & \text{relay path multihop} \end{cases}$$

The above equation clearly indicates that if multiple relay nodes are available in the path, but the node ***S*** has a sink node as its next-hop node, it will never use cooperation. If there are multiple *R* nodes for *S*, then *R* with the higher E_{re} And a shorter distance from *S* is selected to maximize residual energy. The cooperative node is the one satisfying the aforementioned condition.

Relay Strategy:

In this research, as we are considering the Amplification Factor (AF) technique, R multiplies the amplification factor β with the signal received from S before forwarding it to D, i.e., y_RD=β (y_SR). If Ps and Pr are the transmission powers of S and R, respectively, then the factor β can be written as [27]:

$$\beta = \sqrt{\frac{P_r}{P_s|S_{SR}.PL_{SR}|^2 + N_0^2}}$$

where N_0^2 Is the noise spectral density at the relay node? β is also known as Channel State Information (CSI) assisted *AF* relay gain since the relay node needs to estimate the instantaneous channel information of the *S*–*R* channel. β provides amplification at *R* to counter the effects of the channel fading and prevents the relay gain from saturating when the *S*–*R* link undergoes a deep fade. Power is defined as energy per unit time; hence, expressing the transmission powers of *S* and *R* in terms of energy, the above equation can be expressed as:

$$\beta = \sqrt{\frac{E_r}{E_s|S_{SR}.PL_{SR}|^2 + N_0^2.\Delta t}}$$

Normally, fading is independent of time, therefore $N_0.\Delta t \cong N_0$ And β can be rewritten as:

$$\beta = \sqrt{\frac{E_r}{E_s|S_{SR}.PL_{SR}|^2 + N_0^2}}$$

Hence, the signal received at *D* in the second phase can be rewritten as:

$$y_{RD} = h_{RD}\beta(S_{SR}.PL_{SR}(d_1)x_S + N_{SR}) + N_{RD}$$

In this context, the amplitude of the signal received at the source (R) and destination (D) follows a Rayleigh distribution. The links are assumed to operate independently of each other's transmissions and are modeled using Rayleigh fading.

Combining Strategy:

The Co-LAEEBA uses FRC as the combining strategy and demonstrated enhanced performance as compared to other combining techniques such as MRC, Equal Ratio Combining (ERC), and Signal to Noise Ratio Combining (SNRC) [27]. In FRC, signals are weighted with a constant ratio instead of just adding the receiving signals. This ratio indicates the average channel quality and shows the influence of shadowing and other effects. For a single relay node, FRC can be written as:

$$y_d = w_1 y_{SD} + w_2 y_{RD}$$

where y_d Is the combined output signal at *D*, while *w1* and *w2* are the weights of the two links. Numerous relay nodes can be. This expression can be extended to numerous relay nodes. Here, weights are a function of distance, and their ratio can be stated as:

$$\frac{w_1}{w_2} = \frac{d_1 + d_2}{d_2}$$

For *AF* technique *2:1*, while for *DF* technique, *3:1* is an optimal weight ratio [27].

Tools of Research:

MATLAB is chosen for simulating the research conduction. Nowadays, MATLAB is widely preferred by researchers in the WBAN community as the primary software for conducting simulations.

Research Outcomes:

A lot of schemes highlight diverse parameters like

Increasing the period of stability of the network
Maximizing the packet delivery ratio
Lessening end-to-end delay and especially
Reducing the remaining energy consumption.

On the basis of all the above-mentioned challenges, we proposed new routing protocols that should be able to address the above challenges to their optimum levels. These routing protocols will prove to be energy efficient with better throughput, enhancing the stability period of the network. These will be computationally simple and implementable, and will have the feature of energy harvesting and control of path loss.

These new routing schemes will be based on new mathematical models inspired by the modelling designed by modern researchers to develop those dimensions and areas that have not been considered till now. In order to conduct the research in a proper way, a comparative analysis of previously designed methods and techniques has been conducted. Results from simulations of existing schemes were studied.

Results and Discussion:

Simulations are conducted to evaluate and compare the performance of the proposed EH-CoLAEEBA with the existing WBAN routing protocol Co-LAEEBA. This evaluation aims to observe the effects of Energy Harvesting Cooperative routing in EH-CoLAEEBA in contrast to Non-Energy Harvesting Cooperative-based Co-LAEEBA. Parameters used for simulations are presented in Table 3. Results are averaged over six independent runs of simulations.

Table 3. Simulation Parameters

Parameters	Value
Number of nodes	8
Sink position	At the center of the body
Initial energy (E_i)	Advanced node:0.3J Normal node:0.1J
Packet Size	1000 bits
Data generation rate	4000 bits/round
E_{elec}	50nJ/bit
e_{fs}	10pJ/bit/m^2
e_{amp}	0.0013pJ/bit/m^4

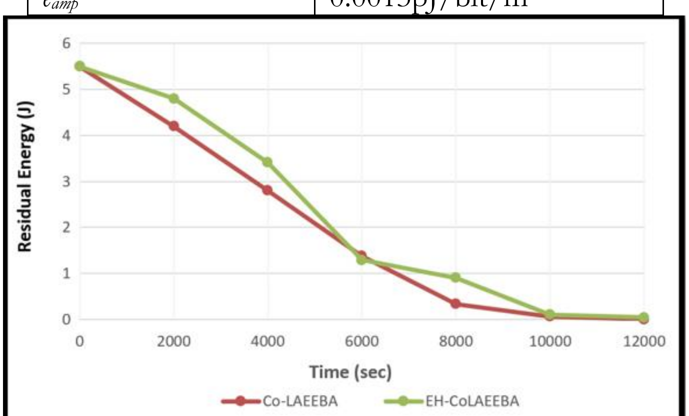

Figure 4. Residual Energy vs. Time (s)

Residual Energy:

In EH-CoLAEEBA, there are two types of sensor nodes in terms of initial energy. There are normal nodes with initial energy equal to 0.1J, whereas advanced nodes have 0.3J as initial energy. The initial total energy of the EH-CoLAEEBA and Co-LAEEBA protocols was kept at 5.6J. The results indicated that non-continuous transmission in EH-CoLAEEBA leads to a better network lifetime as compared to Co-LAEEBA. Fig.4 and Table IV show that the residual energy comparison of EH-CoLAEEBA demonstrates a significantly slower residual energy decay over time. An average improvement of 20.18% is observed in EH-CoLAEEBA as compared to Co-LAEEBA.

Table 4. Residual Energy Dropped(J) After Equal Intervals

S. No.	Name of protocol	Energy after 2000 s	Energy after 4000 s	Energy after 6000 s	Energy after 8000 s	Energy after 10000 s	Energy after 12000 s
1	**Co-LAEEBA**	4.2	2.8	1.38	0.33	0.06	0
2	**EH-CoLAEEBA**	4.8	3.41	1.29	0.9	0.1	0.04

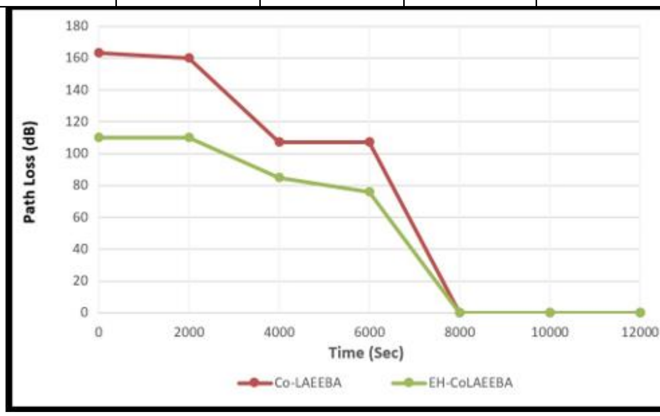

Figure 5. Path-loss (dB) vs. time (s)

Table 5. Residual Energy Dropped(J) After Equal Intervals

S. No.	Name of protocol	Drop after 2000 s	Drop after 4000 s	Drop after 6000 s	Drop after 8000 s	Drop after 10000 s	Drop after 12000 s
1	**Co-LAEEBA**	160	107	107	0	0	0
2	**EH-CoLAEEBA**	110	85	76	0	0	0

Path-loss:

Fig.5 presents the path loss analysis of EH-CoLAEEBA with Co-LAEEBA. We use a constant frequency of 2.4GHz and a path loss coefficient of 3.38 for a standard deviation of σ 4.1. Proposed EH-CoLAEEBA reduces the path loss due to the fact that a threshold value is computed, and on the basis of this, multihop transmission follows different path loss models. EH-CoLAEEBA protocol shows an improvement over Co-LAEEBA protocol by reducing the path loss from 160 dB to 110 dB, which is a considerable improvement over Co-LAEEBA WBAN protocol. An overall improvement of 38.01% in path loss has been observed.

Conclusion:

In this paper, we have proposed mechanisms to route data with minimum path loss over the link in WBANs, in which the merits of both single-hop and multi-hop routing are utilized. In the proposed scheme, an energy harvesting mechanism is used to recharge the batteries instead of replacing them time and again. Validation of EH-CoLAEEBA through simulations justifies its improved performance as compared to Co-LAEEBA, both in terms of Residual Energy and Path Loss.

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