A Review of an Energy-Efficient Routing Algorithm for Wireless Body Area Networks Using Machine Learning

P. Arivubrakan, G. R. Kanagachidambaresan, and Dinesh Bhatia

Abstract The Wireless Body Area Network (WBAN) having sensors and actuators are embedded into the human body to communicate via wearable devices in a wireless environment. Humans can wear devices into the body with various limitations. The healthcare industry plays a vital role in the WBAN to communicate and monitor the patients as a technology-based service. The sensor nodes are capable of transmitting into the human body efficiently. The nodes are communicated via wireless with the other sensors embedded in the human body. The tiny nodes having multipath communication in WBAN. In this paper, WBAN infrastructure and architecture, transmission technologies for body area networks, limitations, and energy-efficient constraints for different aspects of the routing algorithm using machine learning techniques are illustrated. It describes the energy-efficient routing protocol of WBAN is presented in this paper. Finally, as a source of motivation towards the future development of research incorporating machine learning into the supervised learning algorithms into WBAN is also provided.

Keywords WBAN · Energy efficient · Machine learning

1 Introduction

The Wireless sensor networks are basics for the WBAN to define the standard communication between the devices in a multipath environment with low power wearable devices, The Communication standard protocol is the IEEE 802.15.6 is for sending and receiving the messages in the low power devices. The tiny sensor nodes are inserted in and around the body to have a variety of applications in the field of healthcare-related sectors for monitoring the activity of the patients to avoid the death

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rate. The WBAN consists of a number of few sensor nodes as in the form of wearable devices and is set with a broadcasting interface. It further periodically monitors the patients natural signals such as electroencephalogram (EEG), Electrocardiogram (ECG) signals, various blood pressure, insulins, heart rate, body temperature and automatically transmits these data to the nearby surroundings or closest to the health center where the doctors will take the immediate decision after observing all of this information via a remote monitoring system. It allows us to keep track of the alert signals of a human body and provides continuous real-time feedback on the recovery process. The specific characteristics of the WBAN sensors are capable of monitoring the sensing heart bit rate, the temperature of the human, beat rate, and other important physiological parameters. These sensors are transferring the health condition of the patients about the current situations to the doctors Abbasi et al. (2014), Ahmad et al. (2014a), Ahourai et al. (2009), Xiong et al. (2009), Yang and Yang (2006). The Doctors periodically keep track of the records about the patients either through the web or video. The final output of the WBAN is to minimize the death rate and monitor the entire activity of the patients. A WBAN connects the sensor/device to PDA and finally transfers the information via the internet through the wireless communication channel and the self-determining body nodes by using a middle controller, known as Body Node Coordinator (BNC) or destination node as a sink. The information from the BNC to be used for various applications such as the military sector, health-care system, etc. (Fig. 1).

The WBAN has various metrics to establish the Quality of Service (QoS) in wireless sensor network applications. QoS in WSN cannot be directly implied to WBAN since QoS depends on the sensitivity of the applications and the nature of transported data. Hence, depending on the applications, QoS is different in WBAN. The critical patients monitoring systems require the fastest release of information to the doctors for quick recovery and save humans. Traditionally, QoS includes

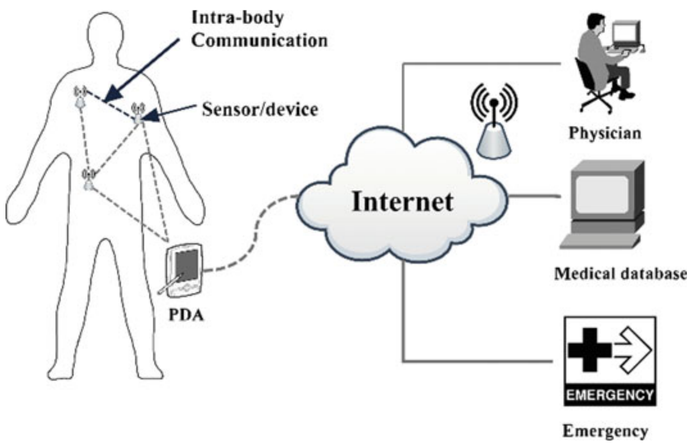

Fig. 1 WBAN infrastructure

Table 1 Comparison of WSN and WBAN

Comparison criteria	WSN	WBAN
Scale	Meter/kilometer	Meter/kilometer
Topology	Static/dynamic	Static/dynamic
Node replacement	Easy	Difficult
Node size	Small size preferred	Should be small
Energy scavenging	Solar, wind	Motion, body heat
Nodes deployment	High	Low
Energy demand	Large	Less

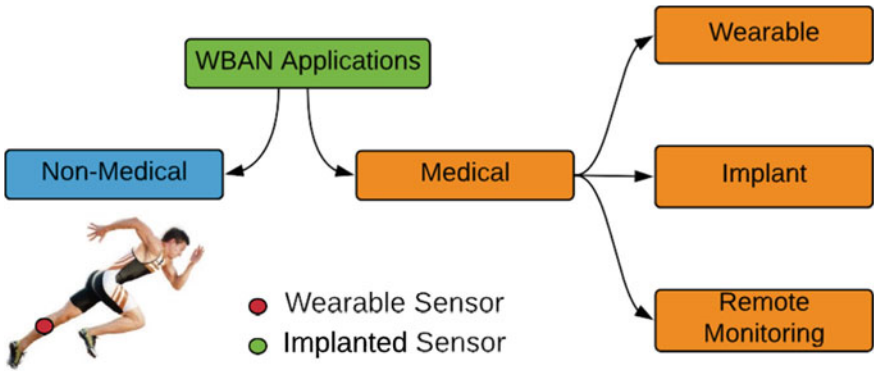

Fig. 2 WBAN applications

latency, transmission power, reliability, and bandwidth reservation to support QoS in WBAN, the following factors need to be considered Cavallari et al. (2014), Javaid et al. (2013), Latre et al. (2011), Movassaghi et al. (2014), Ullah et al. (2012), Yazaki and Matsunaga (2008), Zhang and Sawchuk (2009). The energy-efficient routing is the major factor for the delivery of the data in and around the human body. Power plays a major role in communication and transmission (Table 1).

The various applications of WBAN are medical and non-medical. The medical applications are used in WBAN for good results. Two sensors are available in the medical field. The wearable sensors for the monitoring of the activity of the patients. A small sensor network consists of a large number of nodes and each of these nodes uses the routing protocols to establish the communications to share their data or limited resources to enable the transmission (Fig. 2).

2 Routing Protocols in WBANs

The routing protocol is the best way of finding the shortest path among the multiple nodes of the communication networking system. The routing protocol is the set of rules to establish the best communication with the standard regulations. The entire network for the communication of the wearable devices depends on the protocol. The constraints of the wearable networking for the implanted networks to exhibit the sensor requirements. The Wearable device of the nodes of the requirements can change from the various applications. The allocation of the resources and the harvesting of the energy are the two constraints in the WBAN networks. In WBAN, nodes carry a large number of data endlessly. In WBAN have the priority-based networking standards are limited?

2.1 Network Lifetime

The Network lifetime of a WBAN is the routing constraint for the path establishment from the beginning to the end position Abbasi et al. (2014) Cavallari et al. (2014), Javaid et al. (2013), Movassaghi et al. (2014), Zhou and Hou (2010) and Zhou et al. (2008). For example, the patient's devices are sending the information to the doctors, while at the time of the transmission due to the network is significantly damaged. The network lifetime is expressed as network exhaustion time. Since the change of the battery and increase the charging capacity is not feasible in implant health care devices used in WBANs, The lifetime of the network plays an important role in WBAN when compare to the WSN.

2.2 Resource Constraints

The limited number of the resources of the WBANs will use tiny sensor nodes that perform its functionalities. The WBANs nodes are prone to frequent failure due to limited battery power, storage capacity, and bandwidth limitations, which lead to poor QoS Cavallari et al. (2014), Javaid et al. (2013), Ullah et al. (2012), Xiong et al. (2009), Yang and Yang (2006), Zhou and Hou (2010). Temperature awareness: Rise in temperature is an important issue in WBANs, which is mostly unconsidered in Wireless Sensor Networks. Improvident temperature rise may even cause serious tissue damage which seems to be harmful to the human body. So, the routing protocol should be temperature sensitive which not only detects the temperature rise but also prevents the overheating problem (Fig. 3).

3 Energy-Efficient Routing

Energy consumption in WBAN is an important metric for all battery-powered sensor nodes. In WBANs the available energy sources of nodes are a very primitive factor that determines the usefulness of the network systems. Since the nodes replacement

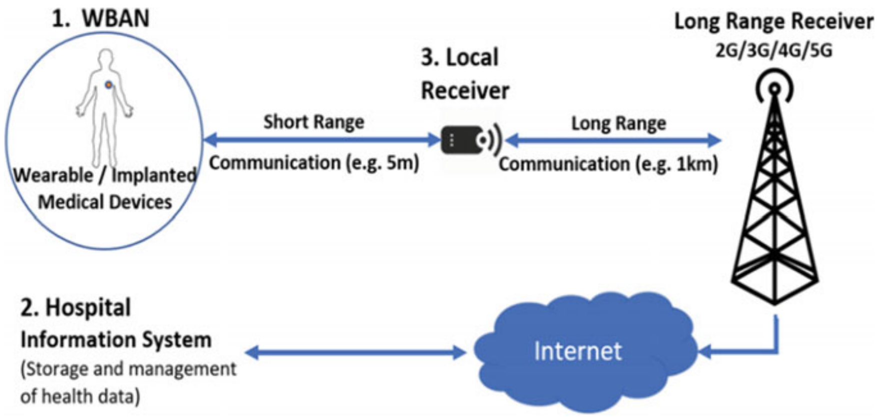

Fig. 3 WBAN communication

at the time of transmission of the patient data is very difficult. So, effective energy utilization is one of the most threatening issues to enable the network successfully.

Thus energy efficiency is the most primitive requirement when designing a routing protocol in WBANs. Some of the energy-efficient routing protocols are explained below. One of the methods to achieve energy efficiency is to perform energy-efficient routing. The factors of the energy-efficient routing protocols in WBAN such as temperature, link, routing matrix, mobility, etc. Ahmad et al. (2014a), Javaid et al. (2013), Latre et al. (2011), Movassaghi et al. (2014), Yang and Yang (2006), Yazaki and Matsunaga (2008), Zhou et al. (2008).

Tang et al. (2005) introduced an energy-efficient and thermal-aware routing protocol for WBANs to minimize the data loss and also reducing the node temperature as well as decreasing the delay.

M-ATTEMPT has four different phases of operation: initialization phase, routing phase, scheduling phase, and data transmission phase. In the initialization phase, all nodes broadcast a packet and this packet includes the sink ID and position. Single-hop communication is used for critical data delivery and normal data delivery multi-hop communication is used. A route with less hop count is selected during the routing phase. If more than two routes are available, a node with less energy consumption to the sink is selected. The proposed protocol introduces a threshold to control the temperature rise. If any node's temperature rises beyond the threshold, the route to the neighboring node will break. This protocol re-route the data if the temperature is above the threshold, without occurring the link break and this process is called the link-hot spot detection. The sink node creates a Time Division Multiple Access (TDMA) schedule for all root nodes in the scheduling phase, while the root nodes send their data to the sink node during the data transmission phase. This protocol provides a high network lifetime Cavallari et al. (2014), Javaid et al. (2013), Latre et al. (2011), Ullah et al. (2012), Xiong et al. (2009), Yang and Yang (2006), Zhou et al. (2008).

An energy-efficient protocol named Distance Aware Relaying Energy efficient (DARE) (Tauqir et al. 2013) to monitor the biological status of patients. This protocol tries to reduce the energy consumption of the monitoring sensors by providing the facility of deploying relay nodes which in turn, helps to reduce the communication distance. For decreasing the energy consumption, the sensors create a link with the sink utilizing an on-body relay, attached to the chest of each patient. The attached body relay retains greater energy resources as compared to other body sensors. It offers a greater packet delivery ratio, longer network lifetime, and better stability period, but it has a high propagation delay.

Ahmed et al. (2014) introduced a routing protocol called Link Aware and Energy Efficient scheme for Body Area Network (LAEEBA). In LAEEBA, a path with a minimum number of hops is selected for transmission. Direct communication is used for emergency data and multi-hop is used for normal data delivery. It consists of the initialization phase, next-hop selection phase, routing phase, energy consumption phase, and path-loss selection phase. Here nodes with minimum energy and minimum distance from the sink will be selected as forwarding nodes. When a node receives all the information from other nodes, the forwarder node transmits the data to the sink. In subject to the operating frequency band, high losses may occur according to the communication protocol adopted for nodes. The path loss model can be selected by using the distance between the node and sink.

Nadeem et al. (2013) introduced energy and power-efficient routing protocol model for WBANs. Stable Increased-throughput Multi-hop Protocol for Link Efficiency in wireless body area networks (SIMPLE) protocol has three phases of operation: initial phase, selection of next-hop, and scheduling. At the initial phase, the sink will send a packet that contains information about the location of the sink, packet ID, location, residual energy. In the selection of the next-hop phase, a new forwarder node is selected in each round based on the cost function. The cost function depends on residual energy and distance to the sink. Here the parameter residual energy is used to balance the energy consumption between the sensor nodes. This protocol ensures minimum energy consumption, increased throughput, and longer network lifetime. In the scheduling phase forwarder node allocate Time Division Multiple Access (TDMA) slots for its root nodes.

Ahmed et al. (2015) introduced a protocol called Cooperative Link Aware and Energy Efficient scheme for Body Area Network (Co-LAEEBA). In this, relay nodes are utilized for cooperation which allows a source node to utilize more than one link at a time. Three advanced nodes act as cooperative nodes. Normal nodes forward packets to the cooperative node in each round. Incoming and outgoing data flow at each node must be equal. The path selection depends on the varying distance between the nodes if the body is in motion. It is an advanced version of LAEEBA.

Javaid et al. (2015) proposed a new energy-efficient routing protocol called iMproved Stable Increased-throughput Multi-hop Protocol for Link Efficiency in wireless body area networks (iM-SIMPLE) in which the operation is carried out in three phases; Initial phase, selection of next-hop, and scheduling. At the initial phase, the sink will send a packet that contains information about the location of the sink, and also sensor nodes send their packet with their ID, location, residual energy.

In the selection of the next-hop phase, a new forwarder is selected in each round. The sink calculates the cost function based on residual energy and distance of nodes to the sink. Based on the calculated cost function, those nodes with minimum cost function will select as a forwarder node. In the scheduling phase, the forwarder node will allocate a Time Division Multiple Access (TDMA) slots for its root nodes. Also, mobility support (arm mobility) is considered in this protocol. This protocol utilizes a linear mathematical model for reducing energy consumption.

The energy consumption is the large scale of the nodes in WBAN that occurs during radio frequency communication, sensing, and data processing of the devices. The Routing metrics play an important role to make effective communication among sensor nodes and increase the lifetime of a WBAN. Energy efficiency is the most important primitive requirement in case of designing a routing path for a better quality of service (Kanagachidambaresan and Chitra 2015; Maheswar et al. 2019; Malathy et al. 2020; Jayarajan et al. 2019; Kanagachidambaresan et al. 2011).

4 Machine Learning Algorithms

Machine learning is the application of intelligence to learn the systems without programmed explicitly. In WBAN, the doctors can access the data uses the patient information for further process. So, machine learning algorithms are very helpful for body area networks. The doctors can learn from history that is already available in devices. The 3 types of machine learning algorithms are supervised learning, unsupervised learning, and reinforcement learning. Machine learning aims to learn from the computers automatically as similar in WBAN the information from the patient is automatically transferred to the doctors without human intervention. In this WBAN, we are looking into supervised learning in which we can teach or train the machine using various data which is well labeled, after that, the machine is provided with a new set of data so that the learning algorithm analyses the given training data sets and produces a correct outcome from labeled data.

4.1 Linear Regression

A regression problem is when the output variable is a real value, such as "dollars" or "weight". Supervised learning deals with or learns with "labeled" data. The linear regression is used to approximate values such as house prizes based on a continuous variable(s). Here, we establish a relationship between independent and dependent variables by fitting the best line. This best fit line is known as the regression line and represented by a linear equation $Y = a * X + b$. The best way to understand linear regression is to relive this experience of childhood. Let us say, you ask a child in fifth grade to arrange people in his class by increasing order of weight, without asking them their weights! What do you think the child will do? He/she would likely look (visually analyze) at the height and build of people and arrange them using a combination of these visible parameters. This is a linear regression in real life! The child has figured out that height and build would be correlated to weight by a relationship, which looks like the equation above.

In this equation:

- Y—Dependent variable
- a—Slope
- X—Independent variable
- b—Intercept.

These coefficients a and b are derived based on minimizing the sum of squared difference of distance between data points and regression line.

Look at the below example. Here we have identified the best fit line having linear equation $y = 0.2811x + 13.9$. Now using this equation, we can find the weight, knowing the height of a person.

Linear Regression is mainly of two types: Simple Linear Regression and Multiple Linear Regression. Simple Linear Regression is characterized by one independent variable. And, Multiple Linear Regression (as the name suggests) is characterized by multiple (more than 1) independent variables. While finding the best fit line, you can fit a polynomial or curvilinear regression. And these are known as polynomial or curvilinear regression.

5 Conclusion

In this context, the importance of developing energy-efficient routing by using the machine learning algorithm in WBAN is illustrated with the survey. Reducing the energy constraints in the WBAN provides a review of suitable machine learning algorithms for better performance and attain the maximum throughput. The frequent replacement of the WBAN leads to the maximum loss so, in this paper, they explained energy-efficient routing algorithms within the domain of the medical sector. In this survey, a review of current research in WBANs, recent literature on different energy-efficient research challenges in terms of routing are provided. In this paper, it is essential to incorporate the WBAN architectures and limitations to address the recent challenges efficiently by using machine learning.

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