LINEAR PROGRAMMING ROUTING FOR WIRELESS BODY AREA NETWORKS – LOBAN ALGORITHM

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Abstract: IoMT systems are one of the most important segments of the future global IoT concept, which includes complete networking and data exchange related to all aspects of human life and activity. As a physical layer of these systems, WBAN is used as a network of wireless sensor nodes placed on certain parts of the human body with the aim of collecting data that is relevant for monitoring the health status of the monitored patient. Data transmission in networks of this type is specific in many respects compared to classic WSN networks, so even when solving problems typical for wireless sensor networks, such as data routing, it is necessary to apply specific solutions. Energy consumption of sensor nodes is one of the basic goals that are set by designers of wireless sensor networks. Short-range technologies implemented on networks that cover smaller areas of the terrain have additional specificities that require special attention. In this paper, the influence of different criteria on problem analysis is observed, as well as the application of several methods characteristic for optimization through linear programming. We propose an original algorithm for routing data through the network called LOBAN, which takes into account two criteria when choosing a relay node, the importance of which is emphasized through different combinations of coefficients in linear programming. The goal of the algorithm is to optimize energy consumption in the network and extend its lifetime.

Keywords: Data Routing, Linear Programming, LOBAN, WBAN

INTRODUCTION

Wireless sensor networks WSN (Wireless Sensor Networks) represent one of the technologies that dominantly influence the further development of the information society. The integration of sensor devices with computer systems and their interconnection enable unrestricted access to all data in real time and timely delivery of the necessary information to the place where it is processed. A special type of wireless sensor networks is represented by WBAN (Wireless Body Area Network). WBAN represents wirelessly networked sensors that are installed in certain positions of the patient's body. These sensors measure specific data that are of interest for health monitoring, such as blood pressure, pulse, body temperature, glucose, pH value, body weight, etc. The network consists of relatively cheap, very small and lightweight wireless sensors. Sensors can be worn (in the patient's clothing or appropriate pouches) or implanted inside the body [1]. Their role is to deliver the specific readings they perform in real time or periodically to the patient himself, his doctor or other persons who monitor the patient's state of health.

Connecting sensors on the human body, especially sensors that are embedded inside the body, via wires is not a reasonable option. Therefore, wireless connectivity has no alternative [2].

As with other types of wireless sensor networks, the critical parameter here is the lifetime of the network. Failure of individual sensors in the network rarely occurs due to failure, as these are very reliable devices, especially when specialized sensors are used to measure certain parameters of the patient's health condition. Compared to classic WSN, the time until the failure of the first sensor node in the network is the most important, since each of the sensors reads a different health parameter.

Communication between sensors consumes the largest part of energy, far more than the actual reading performed by the sensor [3]. Therefore, it is necessary to save energy primarily in the phases of data exchange between sensors. The conventional model of data transmission in a sensor network implies a direct connection of each sensor to a base station. The energy consumed by each sensor, when sending data to the base station, increases with the square of the distance from the base station. Relay data transmission in order to save sensor energy is one of the possibilities that can contribute to saving energy in the network. The role of a relay is played by sensor nodes that transmit messages from other nodes to their destination. Using a relay reduces the distance between the transmitter and the receiver in the network, thus saving energy. Relay transmission is carried out on an ad-hoc basis, so at each step in the transmission of the message to the destination, it is necessary to select the next node in the sequence.

Various approaches to reducing energy consumption in the network have been proposed in the literature. Some of them are based on linear programming. In this paper, we propose a variant of the problem solution that takes into account two criteria, giving them different importance depending on the situation [4].

Related works

A large number of algorithms for data routing in WBAN networks have been proposed in the literature. The solutions are based on different principles: direct transmission, ad-hoc networks, clustering, etc [5-8]. In this paper, we will propose an original solution based on relay transmission and compare it with two older algorithms:

The M-ATTEMPT algorithm belongs to the group of routing algorithms that are determined based on the temperature of nodes as a result of heating caused by sensor activity [9]. It works in parallel in single-hop (for urgent messages) and multi-hop (for normal messages) mode. This routing protocol supports mobility of the human body with energy management. The protocol is thermal-aware which senses the link Hot-spot and routes the data away from these links. After selection of routes sink node creates TDMA schedule for communication between sink node and root nodes for normal data delivery using multihop communication.

The SIMPLE algorithm is a multi-hop relay algorithm [10]. Messages are forwarded to the sink via a single relay node. The main part of the algorithm is the selection of the relay node, where a new selection is made in each round. The sink has knowledge of the residual energy, distance, and ID of each node in the network. A cost function is calculated for each node, and the obtained result is forwarded to all nodes so that they can make a decision on whether to accept the role of a relay node or not. The cost function is calculated by the expression:

$$C.F(i) = {d(i)}/{R.E(i)} \tag{1}$$

Where d(i) is the distance from node i to the sink and R.E(i) is the remaining energy in node i after the energy consumed by the node in that round is subtracted from the energy of the node at the beginning of the round. The node with the lowest cost function is chosen as the relay (forwarder) node in a given round. This node aggregates data from all other nodes and forwards them to the sink. The two nodes that are closest to the sink do not participate in forwarding data from other nodes and send their data directly to the sink.

Data routing in WBAN is specific in relation to other WSNs in several important points [11]:

- The dimension of the network is very small related to the size of the body on which it is located
- The number of sensor nodes in the network is not too large
- The distance between sensors in the network is relatively small
- Sensors are required to be extremely precise and reliable
- The size of the sensors should be as small as possible so that their dimensions do not represent an additional burden for the patient.
- The entire network moves through the space together with the patient's body
- The mutual position of the sensors in the network changes according to the position of the patient's body
- It is necessary to detect all events that may affect the state of individual sensors and the network as a whole
- A high level of data protection is required due to the confidentiality of information about the patient's health status
- Accuracy of transmitted information is extremely important. Loss of data or wrongly

provided information can be fatal to the life of the patient
- Sensors on the human body have different purposes, ie. they do not read the same sizes, so the failure of one of the sensors cannot be replaced by the others

WBAN network

WBAN is a system of wirelessly connected sensor nodes that are placed on specific, characteristic points of the human body with the task of reading various physiological attributes of the patient in real time [11]. The given data must be wirelessly transmitted in some way to the processing center located at a location far from the local WBAN network. WBAN communicates with a remote location usually through one node that has the role of a base station (sink) and acquires data from all other nodes of the associated network. The sink is a node that has no a problem with energy consumption, since it is an easily accessible device that, as such, can easily replace the power source or top it up. This is very important since it is the node that suffers the highest energy consumption as it communicates with the environment by transferring all the data from the network. However, other nodes are powered autonomously and are often implanted under the surface of the body, so replacing the batteries or topping them up requires surgery, which significantly complicates the whole process. Therefore, it is necessary to find a way to somehow minimize the energy consumed by these devices during their work, especially when communicating (since the consumption is much higher there compared to the reading of phenomena and data processing) with the environment. The only way to do this is to apply appropriate protocols for routing data in the network, which aim to optimize energy consumption and increase the lifetime of the network.

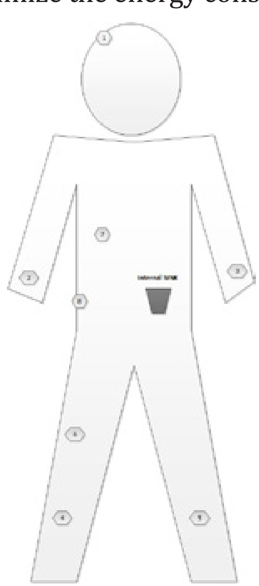

Figure 1. WBAN network, arrangement of nodes on the body used for simulation

Sensors are placed on the patient's clothing, on the surface of the body or implanted inside the body. The arrangement of the nodes depends on the parameters to be read. An example of a network with 8 nodes is shown in Figure 1.

Sensor types and their coordinates are shown in Table 1:

Table 1. *The positions of nodes from the figure 1.*

The node number	Sensor type	X(m)	Y(m)
1	EEG	0.35	1.65
2	T	0.15	0.95
3	SM	0.6	0.95
4	MD	0.2	0.2
5	IMU	0.5	0.2
6	EMG	0.22	0.47
7	LS	0.3	1.17
8	GS	0.2	0.85
SINK	SINK	0.35	1.1

Where sensors are as follows:
- EEG: Electroencephalography
- T: Temperature
- SM: Sweat Monitor
- MD: Motion Detector
- IMU: Inertial measurement unit
- EMG: Electromyography
- LS: Lung Sounds
- GS: Glucose Sensor

Linear programming optimization in WBAN

Linear Programming is a technique used for optimizing a particular scenario in order to get optimal results. It deals with finding efficient solutions with linear equalities and inequalities.

The objective function in linear programming is generally given in the following form:

$$\min f(x_1, x_2, \dots x_n) = c_1x_1 + c_2x_2 + \cdots + c_nx_n \quad (2)$$

In practice, a linear combination of normalized objective functions is often used in order to avoid inconsistencies caused by different quantities taken as optimization criteria, i.e. problem solved:

$$minf(x) = \sum_{k=1}^{p} w_k f_k^0(x) \tag{3}$$

Where: , the weight coefficient of the kth criterion, is the normalized kth objective function . In this way, linear objective functions whose sum of coefficients with variables is equal to 1 are obtained.

According to the given energy models and its possibilities, but also the limitations of linear programming and the specificities of WBAN networks, it is shown that there are a large number of scenarios where linear programming gives good results in optimizing energy consumption when routing data to the destination.

By transmitting the collected data about the patient's state of health through the WBAN network, i.e. sensors placed on the patient's body at each step, when selecting the relay node at which a specific hop ends, a normalized cost function is calculated according to the previous expression.

LOBAN (Linear Optimization Body Area Network)

The WBAN network we propose in this paper is specific because each of the sensors has a different task. By switching off any of the sensors, its function is interrupted, since the neighboring sensors cannot take over its role. Therefore, network lifetime can be defined as the time that has passed from network starting to shutdown of the first sensor, although the network may remain partially functional thereafter. In order to achieve the best possible result, we propose a data routing algorithm that aims at balanced energy consumption in the network. Some other algorithms achieve better results with a differently defined lifespan, e.g. in case the network is considered functional while a certain percentage of the sensor is active.

Therefore, in this paper we propose an algorithm that finds the optimal routing path for WBAN. Each of the sensors should deliver the collected data to the sink periodically. The path along which the data is transmitted is selected in each round, in accordance with the set optimization criteria. The path selection is reduced to the selection of the next node through which the data will be forwarded to the sink, ie. the paths consist of only two hops. Candidates for the next node in the path are all active nodes in the network. In order to achieve the desired goal, it is necessary to take into account two parameters:

The remaining energy of the candidate for the next node. It is advisable to choose a sensor that is in good energy condition for the next node. If the path were established through a node whose energy is already quite depleted, it could be switched off and thus interrupt the life of the network.

Distance of the candidate for the next node from the sink. The energy consumption of the transmitter increases with the square of the distance to the destination. This means that a candidate who has more remaining energy and is farther from the sink could consume his energy faster by forwarding the message in another hop.

However, unlike the SIMPLE algorithm in the proposed algorithm, we use linear programming so that we adjust the influence of the proposed parameters with weight coefficients.

The following expression is used as a normalized cost function:

$$C.F(i) = w_1 \frac{d(i)}{d_{sr}} + w_2 \frac{R.E_{sr}}{R.E(i)} \tag{4}$$

With a constraints:

Where the normalization parameters are:

$$d_{sr} = \frac{1}{n}\sum_{i=1}^{n} d(i) \tag{5}$$

$$R.E_{sr} = \frac{1}{n}\sum_{i=1}^{n} R.E(i) \tag{6}$$

For the relay node, the one with the smallest cost function is chosen.

Simulation results

The authors tested the proposed algorithm in the MATLAB environment, using the coordinates listed in Table 1, and made a comparison with the results obtained for the M-ATTEMPT and SIMPLE algorithms.

Two cases with different combinations of parameters and measured values were tested:

- Number of dead nodes
- Remaining energy in the network.

I Scenario: w1=0.8, w2=0.2

Based on the performed simulation, we obtained graphics:

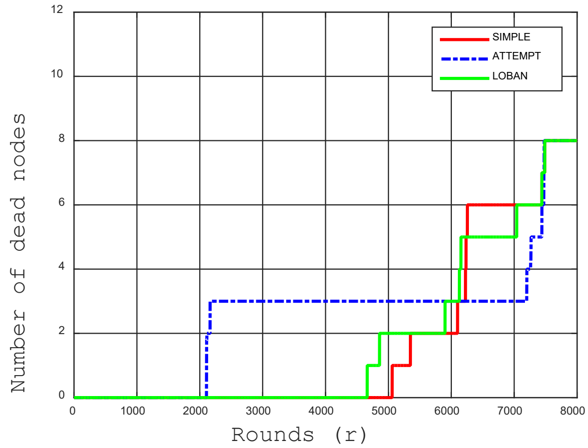

Figure 2: Number of dead nodes w1=0.8, w2=0.2

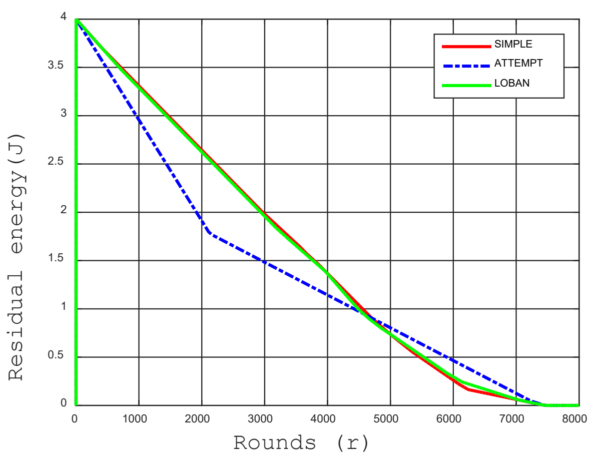

Figure 3: Residual energy w1=0.8, w2=0.2

II Scenario: w1=0.8, w2=0.2

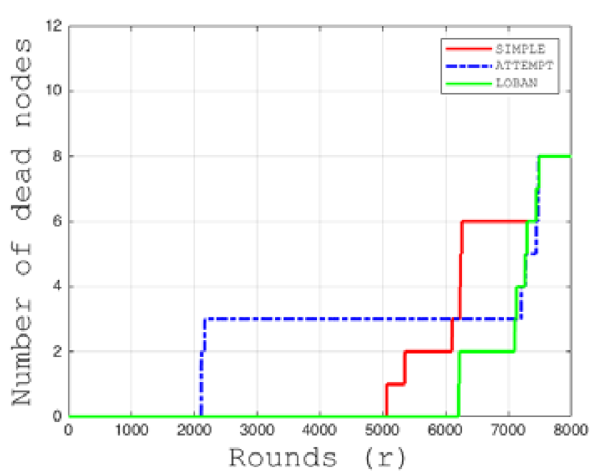

Figure 4: *Number of dead nodes w1=0.2, w2=0.8*

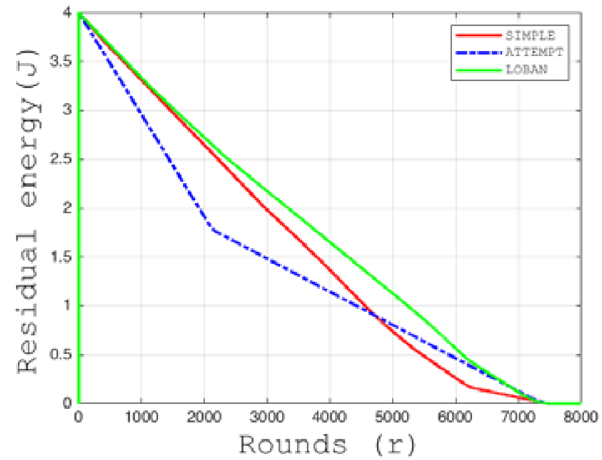

Figure 5: *Residual energy w1=0.2, w2=0.8*

ANALYSIS OF RESULTS

The results of the simulations show significantly better results of the proposed LOBAN algorithm in the second scenario, where we emphasized the importance of residual energy in relation to the distance between the node and the sink.

In the scenario I, SIMPLE gives the best results. The stability period is the longest, and that is the most important thing for WBAN networks.

In scenario II, LOBAN is far better than SIMPLE and especially ATTEMPT.

For LOBAN, the first node shuts down around the 6200th round, while for SIMPLE it shuts down around 5000, and for ATTEMPT already around 2000. Confirmation of the advantages of the LOBAN algorithm in this scenario can also be seen in Figure 5, where we track the change in the residual energy in the network by rounds.

CONCLUSIONS

WBAN networks are one of the most promising applications of short-range WSN networks and one of the most important aspects of future global IoT networking. Health is the most important resource of humanity and deserves worthy attention. Application of modern technology in preserving health is particularly important.

WBAN networks consist of sensors that have their own autonomous power supply. Batteries are not easy to replace, especially if the sensors are implanted inside the patient's body. Most of the energy is spent when sending messages to the sink. Therefore, it is necessary to find such routing protocols that will reduce this consumption to the smallest extent and thus make the stability period of the network as large as possible.

WBAN networks, unlike some other WSNs, can be considered fully functional only as long as all nodes are active. That is why the time until the first node shuts down needs to be extended as much as possible.

In this paper, we proposed the LOBAN algorithm, which showed very good results in accordance with the set goal. This especially applies to the scenario where we gave importance to the residual energy in relation to the distance between the nodes. The simulations showed advantages compared to the classical SIMPLE and M-ATTEMPT protocols.

In their further work, the authors will try to improve the obtained results by introducing additional parameters into the linear function.

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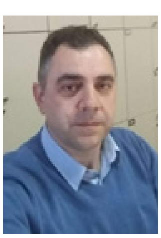
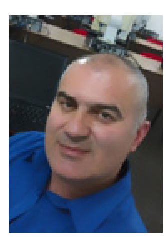


Goran Đukanović received his Ph.D from the Faculty of Electrical Engineering in Banja Luka. He has published more then fifthy scientific papers and three university textbooks, and has gained additional scientific experience by making numerous reviews. He is full professor at the Pan-European University Apeiron (computer sciences) and member of the editorial board of the journal JITA. He is a member of the IEEE, with participation in Computer Society and the Internet of Things Community. His research interest includes mobile computing in IoT, with focus on resource management algorithms and event-driven mobile applications design.



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