JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 37, 1-13 (2021)
DOI: 10.6688/JISE.202101_37(1).0001

Energy-Aware and Stable Routing Protocol for Hospital Wireless Body Area Networks

OMAR SMAIL AND ADDA KERRAR
Computer Science Department
University Mustapha Stambouli
Mascara, 29000 Algeria
E-mail: o.smail@univ-mascara.dz; a.kerrar@univ-mascara.dz

A wireless body area network (WBAN) has recently emerged as a new generation of wireless area networks. Mobile WBANs constitute an active field of research and development as it offers the potential of great improvement pervasive health monitoring and management services. However, the equipment used in WBAN is usually mobile with a constraint on energy. The energy efficiency must be taken into accounts as one of the objectives of the routing protocol designed for this type of network. Although the nodes are mobile causing links failures, most of studies ignore the link stability. In this paper, we propose a stable, reliable and energy efficient routing protocol for mobile Wireless Body Area Networks. It preserves the residual energy of nodes ensuring a reliable transfer of medical data. To achieve this goal, we use an objective model to select energy-efficient paths with stable links. A fuzzy logic system is used for link stability determination. Simulation results show improved performance of our proposed protocol in comparison to the selected existing protocol in terms of energy consumption, routing overhead, packet delivery ratio and end-to-end delay.

Keywords: mobile WBAN network, pervasive healthcare system, distributed BAN communication, energy efficiency, link stability, fuzzy logic system

1. INTRODUCTION

A wireless BAN (WBAN) is a radio frequency technique based on wireless networking technology that interconnects tiny devices with sensor or actuator capabilities in, on, or around a human body. These tiny devices can monitor the human body functions and characteristics from the surrounding environment. The main applications of WBANs are in the areas of health, first aid, military, entertainment, sports, ambient intelligence and human-machine interactions. The introduction of WBAN into medical monitoring and other applications will offer flexibilities and will save cost to both health care professionals and patients. A WBAN system can offer two significant advantages compared to current electronic patient monitoring systems. The first advantage is the mobility of patients with the use of portable devices. The second advantage is the location independent monitoring facility, that is, being an autonomous device; a mobile WBAN node can search and find a suitable communication network to transmit data to a remote database server for storage. Various sensors are installed on or inside the human body to communicate back to a concentrator device, on or near the individual, their readings of the human body's vital signs such as blood pressure, EEG (Electroencephalography), motion sensor and ECG (electrocardiogram). This device may in turn communicate with others via another longer-range network. In BAN, the sensors' bodies generally send their data to a central body coordi-

Received December 12, 2019; revised February 7 & April 1, 2020; accepted April 26, 2020.
Communicated by Flavia C. Delicato.

nator. The body coordinator is responsible for sending biological signals of the patient to the medical doctor in order to provide real time medical diagnostic and allows him to take the right decisions. However, the efficient management of the large number of monitored data collected from various devices of WBANs is an important issue for their large-scale adoption in pervasive healthcare services. Pervasive healthcare is an emerging technology that promises increases in efficiency, accuracy and availability of medical treatment due to the recent advances in wireless communication and in electronics.

In order to establish communication between WBANs devices, techniques from Wireless Sensor Networks and ad hoc networks could be used. The communication architecture for these devices can be centralized or distributed. However, because of its typical properties (several communication technologies coexist, the data collected is not processed locally, the range of the signal and the energy of the batteries is less, the mobility of the nodes is not based on a defined model), current protocols designed for these networks are not always well suited to support a WBAN. Designing such protocols implies challenges including the combination of reliability in transfer medical data transfer, short-range transmission, low data rate, limited resources (especially energy efficiency), body mobility, radio interference, heterogeneous environment, QoS, security and privacy issues [1-4]. In particular, energy efficiency constitutes a significant factor in long-term deployment of WBANs, and had been addressed by some works [5-7]. The class of wireless body network poses another problem is the stability of the links due to the low energy of the nodes (body), their mobility, the short-range transmission and the related problems of radio waves. In this paper, we propose a novel routing protocol for WBAN, called ESR (Energy aware and Stable Routing protocol). ESR protocol is designed for mobile nodes with battery-limited, where link failures and path breaks may occur frequently. Our idea is to calculate the energy cost of each path based on the nodes normalized energy levels. This cost is combined with the cost of links stability. However, because to the imprecision and uncertainty of the information evaluating the stability of the radio links, fuzzy logic enables to model the uncertainty within the subjective formulation of knowledge or opinions. For this we use a fuzzy logic system for link stability determination. The main performance of this protocol is to select the path that ensures the least energy consumption with stable links in order to assure the reliability in the transfer of the monitored data with an increase network lifetime. These data can be the basis of effective pervasive health systems. ESR is an extension of our work [8].

The paper is organized as follows: Section 2 provides a review of related works on energy aware routing protocols in wireless body area networks. Section 3 describes the different WBAN communication architectures. Section 4 gives the design details of our ESR protocol. Section 5 provides simulation results of its performance evaluation. Section 6 concludes this work.

2. RELATED WORK

In WBAN technology, numerous routing schemes are proposed considering different objectives. In this section, we present some energy efficiency routing protocols. Traditionally, there are two routing approaches in BANs. One approach is to integrate the routing functions with the MAC layer using a fundamental cross-layer approach. The second approach is to design a routing layer on top of the MAC layer (in network layer), where link qualities are measured, and taken into accounts during the path computation. The protocol SIMPLE is introduced in [9]. In this protocol, a cost function is used to select parent or forwarder node with high residual energy and minimum distance to sink. Nodes with lowest cost are elected as parent nodes. The residual energy parameter balances the energy consumption among the sensor nodes while the distance parameter ensures successful packet delivery to sink. The sensors select their parent node and transmit their data to sink through forwarder node, except two sensor nodes for ECG and Glucose level are placed near the sink. The simulation results show that proposed routing schemes enhance the network stability time and packet delivered to sink. The protocol Co-CEStat is introduced in [10]. This protocol utilizes the merits of both direct and cooperative transmissions to achieve higher stability period and end-to-end throughput with greater network lifetime. Co-CEStat uses a multi-tier architecture in which nodes are affixed to the body of the patient and the sink is placed at the center of the body. The proposed protocol is an energy efficient routing protocol, which utilizes dynamic routing with cooperation between nodes for data forwarding. By avoiding redundant data transmission, Co-CEStat is efficient in terms of energy conservation and overall network throughput compared to other protocols. In [6], a protocol is proposed which takes multiple parameters of the WBAN network node into account, such as residual energy, transmission efficiency, available bandwidth, and the number of hops to the sink. A maximum benefit function is built to select the next hop node by normalizing the node parameters, and dynamically select the node with the largest function value as the next hop node. The proposed method can achieve efficient multi-hop routing transmission of data and improve the reliability of network data transmission. In [7], the authors present a thermal-aware, energy-efficient, and reliable routing protocol named thermal and energy aware routing. In the given perspective, thermal and energy aware routing considers the weighted average of three costs while selecting the routing path: energy consumption, heat dissipation, and link quality (between communicating nodes). Simulation results demonstrate that the proposed protocol is efficient in terms of energy consumption, thermal impact, and packet reception rate. The work in [11] proposes a new Energy aware Peering Routing protocol (EPR), which includes a new mechanism of peer discovery with routing table construction that helps to reduce network traffic load, energy consumption, and improves BAN reliability. The proposed BAN peering framework and routing protocol are designed to display in real-time BAN data, avoid a fully centralized system, and discover the dedicated BAN data display unit dynamically. Both centralized and distributed approaches are used in the proposed scheme. Only the central computer holds the information of BANs and display units, which helps to improve privacy and better control BAN communication. The BAN data is displayed on the display unit in a distributed manner, which reduces traffic load and helps to improve patient mobility.

The majority of energy efficient protocols for mobile WBANs select the next hop based on its residual energy, because if a node is willing to accept all route requests only because it currently has some residual battery capacity, too much traffic load may be routed through that node. In addition, energy is not the only factor since the nodes can be mobile which can cause their disconnection even if they have enough energy. So, the study of their stability is essential. On the other hand, these protocols are based on the selection of one hop to reach the destination, while several nodes (multi-hop) may be required to reach the destination. Finally, the majority of these protocols have been compared only with their original protocols, or with protocols which do not explicitly consider energy consumption, and thus these performance evaluations are not fair. All of these drawbacks are resolved by our proposed solution, described in the following sections.

3. BAN COMMUNICATION ARCHITECTURE

In this section we describe the communication architecture of a ban network. This network is composed mainly of human bodies; each body can have body implants and wearable sensors that send their data to a central device known as the BAN coordinator. The medical device controller is used to collect data from different BAN coordinators to command and control the personal-BAN. These controllers can be static or mobile and can be on human body. In several cases, the medical data are transmitted to the external world, such as emergencies, the nurse or medical servers. Data transmission between medical devices controllers and the nurse or medical servers is provided by Internet network. These data form the basis of pervasive healthcare systems allowing to realize long-term health monitoring and data analysis of patients in different environments. The two possible BAN communication scenarios are indoor and outdoor. The BANs in the hospital and at home are considered as indoor scenario. Thus, we consider a three tiers communications architecture: Communication Tier-1 (*i.e.*, intra-BAN communications), Communication Tier-2 (*i.e.*, inter-BAN communications), and Communication Tier-3 (*i.e.*, beyond-BAN communications), as shown in Fig. 1.

We focus on the inter BAN communication which is divided into a centralized BAN communication and a distributed BAN communication with static coordinator (see Fig. 2) because they represent the major use cases.

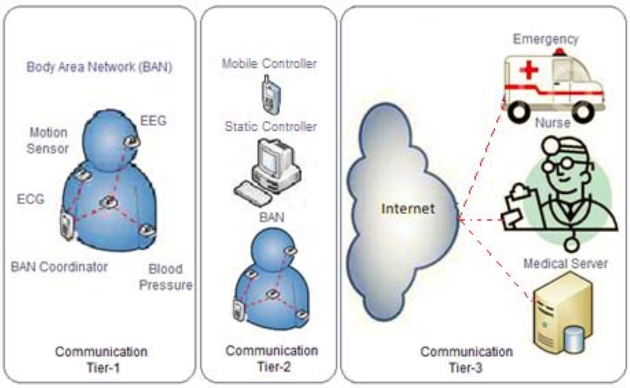


Fig. 1. BAN communication architecture.

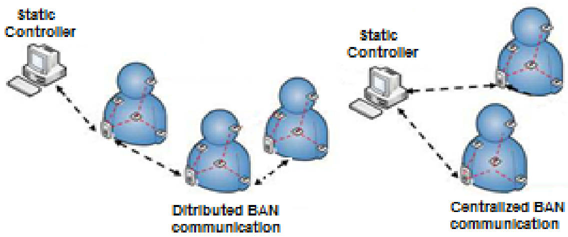


Fig. 2. Centralized and distributed BAN communications.

A static controller exists in a centralized BAN communication and is connected with BAN coordinators of several personal-BANs. The static controller is able to command a BAN coordinator in order to control a personal-BAN and runs as an internet gateway. In a distributed BAN communication, data transmission among personal-BANs is performed without a static controller. This type of communication is also called point-to-point communication. In point-to-point communication, the BAN coordinator will discover a static controller to send him these data. For this discovery, BANs coordinators interact and can cooperate to exchange routing information.

4. ENERGY AWARE AND STABLE ROUTING PROTOCOL

The main objective of this paper is to develop an improved routing protocol based on a network layer routing approach, named Energy aware and Stable Routing protocol (ESR), which ensures a reliable transfer of medical data for health monitoring systems. The ESR protocol is intended to be employed in hospital environment for body networks mainly in a distributed BAN communication. We use an objective function to select energy-efficient paths with stable links.

4.1 Path Discovery Process

When a source BAN coordinator requires a route toward a static coordinator, the source BAN coordinator checks its routing table for any available path toward this destination static coordinator. If a path is not present or is invalid, the source BAN coordinator performs route discovery: it broadcasts a route request message to all of its neighbors. When an intermediate BAN coordinator node receives a route request message, it ensures that the received request is not a duplicate message in order to prevent looping paths. Otherwise, the route request receiving node verifies whether it has any valid path toward the destination static coordinator in its routing table or not. If valid paths are found, the node forwards a route request message to each valid path neighbour. When the destination static coordinator receives the first route request message, it waits for a certain time and collects all other route request messages arriving during this time interval, after the time expiration it must respond with route reply message. When a BAN coordinator node receives its first route reply message, it creates a path entry towards the node from which it received this message and updates its routing table.

4.2 Path Routing Selection

This section describes path selection routing. The choice of the best path between a source BAN coordinator node s and destination static coordinator node d, is done according to energy consumption and path stability. Here, two functions are defined: the energy cost $fep_j(t)$, which characterizes a path j at time t from an energetic point of view and the stability cost $fsp_j(t)$, which represents the stability of path j at time t.

4.2.1 Energy aware function

Let $fepsd_j(t)$ be the minimum residual energy of nodes constituting the path j for a source BAN coordinator node s to destination static coordinator node d at time t:

$$fepsd_j(t) = \min_{node\_i}^{length(j)} (fen_{i,j}(t)). \quad (1)$$

Where $fen_{i,j}(t)$ represents the energy cost function of node i belonging to the path j:

$$fen_{i,j}(t) = \frac{Elev_{i,j}(t)}{DR_{i,j}(t)}.w_{i,j}. \quad (2)$$

$Elev_{i,j}(t)$ denotes the energy level of node i belonging to the path j at time t, given by:

$$Elev_{i,j}(t) = \frac{E_{i,j}(t)}{Esd_{average}}. \quad (3)$$

Where $E_{i,j}(t)$ represents the node i residual energy belonging to the path j at time t and $Esd_{average}$ is the average residual energy of nodes that participated in the path discovery process between one source BAN coordinator node s and one destination static coordinator node d. w_{ij}: weight factor of node i belonging to the path j, which depends on various factors, like battery's quality, capacity and lifetime. $DR_{ij}(t)$ is the drain rate of the node i belonging to the path j at time t, which is defined as the rate at which energy is consumed at a given node usually, when a node is used by others paths or when the energy consumption is affected by external phenomena.

4.2.2 Link stability aware function

The evaluation of the radio link stability is a function of a number of metrics that are usually imprecisely estimated, expressed in linguistic terms such as low link stability, high link stability, *etc.* Fuzzy logic provides a rigorous algebra for dealing with imprecise information. It is a mathematical discipline invented to express human reasoning in a rigorous mathematical notation. Unlike classical logic where a proposition is either true or false, fuzzy logic establishes the approximate truth value of a proposition based on linguistic variables and inference rules. To develop a fuzzy inference system, the input and output variables should be defined as membership functions. Fuzzy rules (IF-THEN) that connect the input memberships with the output membership are then suggested, see Fig. 3. In this system, the node mobility parameter is fed through a fuzzy inference system to compute the quality of Link stability. The protocols based on node mobility use some criteria inherent to the nodes mobility such as their coordinates, directions of movement or speeds. We use the node coordinates for our protocol. Our protocol exploits the discovery process and hello messages to collect the neighbour nodes coordinates.

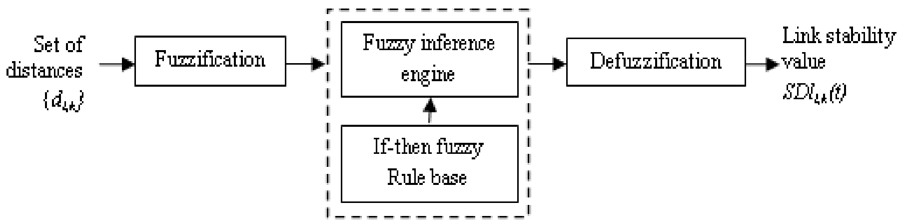


Fig. 3. Fuzzy Inference system for link stability determination.

To determine the link stability between two nodes *i* and *k*, the node *i* periodically sends message to the node *k*. When the node *k* receives the message, it detects its coordinates then sends it to the node *i*. Based on this information, the node *i* calculates the distance that separates the node *k* noted by $d_{i,k}$. These distances constitute the input of the fuzzification step.

The fuzzy inference engine is based on fuzzy IF-THEN-based rules, which are written by a professional designer. In our case, we used the following five simple fuzzy rules:

If {the distances are equal} **then** Link stability is high
If {the distances are equal more on average} **then** Link stability is medium high
If {the distances are equal on average} **then** Link stability is medium
If {the distances are equal less on average} **then** Link stability is medium low
If {the distances are disparate} **then** Link stability is low

Defuzzification is a mathematical method that uses a weighted mean approach to extract a crisp output value from the aggregation of the fuzzy output representation. There are different approaches used to find the crisp output. Our model is based on the standardized measure of dispersion of a probability or frequency distribution. In our case, it is the measurement of distances dispersion between two neighouring nodes. The function $fsl_{i,k}(t)$ is used to quantify the measurement accuracy between node *i* and its neighbor *k*. If the $fsl_{i,k}(t)$ tends to 0, then we have a good distribution of distances, which means that the link is high stable. If it is large, this corresponds to a poor distribution, which means that the link is low stable. The function $fsl_{i,k}(t)$ represents the coefficient of variation, also known as relative standard deviation, $fsl_{i,k}(t)$ is given by:

$$fsl_{i,k}(t) = \frac{SDl_{i,k}(t)}{Ml_{i,k}(t)}. \tag{4}$$

Where $Ml_{i,k}(t)$ represents the mean of the m distances recorded between the node *i* and node *k*, defined as follows:

$$Ml_{i,k}(t) = \frac{\sum_{t=t1}^{tm} d_{i,k}(t)}{n}. \tag{5}$$

$SDl_{i,k}(t)$ denoted the standard deviation of the distances recorded between the node *i* and node *k*, $SDl_{i,k}(t)$ is given by:

$$SDl_{i,k}(t) = \sqrt{\frac{1}{n}\sum_{t=t1}^{tn}\left(d_{i,k}(t) - Ml_{i,k}(t)\right)^2}. \tag{6}$$

We define $fspsd_j(t)$ the path cost function stability, given by:

$$fspsd_j(t) = \max_{node\_i}^{length(j)}(fsl_{i,k}(t)). \tag{7}$$

With *n* defined as the nodes number of the path *j* and *k* as the neighbor nodes of the node *i*. The path cost function stability is based on the cost function stability of the links constituting this path. $fsp_j(t)$ is defined as the maximum stability cost of links constituting the path j, for a source BAN coordinator node s to destination static coordinator node d at time t.

Fig. 4 shows the structure of an entry of the routing table of a node i. The discovery process must take into accounts the field Sequence number in order to ensure the freshness of paths and the maximum hop count for all the paths, denoted respectively by *Sequence_number* and *advertised_hopcount*. For each destination static coordinator known by the node i there is an entry. *Route_list* contains all known neighbouring nodes of a node i which leads to that destination static coordinator. Each neighbour for that destination static coordinator is identified by its *nexthop* address, and the *hopcount* field is the number of hops required to reach that destination static coordinator using this neighbour. We add two new fields to the basic routing table, *Ei* and *distances_list*. The field *Ei* denotes the residual energy of a node i and the field *distances_list* indicates registered distances between the node i and its neighbours over different time.

Destination static coordinator
Sequence_number
Advertised_hopcount
Route_list
{(nexthop1, hopcount1, E_1, distance_list {(d_{i1}, t_1), (d_{i1}, t_2),..}),
(nexthop2, hopcount2, E_2, distance_list {(d_{i2}, t_1), (d_{i2}, t_2),..}),..}
Expiration timeout

Fig. 4. Structure of a routing table entry for ESR.

4.2.3 Objective problem formulation

We design our path selection principle on the ordering of paths according to the energy consumption of their path nodes and the link stability of their path links. To satisfy this, we use a model using arbitrary importance weights for each criterion (α and β). The corresponding objective function $fp_j(t)$ is defined by combining Eqs. (1) and (7):

$$fp_j(t) = \alpha fep_j(t)+\beta/fsp_j(t). \tag{8}$$

Our idea is based on sorting all paths between a source BAN coordinator node s and destination static coordinator node d by the descending value of $fp_j(t)$. The path with the maximum $fp_j(t)$ is chosen to forward the data packets. We note that the weights α and β are chosen so that the condition $\alpha + \beta = 1$ is satisfied. Algorithm 1 constructs the routing table of node i and computes two path cost functions, one for the energy and one for the stability.

Algorithm 1: Routing table construction for node i.

if (it's the first passage of the route request message by node i for node destination d)
  then if (fen_{ip} < *min_cost_energy_p*) **then** *min_cost_energy_p:=*fen_{ip};
endif
distances_list := {distance collection between the nodes i and j, at successive times}
if (fsl_{ip} > *max_cost_stability_p*) **then** *max_cost_stability_p:=*fsl_{ip};

endif
route_list^d_i:= *NULL*;
insert (*j*, *hopcount*^d_j +1, E_j, *distances_list*) **into** *route_list*^d_i;
elseif (it's a passage of other route request message by node *i* for node destination *d*) **then**
if (fen_{ip} < *min_cost_energy_p*) **then** *min_cost_energy_p:=*fen_{ip};
endif
distances_list := {distance collection between the nodes *i* and *j*, at successive times}
if (fsl_{ip} > *max_cost_stability_p*) **then** *max_cost_stability_p:=*fsl_{ip};
endif
insert (*j*, *hopcount*^d_j +1, E_j, *distances_list*) **into** *route_list*^d_i;
endif.

5. PERFORMANCE EVALUATION OF ESR

In this section, we present simulation results to evaluate the efficiency of our proposed protocol. First, we present the metrics used for this performance evaluation, then we evaluate our protocol by comparing it with the protocol EPR [10]. Secondly, we will use EPR as a reference for our performance evaluation because it has the same characteristic as our protocol, namely it is an energy aware routing protocol for hospital body area network communication.

5.1 Performance Parameters

We evaluate four key performance metrics. Energy consumption is the average of the energy consumed by nodes participating in packet transfer from the source BAN coordinator node to the destination static coordinator node during the whole simulation. The routing overhead is measured as the number of control messages transmitted at each node during the simulation. The Packet delivery ratio (PDR) is defined as the ratio of data packets received by the destination static coordinator node to those generated by the source BAN coordinator over the total duration of the simulation. End-to-end delay is the average transmission delay of data packets that are delivered successfully during simulation.

5.2 Performance Evaluation

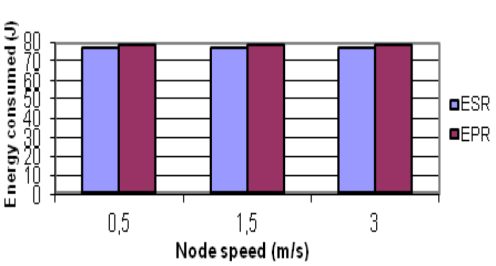
We carried out simulations to determine the effectiveness of our protocol. The principal goal of these simulations is to analyze our protocol by comparing it with other protocols, mainly EPR [11]. The values of simulation parameters are summarized in Table 1.

Table 1. Simulation parameters.

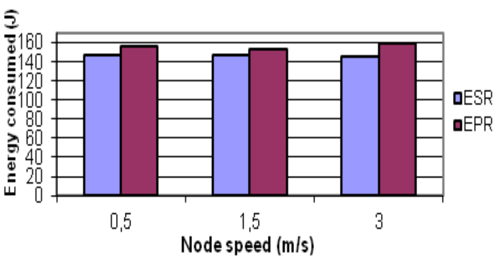
Communication Model	Constant Bit Rate (CBR)	Transmit power	13.80 dBm
MAC type	IEEE 802.15.4	Reception power	12.84 dBm
Mobility model	Random Waypoint	Drain Rate	10% ~ 50%
Terrain range	100m × 100m	Route request wait time	0.3 s
Transmission range	10m	Route reply wait time	0.3 s
Number of mobile nodes	4, 8 and 16	Simulation time	400 s
Packet size	32 bytes	α	0.4
Initial node energy	10-50 J	β	0.6

To evaluate ESR, we use the network simulator ns-2 [12]. Each simulation run has a duration of 400 seconds. We vary the number of network BAN coordinator nodes from 4 to 16 to obtain different scenarios in a 100m × 100m environment. These parameters are typical for applications based on the 802.15.4 standard [13, 14]. The Random Waypoint model is used to simulate BAN coordinator movement; each BAN coordinator node moves with a speed randomly chosen from 0 to 3 m/s. The radio model is a shared-media radio with a nominal bit-rate of 250 Kbps and a nominal radio range of 10 m which is compatible with the IEEE 802.15.4 standard. We assume that a node consumes 12.84 dBm while receiving and 13.80 dBm transmitting [14]. Each simulation is carried out under a different number of network nodes and the performance metrics are obtained by averaging over 20 simulation runs from one source BAN coordinator to the static coordinator. In our simulations, we initialized the energies of the nodes randomly between 10 and 50 Joules (uniform distribution), which corresponds to the average capacity of a BAN coordinator battery.

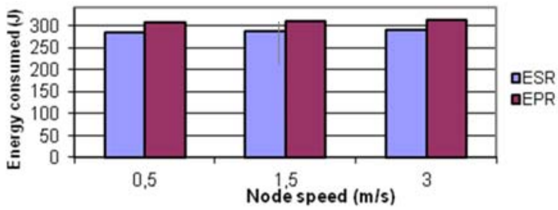
From Figs. 5 (a) and (b), we can observe that the energy consumed by our protocol ESR is less than the EPR protocol; this decrease is significant in the case shown in Fig. 5 (c): between 57% and 91% on average, the reason is that when the speed of nodes increases, this promotes link instability and increases link breaks. Our protocol resolves this ineffectiveness by selecting paths combining energy efficiency with stable links. ESR focuses not only on the energy capacity of a node, but also on the path stability.



(a) Number of network nodes: 04 nodes.



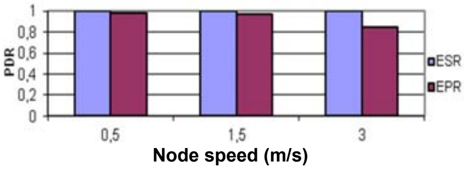
(b) Number of network nodes: 08 nodes.



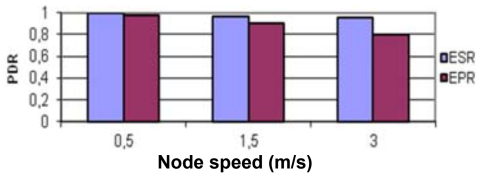
(c) Number of network nodes: 16 nodes.

Fig. 5. Energy consumed versus node speed.

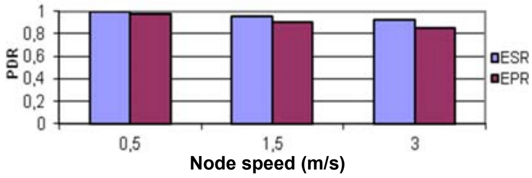
In Fig. 6, we observe for the scenarios with low mobility, ESR offers a rate (PDR) that slightly exceeds that of EPR, because in these cases the links are stable (*i.e.* links failures due to mobility are minimal). For higher mobility scenarios, the PDR of the ESR is more important than EPR. This is because the mobility of the nodes makes the links unstable which favors their failures and the exhaustion of the energy of the nodes. The ESR protocol gives better results compared to EPR, since the selected paths for the data packet transmission are paths with less breaks ensuring reliable transmission. Another reason, is that our protocol does not launch a new path discovery process when an active path breaks, it selects the next best available path, this ensures better reliability of the data packets transmission. ESR delivers between 93% and 100% of the packets in all simulated cases.



(a) Number of network nodes: 04 nodes.

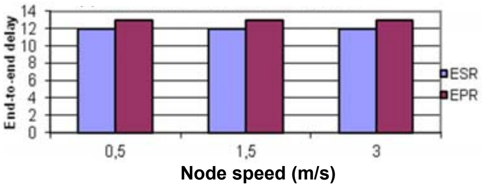


(b) Number of network nodes: 08 nodes.

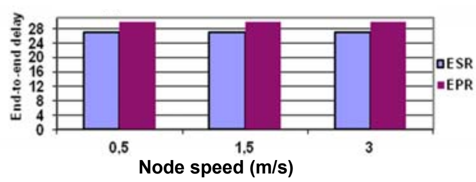


(c) Number of network nodes: 16 nodes

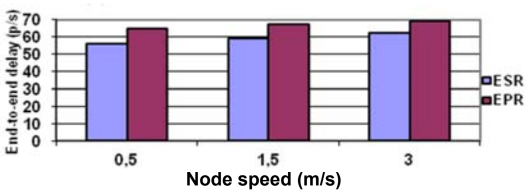
Fig. 6. PDR versus node speed.



(a) Number of network nodes: 04 nodes.



(b) Number of network nodes: 08 nodes.



(c) Number of network nodes: 16 nodes.

Fig. 7. End-to-end delay versus node speed.

Fig. 7 shows the end-to-end delay. The end-to-end delay for all tested BAN routing protocols increases with the network size, but the end-to-end delay of ESR is lower than EPR. When the number of nodes of a network is between 4 and 8, the delay of the ESR protocol is nearly 10% lower than that of the EPR protocol, and nearly 15% lower when the network number of nodes equals to 16. Our ESR protocol prefers energy-efficient paths with stable links, which ensures fewer path breaks. Moreover, ESR is a routing protocol which uses alternative paths when a link of a path is broken. This alternative path is chosen among the most stable paths with sufficient energy which minimizes link failures, and reduces the delay.

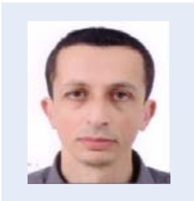
6. CONCLUSION

In this paper we have proposed a new energy aware and stable routing protocol (ESR) for mobile WBAN networks. This protocol is designed for a hospital environment. Mobile WBAN networks are characterized by their instability: link failures and path breaks occur frequently. Moreover, the frequent changes of topology exhaust the batteries of the nodes, which decrease the network performance. The proposed protocol ESR uses an energy and stability aware mechanism which exploits the residual energy and stability of nodes to select the best path for transmitting data packets. This concept improves the network performance when compared to the state of the art. Simulation results have shown that our protocol consumes less energy, minimizes the routing overhead traffic, reduces delays and ensures good reliability. We conclude that our protocol ESR improves WBAN network performance. These performances ensure the reliability of medical data transfer, contributing to the development of medical monitoring and analysis solutions such as pervasive healthcare systems.

REFERENCES

1. M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. Leung, “Body area networks: A survey,” *Mobile Networks and Applications*, Vol. 16, 2011, pp. 171-193.
2. W. Xu, C. Javali, G. Revadigar, C. Luo, N. Bergmann, and W. Hu, “Gait-key: A gait-based shared secret key generation protocol for wearable devices,” *ACM Transactions on Sensor Networks*, Vol. 13, 2017, pp. 1-27.
3. Q. Lin, W. Xu, J. Liu, A. Khamis, W. Hu, M. Hassan, and A. Seneviratne, “H2B: Heartbeat-based secret key generation using Piezo vibration sensors,” in *Proceedings of the 18th International Conference on Information Processing in Sensor Networks*, 2019, pp. 1-12.
4. V. Bhanumathi and C. P. Sangeetha, “A guide for the selection of routing protocols in WBAN for healthcare applications,” *Human-Centric Computing and Information Sciences*, Vol. 7, 2017, pp. 1-19.
5. J. Elias, “Optimal design of energy-efficient and cost-effective wireless body area networks,” *Ad Hoc Networks*, Vol. 13, 2014, pp. 560-574.
6. Y. Qu, G. Zheng, H. Wu, B. Ji, and H. Ma, “An energy-efficient routing protocol for reliable data transmission in wireless body area networks,” *Sensors*, Vol. 19, 2019, pp. 1-15.
7. A. Ghufran, M. Danish, and I. Saiful, “Thermal and energy aware routing in wireless body area networks,” *International Journal of Distributed Sensor Networks*, Vol. 15, 2019, pp. 1-12.
8. O. Smail, A. Kerrar, Y. Zetili, and B. Cousin, “ESR: Energy aware and stable routing protocol for WBAN networks,” in *Proceedings of the 12th International Wireless Communications and Mobile Computing Conference*, 2016, pp. 452-457.
9. Q. Nadeem, N. Javaid, S. N. Mohammad, M. Y. Khan, S. Sarfraz, and M. Gull, “SIMPLE: Stable increased-throughput multi-hop protocol for link efficiency in wireless body area networks,” in *Proceedings of IEEE 8th International Conference on Broadband and Wireless Computing*, *Communication and Applications*, 2013, pp. 221-226.

10. S. Ahmed, N. Javaid, and S. Yousaf, "Co-CEStat: Cooperative critical data transmission in emergency for static wireless body area network," *Journal of Basic and Applied Scientific Research*, Vol. 4, 2014, pp. 200-216.
11. Z. A. Khan, S. Sivakumar, W. Phillips, and N. Aslam, "A new patient monitoring framework and energy aware Peering Routing Protocol (EPR) for body area network communication," *Journal of Ambient Intelligence and Humanized Computing*, Vol. 5, 2014, pp. 409-423.
12. The Network Simulator ns-2, http://www.isi.edu/nsnam/ns.
13. C. E. Aitzaouit and A. Latif, "Performances comparison of IEEE 802.15.6 and IEEE 802.15.4. Optimization and exploitation in healthcare and medical applications," *International Journal of Advanced Computer Science and Applications*, Vol. 8, 2017, pp. 461-467.
14. E. Morin, M. Maman, R. Guizzetti, and A. Duda, "Comparison of the device lifetime in wireless networks for the Internet of Things," *IEEE Access*, Vol. 5, 2017, pp. 7097-7114.



Omar Smail is an Assistant Professor in Department of Computer Science, University of Mascara, Algeria. His research interests include routing in ad hoc networks, power management in wireless communications, wireless network stability and traffic engineering.

Adda Kerrar received his Master of Science in Computer Science in 2015 from the University of Mascara, Algeria. His research interests include routing in wireless communication networks and mobile computing.