Energy saving model for wireless sensor networks: sports medical application

IMEN KOULOUGHLI, HASSINE MOUNGLA, HICHEM HADDOU BENDERBAL

***Abstract*—**The present paper focuses first on small wireless sensor networks in the medical-sports field. A protocol solution is designed and dedicated to dynamic routing and energy saving. This solution called DREEM (Dynamic Routing Energy Efficient Model) consists of: - A standby strategy, which we propose, and which allows extending the service life of the network, - A locating algorithm called CTA (Closer Tracking Algorithm) used to locate the sensors based on the RSSI metric (Received Signal Strength Indication). To adopt this algorithm for our case study, some necessary modifications were carried out in order to determine the position the athlete was in, and based on that, it became possible to choose a topology that helps to apply the third algorithm of a routing protocol called ELQR (Energy and Link Quality Based Routing) - The routing protocol ELQR in which the status of the link is taken into consideration. Note that in the routing tables, there is also one more column that is especially dedicated to the residual energy of neighboring nodes.

***Keywords*—** Dynamic routing, Energy saving, Wireless Body Area Network (WBAN), Wireless Sensor Network (WSN).

I. Introduction

Today, technological advances in wireless communication technologies and microelectronics make it possible to create small communicating systems, equipped with sensors, at reasonable costs. Lately a new research area has emerged; it is the area of Wireless sensor networks (WSN). It has the advantage of offering economically attractive solutions. These networks are supposed to collect data from an environment t and then disseminate them across the network. This type of sensor networks could have very diversified applications. Tracking the condition of an athlete is a task that requires several investigations, since the interaction of various disciplines comes into play.

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Sensors are implanted on the body of the athlete; they must be placed intelligently in order not to impede his physical activity. These sensors are supposed to communicate with each other and then send the collected information to the base station. One of the major problems with these sensor networks is to find the most suitable routing protocol in order to consume as little energy as possible.

Indeed, most current research focuses either on Media Access Protocols or on routing protocols, regardless of the probability that some of the sensors composing the network may be mobile (sensors positioned on the arms and/or on the feet), which implies a momentary change in the topology. Numerous research studies have been carried out in the field of wireless sensor networks (WSN). Authors in [1] proposed MobiNet whose objective is to enable mobile sensors to detect surrounding sensors in the visited network through passive listening in order to select one of them to transmit the messages. MobiNet has been evaluated by simulation. Simulation results show the benefits of MobiNet in terms of message delivery and lower energy consumption through the listening processes.

The LEACH protocol was improved using Fuzzy Logic (LEACH-FL) [2] which takes the battery level, distance and node density into consideration. The proposed method was proven making a better selection by comparing simulations using Matlab.

A Mobility-Based Clustering (MBC) protocol was proposed in [3] for wireless sensor networks with mobile nodes. In the proposed clustering protocol, a sensor node elects itself as a cluster-head based on its residual energy and mobility. A non-cluster-head node aims at its link stability with a cluster head during clustering according to the estimated connection time. Authors in [4] built a framework for investigating the joint sink mobility and routing problem by constraining the sink to a finite number of locations. They formally proved the NP-hardness of the problem. They also investigated the induced sub-problems. In particular, they developed an efficient primal-dual algorithm to solve the sub-problem involving a single sink, and then they generalized this algorithm to approximate the original problem involving multiple sinks. Finally, they applied the algorithm to a set of typical topological graphs. The results obtained demonstrated the benefit of involving sink mobility, and they also suggested the desirable moving traces of a sink.

The authors in [5] succeeded in making a comparative study between short-range wireless communication protocols, such as Bluetooth, Wifi and ZigBee. In the work of [6], which concerned the location of the sensors, the author proposed a very special technique to place the different sensors in the network.

In [7], Abdallah Makhoul focused on estimating the distances between sensors; this can be done in different ways. The Body Area Network (BAN) is a wireless network technology that is based on radio frequencies; it consists in interconnecting on, around or in the human body, tiny devices (sensors) capable of performing measurements or acting actively (actuators). Several research studies have been carried out in this field, and the most important ones are cited here.

A New MAC Protocol was proposed in [8] for emergency handling in Wireless Body Area Networks (WBAN). The author proposes a new MAC superframe structure which can handle emergency data as well as regular periodic data at the time of emergency. The simulation result shows low latency and increased throughput of the proposed superframe.

A reliable, power efficient and high throughput routing protocol, named Energy Efficient and Reliable Data Transfer (EERDT) for WBAN, was proposed in [9]

In their work, Rani Kumari and Parma Nand analyzed the performances of the various routing protocols of the wireless network in the *Wireless* Body Area *Network* (WBAN) and Wireless Sensor Network (WSN). Moreover, they compared their performances in the same network as well as in a different network using different parameters such as P*acket Delivery Ratio* (PDR), latency and throughput, etc. Their paper intends to show that the wireless protocol needs to be updated in order to perform well within the *Wireless* Body Area *Network* (WBAN).

II. METHODS

New mechanisms are proposed in this paper, They are based on artificial intelligence; they allow, on the one hand, responding to mobility concerns in a network with high constraints and, on the other hand, to save the energy of sensors as well as that of the network. This is done using DREEM (Dynamic Routing Energy Efficient Model), which consists of a standby strategy for sensors, which is proposed here, along with a localization algorithm and a routing protocol. The solution is developed in such a way that the quality of monitoring is not affected and that the routing of the information is optimal.

A. *Wireless Sensor Network*

Our network is made up of different sensors which are to be fixed on the athlete's body. In this network, each sensor node represents a source of data that should be forwarded to the base station and stored.

B. *Location of Sensors*

The locations of the sensors were selected with the help of the results found in some of the above mentioned research works. This was accomplished using 18 sensors and a base station. They were arranged in a way to be at a distance smaller than 0.52 m from each other. Fig.1 shows the position of each sensor on the athlete's body. The sensor in black color represents the base station (Sink). The sensors in orange color represent the significant sensors. The gray sensors represent ordinary sensors.

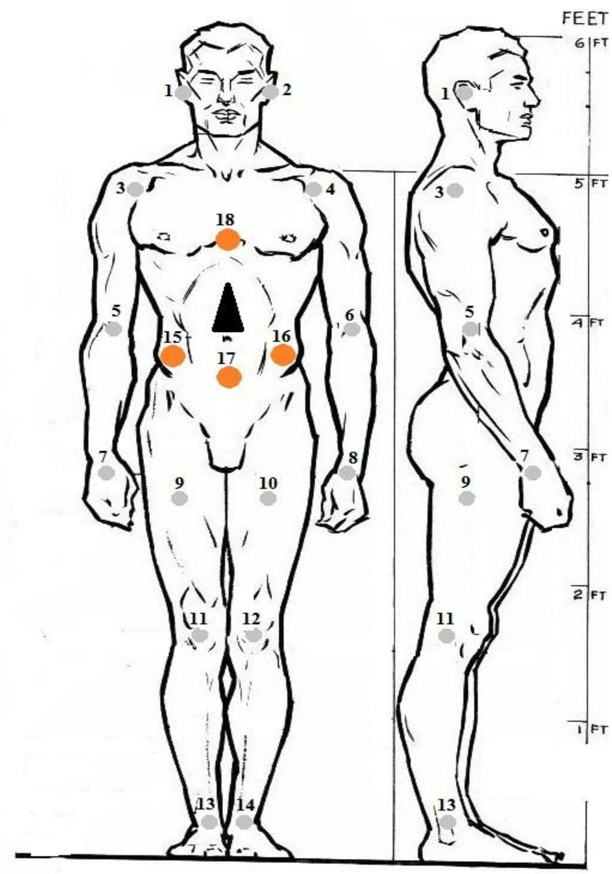

Fig.1. Positions of sensors on the athlete's body

C. *Athlete's positions and topologies*

In the present study, the sports activity of "Running" was selected. Moreover, the essential and most common positions were selected for an athlete with a normal morphology (1.80 m). This study consists in permanently monitoring the movements of an athlete, which is a fundamental issue in the field of sports medicine.

For this reason, it was deemed necessary to start by determining the different physical positions of the sportsman. These are four: "Relax", "On your marks", "Ready" and "Go". To each position is associated the appropriate topology, according to the locations of the sensors. The main points at the start are the three orders: "On your marks", "Ready" and "Go".

D. *Detecting the position of the athlete*

In order to identify the athlete's position, two types of criteria were used. The first one was used to ensure the quality of the link, using Link Quality Estimators (LQEs) [10], and more specifically ETX (Expected Transmission Count), which is based on Packet Reception Ratio (PRR) and the Four-bit which is based on ETX, which according to the comparative study conducted by [10], are the best.

The second type of the parameters used allows locating the sensor in question, in order to identify the athlete's position. Among the localization methods used in sensor networks, two categories are worth mentioning, i.e. the methods that are not based on inter-node distances and those that are. The first ones are those that do not calculate the distances between neighboring nodes; they use other information, such as the connectivity, to estimate the position of the nodes. The second methods are the ones that estimate the distances between the nodes in order to determine the positions [11]. Several techniques have been developed for estimating the distances between neighboring nodes. In our case, it was decided to use this type of method, using the Received Signal Strength Indication (RSSI) technique [11] for estimating distances. The RSSI method seems to be the most appropriate because it does not oblige us to integrate any equipment that is different from that which already exists in each sensor (their radios). In order to identify the athlete's condition, the distances between some sensors had to be considered. For example the sensors selected to check the position "On your marks" are: Sensor number 16, located on the left hip, and sensor number 14 on the left foot, which are separated by a distance smaller than 0.5 m. Sensors 7 and 3 on the right arm and sensors 8 and 4 on the left arm must have the same distance between them, i.e. D (3, 7) = D (4, 8) ≤ 0.6 m.

E. Standby strategy

The dominant use of the radio is often found in multi-hop communications which generally correspond to sending data from the nodes to one or more base stations. To conserve the energy of a sensor node, the *ideal would be* to switch off its radio if it is not a data source or a routing relay in the multi-hop communication. However, turning radios off makes the nodes unavailable for multi-hop communication. In our model, it was decided to set up a clock that can determine, among the sensors of the network, the one that must be active and the one that must be in standby mode. This must be achieved according to certain rules:
- The order must be decided according to the importance of the role of the sensor,
- The procedure must be repeated periodically,
- When some sensors are active, the others are in standby mode.

In order to be able to put the sensors to sleep, according to their types, an algorithm has been proposed.

N	Role	Duration	Nodes in use
1	Blood pressure	10	5, 8, 17, 11
2	Electrocardiograph	5	6, 7, 15, 14
3	Blood and oxygen flow	10	16, 9, 10, 13
4	Breathing	10	18, 12, 4
5	Temperature	5	1, 2, 3

Table 1: Role of sensors

In order to be able to put the sensors to sleep, according to their types (Table 1), an algorithm has been proposed. First, some variables and functions are defined in the following:
- [Clock seconds] to get the current time in seconds. All sensors are in the standby mode when the algorithm is started,
- Set IT [clock seconds] is placed at the beginning of the algorithm in order to keep the initial launch time. Immediately afterwards, the sensors of type1 are awakened with the function "Wake-up". A variable E is also necessary to describe the status of the energy of a sensor. This variable will be among the conditions to be considered in the loop,
- the different types of sensors are defined using the variable "Type" which is initialized to Type (1). However, it is necessary to start first by creating these types, using for example the function Set Type (1) [N5, N8, N11, N18] for blood pressure ... etc.

A variable of Type (i), where i is initialized to 1, is necessary.
- A variable TE is used for the elapsed time, for each type, in order to know the one that will be awakened immediately afterwards. The variable TE is initialized to 0.

III. Results and Discussion

A. How the model works

Before forwarding the information to the base station, it is necessary to know the route to be followed; this route is chosen according to the different positions of the sensor nodes. For this reason, a localization algorithm is used.

B. Closer Tracking Algorithm (CTA)

Yu-Tso Chen et al. proposed the Closer Tracking Algorithm, which is based on the algorithm Received Signal Strength Indicator (RSSI) in [12]. This algorithm allows locating the mobile nodes; it is based on the fusion of two other algorithms, i.e. Real Time Tracking (RTT) and an improved version of Fingerprinting (FPT) which is also called Approximately Closer Approach (ACA).

In order to extend the lifetime of the network of sensors and ensure the quality of radio links between them, the routing protocol ELQR (Energy and Link Quality based Routing Tree) was chosen to be used.

The routing protocol (ELQR) was developed by A. Sivagami; it takes into account the quality of the links and the saving of energy [12]. For networks that have an energy constraint, such as wireless sensor networks, the retransmission of packets plays an important role in the lifetime of the network. In order to improve this lifetime, retransmissions are minimized by sending the packets via good quality channels. In addition, the network lifetime increases when the loads on nodes, having the best link quality, are well balanced. Fig. 2 shows the architecture of this algorithm.

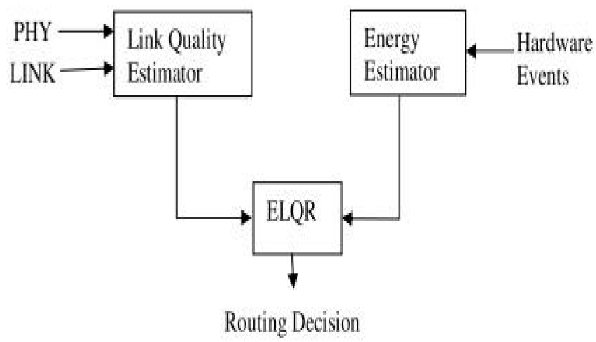

Fig.2.ELQR Architecture

C. Schematic of the Dynamic Routing Energy Efficient Model (DREEM)

This section gives an example to clarify the principle of our model. Here, the position "Relax" is considered because all the nodes are visible. The role "ECG" (sensors 6, 7, 14 and 15) is chosen.

The algorithm starts by locating the mobile nodes. In this example, the node 7 is placed on the right hand of the athlete. The N_neighbor is a variable that represents, in our algorithm, the number of reference nodes in a "Blind node" hop and BID is a predefined identification of the "Blind node". The N_neighbor of node 7 is 2 because there are 2 reference nodes with one jump (RID: 15, 17); RID is a variable that represents a predefined identification of a reference node. The closestRID is a rid which refers to RID; it represents the closest node to the "Blind node" BID. In our example it is equal to 15. Applying the last step of the CTA, one can see that the choice was made on R3 (the zone of node 7), as shown in Fig.3 (B).

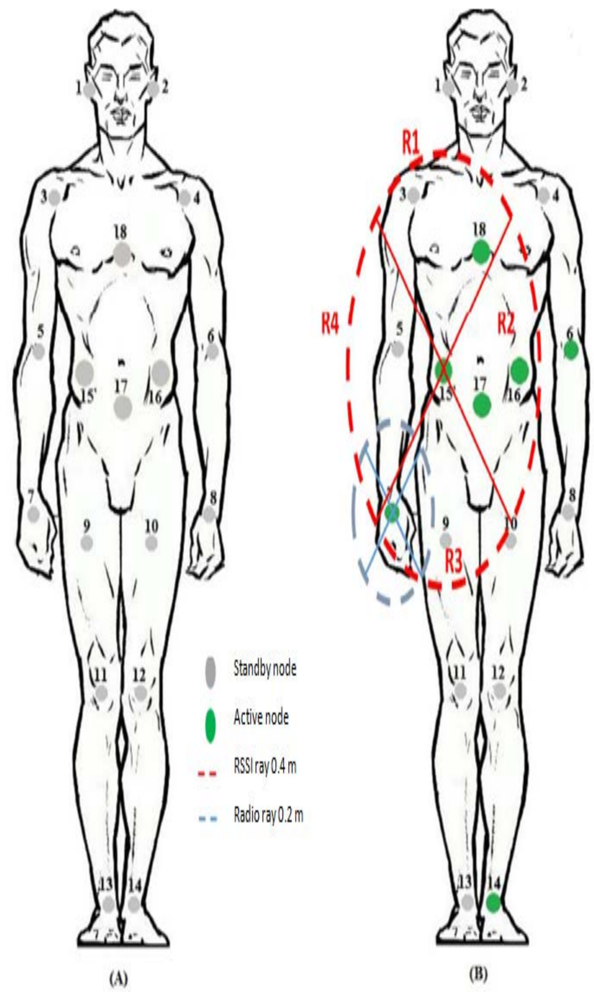

Fig.3. Localization of the right hand

Now, it is a question of passing the information captured by the sensor node 14 to the base station, as shown in Fig.4 Taking into consideration the fact that the sensors between the source and destination are in standby mode and that the use of a high radio frequency affects the lifetime of the network, then it becomes necessary to wake up the parents (using the routing algorithm included in DREEM). Once the routing process is finished, the parent is put back in sleep mode if its type is different from that of the source.

The parent is selected according to the ratio ETX / Energy. For example, if the sensor 13 has an ETX greater than that of sensor 12, even with the same energy, though sensor 13 is closer to 14, then the algorithm automatically chooses the sensor with the minimum ETX , which in this case is sensor 12. Obviously, a topology is to be followed.

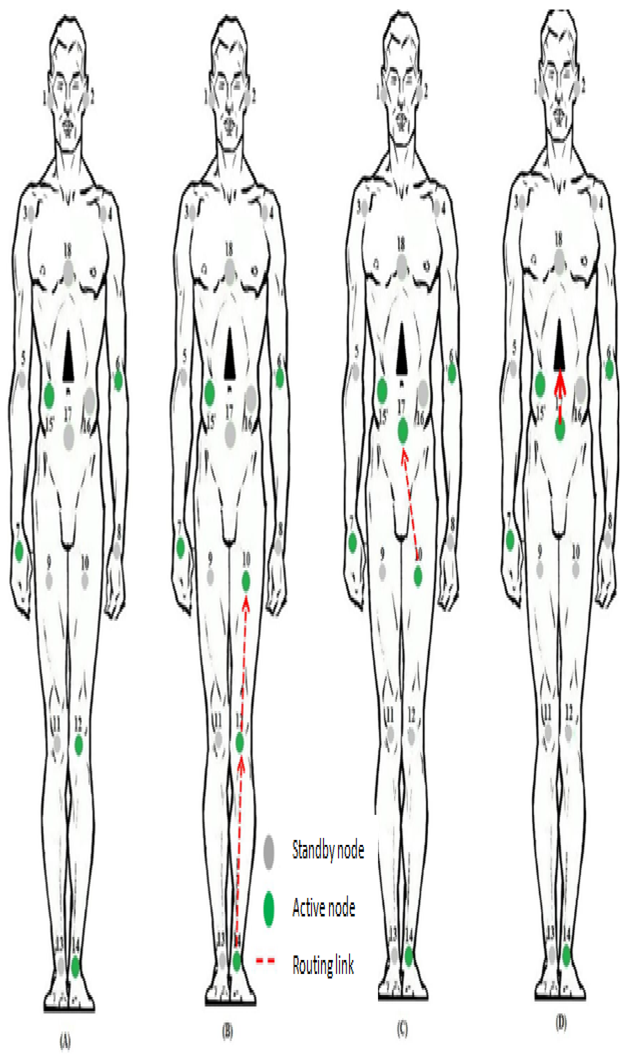

Fig.4. Routing with DREEM

IV. Conclusion

In this article, an original model has been designed; it is called Dynamic Routing Energy Efficient Model (DREEM). The novelty and originality of this model lie in the combination of three techniques, carefully selected and adapted to the case of sports medicine.

A standby strategy was first created in order to save the energy of the network as much as possible. This strategy is specific to our model. For the same purpose (energy saving) two other algorithms have been integrated.

The first one is specific to localization and the second for routing .The merger of all three algorithms allowed us to have a complementarity whose objective is to save as much energy as possible in our model.

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