A New Reinforced MAC Protocol for Lifetime Prolongation of Reliable Wireless Body Area Network

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ABSTRACT

Recent development of sensors and sensor networks has allowed the creation of new emerging systems which is used as promising solutions in several types of applications. Among which, wireless body area networks (WBANs) is an example that enable continuous monitoring of patients vital signs parameters in daily life situations. Reliability and energy optimization are considered amongst the important and challenging issues in WBANs. The standard IEEE 802.15.4 MAC (Media Access Control) is of paramount importance protocol for medical sensor body area networks, owing to its low-power, low data rate and low-cost features. In this paper, we propose a reinforcement optimized MAC protocol based on IEEE 802.15.4 dubbed RMAC. The proposed protocol aims to enhance the reliability and to extend the network lifetime, by reducing the energy consumption. NS2 simulator is used for the implementation of the protocol and for the performance evaluation in comparison with the Standard IEEE 802.15.4. The simulation results show that our protocol outperforms the Standard in terms of reliability and network lifetime.

Keywords: IEEE 802.15.4, WBAN, Energy optimized GTS, Reliability, Superframe adaptation.

1. INTRODUCTION

The rapid growth of the elderly population, especially in developed countries, makes a new challenge to improve the life quality of persons. One promising application in this area is the integration of the latest sensors technologies which would allow people to be constantly monitored. Recent advances in low-power integrated circuits, wireless communications, and physiological sensing have led to the development of miniature, low cost, low power, intelligent, multi-functional sensor nodes, capable of processing information locally and communicate un-tethered in short distances. Besides the sensing operation, these devices can communicate between them and/or with a central server forming a system called Wireless Body Area Networks (WBAN). A WBAN allows continuous monitoring of the patient's vital signs parameters in daily life situations, without constraining their normal activities. In fact, the reason for the patient staying in hospital is not that he actually needs active medical care, but is simply continual observation. Therefore, efforts have been made to avoid acute admissions and long lengths of stay in the hospital, which become extremely costly. Hence the focus of health policy has shifted away from the provision of reactive, acute care toward preventive care outside the hospital [1-2]. Investment in technologies that enable remote monitoring would lead to long-term gains in terms of hospital finances and patient care. It is worth noting that WBAN technology will change paradigm of healthcare and then the healthcare services will be available casually. In a patient monitoring system, data transmission reliability is extremely important. Likewise, energy efficiency optimized is one of the overriding challenges for the WBANs that aim to extend the network lifetime.

Transmitting measured vital biomedical information upon wireless channel requires an effective, dynamic and reliable protocol at medium access control (MAC) sub-layer, which is in charge for awarding the channel resource amongst different users. One of the most broadly studied MAC protocol for WPANs (Wireless Personal Area Networks) is the IEEE 802.15.4 MAC protocol, which is ready and suitable for applications to connect WBAN to larger networks. The use application selected for this study is a WBAN, that consists of six heterogeneous medical sensors carried by the patient and send their data to a coordinator node sensor, which will subsequently transmit the combined data to a record home PC connected to a medical network. The coordinator node is connected to the home PC, which is connected via intranet or internet with remote medical staff network. In this paper, we introduce a new reinforcement protocol MAC (RMAC), that enhances the re-

Manuscript received on April 21, 2018 ; revised on June 8, 2018.
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liability and to extend the network lifetime. The rest of the paper is organized as follows: previous related work is discussed in the next section. In section1.2, we present an overview of the IEEE 802.15.4 standard. The detail of the Reinforcement MAC protocol proposed is highlighted in the section1.3. Sections 2 and 3, report the simulation environment and simulation results, respectively. Finally, section 4 concludes the paper.

1.1 Related work

Wireless Body Area Networks (WBAN) is a particular type of Wireless Sensor Networks (WSN). So, some protocols used in WSN can be used also by WBAN and it is useful to take into account the relevant research into protocol designed for WSNs when implementing protocols for WBANs. But there are intrinsic differences between the two networks, especially in the case of heterogeneous medical sensors where each one has a different required traffic arrival rate and data transmission rate. In the literature, several works present a performance evaluation of IEEE 802.15.4 and/or Zigbee protocols, most of them are based on simulations [3-5] or analytical models [6-7]. Lu et al. [3], studied an effective compromise between power consumption, throughput and latency in star topology with beacon enabled. They conclude that small nodes duty cycle allow substantial energy saving. Rinki Sharma et al. [8], present the performances of ZigBee based sensor network for patient monitoring through NS2 simulator. The performances are measured in terms of packet delivery ratio (PDR), average delay, throughput and energy consumption. The obtained results can be used to choose the appropriate nodes density, data transmission rate, amount of data to transmit and duration of communication. A comprehensive performance evaluation and analysis of the slotted CSMA/CA medium access mechanism deployed by the IEEE 802.15.4 protocol in beacon-enabled mode is presented in [9]. The authors show the impact of parameters such as super frame order, beacon order, back off exponent, frame size and CSMA/CA overheads on the network performance, particularly in terms of throughput, average delay and the energy consumed by the network. In [10], the author presents a performance study of both beacon and non-beacon modes of IEEE 802.15.4 MAC protocol and concluded that the non-beacon mode overrides the beacon mode in term of throughput and latency but with high waste of power consumption. All these works do not use the adjusted topology in WBAN, that consider the heterogeneous property of WBAN applications.

With regards to GTS (Guaranteed Time Slot) allocation mechanism, [11] and [12], furnish an allocation methods to reduce the bandwidth waste. The irst one provides a mechanism to enable more devices in one time slot. The second one divides the CFP (Contention Free Period) period into 16 equal time slots to allocate the time slot and reduce the bandwidth waste, especially for low data rate sensors, its disadvantage is to contend with other device in the CAP (Contention Access Period) period to have the channel access. In [13], the authors present a new GTS allocation system to reduce the transmission power consumption and delay time. A slotted beacon scheduling to reduce the power consumption is presented by [14] in the case of the hierarchical tree topology and beacon-enabled network. These works ignored the fact that different physiological parameters sampled by different sensors mostly have important differences in terms of traffic arrival and data rate.

In [15] a new mechanism to enhance the performance and utilization by using CFP is presented. The work aims to cope with the competitor access to the radio channel using GTS in the CFP period. Based on network calculus [16-17], the authors proposed a theoretical performance evaluation of the GTS allocation. Their work evaluates the impact of Beacon Order (BO) and Superframe Order (SO) on the delay, throughput and energy consumption of the GTS allocation in WSN. In [18], an algorithm to optimize a GTS allocation is proposed by the author, it aims to improve reliability and bandwidth utilization in IEEE 802.15.4-based Wireless Body Area Networks. An energy efficient MAC protocol (Body MAC) is proposed in [19]. It uses flexible bandwidth allocation to improve node energy efficiency by reducing collision and by decreasing the radio transmission times, idle listening and control packet overhead. In order to increase the WBAN network lifetime, the author proposes an integer linear programming model which optimizes the number and location of relays to be deployed and the data routing towards the sinks, minimizing both the network installation cost and the energy consumed by wireless sensors and relays [20]. Even though WBAN has been assumed as a single-hop star network in [21], several works have examined the performance amelioration obtained by conventional multi-hop cooperative relaying schemes [22-23]. Depending on Braem et al. [22], use of multi-hop communications could lead to a more energy efficient and reliable network topology. Antonio G.R et al. [24] propose a new mechanism to enhance the lifetime of network. The algorithm provides multi-hop support over 802.15.4 through the division of the network into time zones. The author in [25], proposes an energy-efficient MAC scheme to support multi-hop transmission, designed for BAN. The basic idea is that the body sensors send their data to the coordinator using multi-hop transmission in order to maximize the BAN lifetime. Authors in [26-27], show the effect of adding a relay network to the network of body sensors to reduce energy consumption of sensor nodes when transmitting data to the sink. For im-

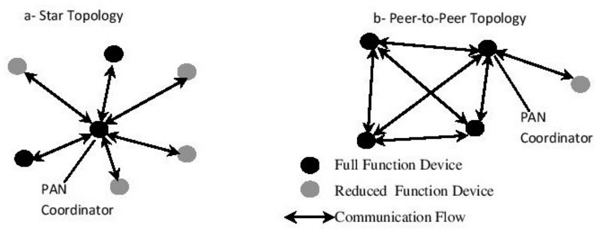

Fig.1: *Star and peer to peer topology examples.*

proving the network lifetime, most of works use an additional relay node as a relay function which reduces the comfort of the person being monitored.

1.2 IEEE 802.15.4 MAC Overview

The IEEE 802.15.4 standard specifies the physical layer and the MAC sub-layer for Low-Rate Wireless Personal Area Networks (LR-WPANs) which emphasizes on short-range operation, low-data-rate, energy-efficiency and low-cost [28]. The standard distinguishes between two types of nodes. A Full Function Device (FFD) can operate in three different manners. It can be a PAN coordinator and talk to any other devices, an ordinary coordinator or an end device. A Reduced Function Device (RFD) can operate only as an end device and then communicate only with its associated FFD. Two network topologies are supported by the standard. The star topology and the peer to peer topology (Figure.1). In the star topology (Figure.1-a), the communication is established between devices and a single central controller, called the PAN coordinator, which is in charge of managing the entire PAN. In the peer-to-peer topology (Figure.1-b), any device is able to communicate with any other device as long as they are in range of one another. This topology has also a PAN coordinator, which works as the root of the network. Peer to peer topology permit more complex network formations to be implemented, such as mesh networking topology. A cluster-tree is an example of the use of the peer to peer topology. In this special case, most devices are FFDs. Any FFD is able to act as a coordinator and provide synchronization services to other devices or other coordinators. A node can communicate only with its parents or children nodes.

The IEEE 802.15.4 MAC takes in charge two operational modes that may be selected by the PAN coordinator.

For purpose of synchronization and association control, each superframe is limited by periodically transmitted beacon. The superframe consists of active and inactive periods. The active period is the part in which the PAN coordinator interacts with network nodes (terminals), while it switches into sleep mode to save energy in the inactive portion. The length of these periods are specified by two parameters: the beacon order (BO) and the superframe order (SO). The first one (BO) determines the length of the superframe (Beacon Interval) while the second one (SO) specifies the length of the active part (superframe duration).
The beacon Interval is defined as follows:

$$BI = aBaseSuperFrameDuration * 2^{BO}$$

for $0 \leq BO \leq 14$
The superframe duration is defined as follows:

$$SD = aBaseSuperFrameDuration * 2^{SO}$$

for $0 \leq SO \leq 14$

Where the value of a BaseSuperframeDuration is 960 symbols (a symbol correspond to 4 bits). This value indicates the minimum length of the superframe, corresponding to SO=0. In IEEE 802.15.4 standard with 2.4 GHz frequency range at 250 kbps, the SO values ranging from 0 to 14 gives the corresponding superframe durations between 15.36ms to 251.6s. The active part, which is called, the superframe, is divided into 16 slots of equal duration, and it consists of a beacon, a contention access period (CAP), and a contention free period (CFP).

Any device wants to communicate during the contention access period (CAP) between two beacons competes with other devices using a slotted CSMA-CA or ALOHA mechanism, as appropriate [27].

The CFP part is optional; it is dedicated for the low-latency applications or applications requiring specific data bandwidth, and the time slots of CFP are allocated on demand by the nodes. Upon receiving the nodes requests, the PAN coordinator checks whether there are sufficient resources in which the length of the cap cannot be shorter than a Min CAP Length (220 bytes) and, if possible, allocates the requested time slots. This kind of reservation of time slots called Guaranteed Time Slots (GTS). If the available resources are not sufficient, the GTS request is rejected. The PAN coordinator allocates up to seven of these GTSs, and a GTS is allowed to occupy more than one slot period. Any device transmits in a GTS ensures that its transaction is complete before the time of the next GTS or the end of the CFP.

1.2.1 One hop (star) topology

The IEEE 802.15.4 standard uses the beacon enabled mode to synchronize the communication between the PAN and the nodes of the networks. The used superframe in this case is illustrated in the Figure.2. The standard MAC supports two operational modes selected by the PAN coordinator; the Beacon enabled mode, in which beacons are periodically sent by the PAN coordinator to identify its PAN network and to synchronize associated nodes, and non-beacon enabled mode, in which MAC is ruled by non-slotted CSMA-CA mechanism. In this last mode, there is no

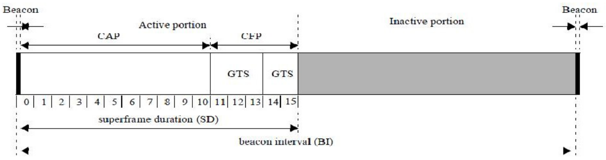

Fig.2: *The superframe structure-star topology.*

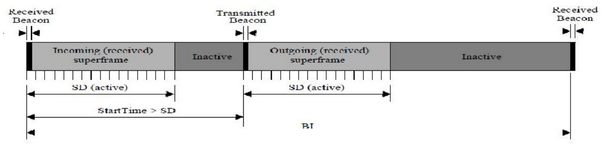

Fig.3: *The relationship between incoming and outgoing beacons multi-hop.*

superframe and slot synchronization. So, the protocol uses the carrier sense multiple access with collision avoidance (CSMA-CA) and cannot support the energy saving applications because the network is always in active status.

1.2.2 Multi-hop (cluster-tree) topology

The multi-hop transmission is used in the peer to peer network topology. In this kind of topology, there are two types of coordinator. The PAN coordinator which acts as a sink, and the ordinary coordinator that may periodically transmit its own beacons. The ordinary coordinator shall maintain the timing of both the superframe in which its coordinator transmits a beacon (the incoming superframe) and the superframe in which it transmits its own beacon (the outgoing superframe). The relationship between incoming and outgoing superframes is illustrated in Figure.3.

As shown in figure3, the overlap is occurring between the active period and the inactive period. So, for each ordinary coordinator, the overlap takes place between the incoming frame from its parents and the outgoing frames to their child. Note that the ordinary coordinator transmits its superframe to its child only in the inactive period when the PAN coordinator switches to sleep mode. It is worth noting that the ordinary coordinator must listen to the arrival of its parent's beacons to synchronize with the network before it begins to send its outgoing superframes to its child nodes. Few works in the literature treat simultaneously one-hop (star topology) and multi hop (peer-to-peer topology) aspects to assess IEEE 802.15.4 MAC protocol performance, especially the topology adjustment according to the application or the system situation. This feature pushes us to work more in this field, and propose finally RMAC protocol.

1.3 Reinforcement MAC protocol

In this section, we propose the Reinforcement MAC protocol dubbed (RMAC). It is based on the standard IEEE 802.15.4 MAC protocol. The primary aim of this protocol is to enhance the reliability and to extend the network lifetime by optimizing the energy consumption of sensor nodes. For that, the scheme consists of two steps.

1. All the associated nodes use IEEE 802.15.4 star topology with GTS allocation to communicate with coordinator, but with swapping between CAP and CFP periods.
2. The network is transformed from one-hop star topology to multi-hop topology when the first sensor detects own energy drop below a certain predefined threshold.

Step 1 : In this step, all the associated nodes use the star topology with GTS allocation to communicate with the PAN coordinator but with exchange between CFP and CAP periods. The swapping operation between CAP and CFP allows the transmission of data in CFP before those in the CAP period. Since there is a variety of medical sensors in typical WBANs, data delivery rates in these networks span a wide range from very low sampling rates, as the temperature sensors, to rates of several hundreds of Kbit/sfor ECG sensors. So, if the different sampling rates of nodes are treated evenly, the performance of the network will be reduced by the unbalanced traffic load [29-31]. The IEEE 802.15.4 standard has some drawbacks among which, first, contention would occur in the case when the offered load exceeds the capacity of the GTS allocation (might be allocated but unused time slot in the GTSs). Second, the expiration period of the GTS allocation might be too short for low-rate traffic. It is worth noting that a GTS may use it only partially when it is allocated to a node with a low arrival rate (when the amount of guaranteed bandwidth is higher than its arrival rate) [11]. This leads to under utilization of the GTS bandwidth resources. It is practically impossible to make a balance between the arrival rate of a node with its guaranteed GTS bandwidth, since the duration of the GTS in the superframe is fixed by the IEEE 802.15.4 standard. This wasted bandwidth due to the node's low data rate compared to the explicit allocated guaranteed bandwidth can be transferred to be used during the CAP period. Note that the right sharing of a GTS is effective when the arrival rates of the flows are analogous. For example, aflow with an arrival rate of 50 kbps cannot fairly share the same resource with aflow with an arrival rate of 1 kbps [11].

Therefore, for these reasons mentioned above, the idea consists in the separating the two types of traffic.

- The nodes with high data rate (kbps order) use the allocated GTS in the CFP period (TDMA protocol).
- The nodes with low data rate (bps order) compete

in the CAP period, using the slotted CSMA-CA mechanism.

Moreover, on the one hand, for the nodes using CFP period and for each GTS allocated, only the concerned sensor wakes up to make a data delivery, while all other sensor nodes are kept sleeping for saving energy. Furthermore, when its GTS expires, the node will switch off the transceiver and shifts to sleep mode. On the other hand, using allocated GTS for sensor nodes with high data rate, this leads to reduce the number of nodes (with low data rate) that compete to the CAP period, and therefore increase the throughput. So, for the optimal and effective use of bandwidth and GTS, we propose that every time a sensor node sends a data frame to the PAN coordinator, it includes the size of data packets and a field dubbed Priority. By default, all the sensor nodes have the same Priority which is zero. For each sensor node using the CAP period, when it detects a value outside the defined interval, it asks the PAN coordinator to allocate a GTS, and it changes the value of the priority field to 1. For example, the number of pulse for an adult ranges from 60 to 100 (bradycardia=60 and tachycardia =100). In this case, when the value is outside the interval, the value of the Priority field should be set 1. To allow the above information exchange, two additional fields should be added to the general MAC frame format of the IEEE 802.15.4. The modified frame is presented in Figure 4.

Algorithm 1 Phase2 RMAC at sensor node

Require: x,n,y,t //n: nodes number, y:data interval
  $x = 0$ //x : Priority value, t: data values
  $Period = CAP$
  for i=1,n **do**
    if $t \neq y$ **then**
      $noeud\ i\ asks\ a\ GTS\ from\ coordinator$
      $x = 1$
    end if
  end for
Ensure: noeud i expects a GTS from coordinator

Algorithm 2 Phase2 RMAC at coordinator

Require: x,n,z //n: nodes number, z:GTS number
  $x = 0$ //x : Priority value
  $Period = CAP$
  for i=1,n **do**
    if $x = 1$ **then**
      $i = GTS$
    end if
  end for
  $z = z - 1$
Ensure: noeud i receives a GTS from coordinator

The data length list of the sensor nodes located inside the PAN is maintained by the coordinator, and it updated after every received data packet based on the information extracted from packet's header. The coordinator checks the data length list and Priority fields before sending the beacon. This operation is done in two phases. In phase 1, the PAN coordinator allocates the GTS slots based on the data length of the transmitter sensor node. And then calculates the number of GTS for all nodes with high data rate, because they use TDMA protocol (GTS allocation). At the end of this step (only the first one), the coordinator sets the number of allocated GTS since the same sensor nodes are used in the application and the data frames are generated periodically. In phase 2, as the emergency data is totally unpredictable, the PAN coordinator checks the value of Priority field from the packets headers. If it finds a sensor node with priority =1 (node with emergency data), and didn't get a GTS in phase 1, it allocates to it one GTS slot. This slot is taken from the last sensor node, since in the IEEE 802.15.4 standard, the GTS allocation is performed in a first-come-first-served fashion. This technique ensures an immediate channel access to sensor nodes with priority traffic, like emergency data, especially for sensor nodes with low data rate which use the CAP period to send their data.

Step 2 : The RMAC protocol is based on the fact that the topology is adaptively adjusted by the coordinator WBAN, since it is the master node having the ability to control the whole network. In this step, first, we assume that all nodes have the capacity to accurately measure their residual powers of their batteries [33]. We defined Ei to be the ratio of the remaining battery energy to the initial battery energy for node i. When a sensor node i, detects that its residual energy reachs a predefined threshold denoted Eth, it minimizes its transmission power and ask for help.

Consequently, a relay node becomes necessary to route the data of sensor node i to the WBAN coordinator, and, then provides relay service. In this time, the network topology is switched from single-hop to multi-hop, and the superframe is adapted to sustain this change. In this scheme, the principal operations consist of three phases. Relay demand, relay reply (answer) and superframe adaptation.

Relay demand : Every node i in the network detects its current energy Ei below Eth, it initiates relay demand to inform the PAN coordinator of its energy lack (EL). The node i conveys a dedicated frame (energy lack EL) to the PAN coordinator if it hasn't a data interaction with the coordinator at the time of detection the Eth. Otherwise; it piggybacks the information on to the interacting frame via one [1] reserved bit notification in the frae control field on the frame format. When the dedicated frame or the piggybacked frames received by the PAN coordinator,

Octets:2	1	0/2	0/2/8	0/2	0/2/8	0/1	0/1	0/5/6/10/14	Variable	2
Frame control	Sequence number	Destination PAN Identifier	Destination address	Source PAN Identifier	Source Address	**Data Length**	**Priority**	Auxiliary Security Header	Frame payload	FCS
		Addressing Fields								
MHR									Mac Payload	MFR

Fig.4: *Modified general MAC frame format.*

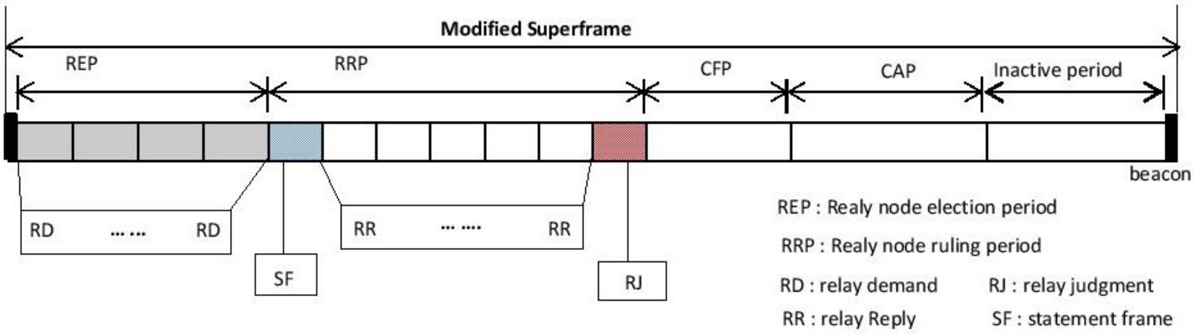

Fig.5: *Superframe in relay reply.*

it answers by transmitting an acknowledgment to the node i. This procedure is terminated when the node i receives the ACK from the PAN coordinator.

Relay reply : Once the Coordinator receives the message (EL) from node i, it executes the relay reply operation in the next superframe. The purpose of the relay reply is to find a relay node for node i which transmits successfully (EL) frame to the coordinator, among the network nodes. In this case, the structure of the superframe must be changed. So, the active period of superframe contains 5 parts instead of 3 [32].

The two new time periods are named relay node election period (REP) and relay node ruling period (RRP) respectively. So, the active portion includes the following: beacon, REP, RRP, CFP and CAP. To avoid collision, the TDMA is used to transmit packets in the new periods REP and RRP. The periods CFP and CAP for the adapted superframe are complying with the original standard IEEE802.15.4, but with swapping between them. The new format of amended superframe is presented as below (Figure 5)

Beacon : In addition to the ordinary functions of beacon such as synchronization between the coordinator and the network associated nodes, it must notify which is the (EL) node in the network. To do this, we adjust the format of the beacon frame by adding fields as shown in Figure 6. The relay pending address field contains a list of nodes that communicate successfully their (EL) status to the PAN coordinator. The addresses are saved in the field according to the arriving of messages to the coordinator and it indicates the order to emit a relay demand (RD) frame in the REP period following the beacon. Every (EL) node mined its broadcasting sequence in the relay pending address field, and then realize at what time slot it is permitted to send out a (RD) frame in the next REP. For all nodes having enough energy (Energy Enough EE), they must be awake during the entire period REP to perform a reply to EL nodes. The Distance field contains all the distances between the different nodes of the network. When any node (EL) sends a relay demand, the coordinator checks this field, and rearranges the order of the distances according to the query received from (EL) node. For the first time, the distances between sensors are measured by medical staff when installing the sensors on the human body.

Relay node election period (REP) : This period starts just after the beacon. The PAN coordinator reserves one or more time slots that are affected to the (EL) nodes depending on their order in the relay pending address ïňĄelds, in order to ïňĄnd all energy enough neighbor nodes for each (EL) node. To save energy, each (EL) node should transmit its relay demand frame with the low power level supported by its transceiver in the corresponding time slot of the REP.

Relay node ruling period (RRP) : The period when the PAN coordinator collects all enough-energy node information for each (EL) node and selects the appropriate relay node for it, it is dubbed the RRP. All (EE) nodes are expected to answer the relay demand (RD) in the previous REP by sending a relay reply (RR) to the PAN coordinator. For each (EE) node, the relay reply payload comprises its current

Octets:2	1	4/10	0/5/6/10/14	2	variable	variable	variable	variable	variable	2
Frame control	Seq number	Adressing field	Auxiliary security header	Super-trame specificatio	GTS field	Pending adress field	Relay pending adress field	**Distances field**	Beacon payload	FCS
MAC header				MAC Payload						MAC footer

Fig.6: *Beacon frame format in relay reply.*

energy Ei and the list of the (EL) nodes listen within the REP period. It is worth noting that in the starting of the RRP period, the PAN coordinator diffuses a statement frame (SF) to avoid collision between relay reply (RR) frames transmitted together by different (EE) nodes. This statement frame contains an ordered list of addresses of (EE) nodes that correspond to the transmission their particular (RR) frame. To get the transmission sequence, every (EE) node hears to statement frame in the network. Each (EE) node knows the time to transmit its (RR) frame, only after extracting its own transmission sequence.

Once the PAN coordinator receives all (RR) frames from (EE) nodes, it takes their current energy Ei , assigns weights corresponding from the lowest current energy to highest, and then chooses the closest (EE) node with the maximum energy among all neighbors in the network as the relaying node for the pertinent (EL) node. For doing so, the coordinator will proceed as follow:

1. Network establishment: initialize all nodes within the network. Attribute the coordinate (0,0) for the first (EL) node, denoted EL1. Generate the coordinate of node i denoted by (x_i, y_i).
2. Calculate distance matrix to EL1 node DN*N according to the coordinates of the nodes.
3. Calculate transmission energy cost and get the energy consumption matrix, denoted by ecN*N, according to the (Heinzelman et al.) radio model [33], and then attribute a corresponding weights from lowest energy consumption to the highest.

$$E_{tx}\left(k,d\right) = E_{TXelec} \cdot k + E_{amp} \cdot k \cdot d^2$$

   Where in E_{tx} represents the transmission energy, E_{TXelec} represents the energy dissipates to run the circuitry for the transmitter, E_{amp} represents the energy for the transmit amplifiers, d distance between transmitter and receiver and finally k is the number of transmitted bits.
4. Calculate the average of weights assigned to the current energy Ei and to the consumed energy ec.
5. Use Dijkstra algorithm to derive one minimum energy consumption path to the coordinator, during which mark the nodes that are chosen as a relay node. Repeat the routine for each EL node.

As a conclusion, the overcurrent protection used in the conventional BMSs, which are commercially available, can be divided into 2 types,

1 Overcurrent protection with simple comparator using analog circuit denoted here as "low cost BMS"

2 Overcurrent protection with time-delayed comparator using instant BMS IC denoted here as "Normal BMS". Even in a high-grade BMS, the overcurrent protection is done by the instant IC as well.

This information will be extracted by the (EL) node from the next coming beacon. Before the end of the RRP period and in its last time slot, the PAN coordinator diffuses a relay judgment frame (RJ) which contains the list of addresses of the EL nodes and their corresponding relay address list.

Upon receipt of the RJ frame, each EL nodes checks if its address is among the addresses mentioned in the frame. If so, it becomes a convoyed node and then reads its relaying node from the corresponding list. After that, the EL node communicates only with his EE node using its low level power supported by the transceiver. In case of its address is not in the EL address list, he it amplifies its transmission power and then undertakes the relay demand operation. This operation is repeated until the relay ruling is taken for the EL node. For the EE node, when he it receives RJ frame, he it checks the list to determine whether EL node is chosen like convoyed node. In this case, EE node communicates not only with the PAN coordinator but also with the selected EL node. Otherwise, if not being selected, it maintains its regular procedure and communicates with the PAN coordinator.

Superframe adaptation : After knowing which EE node has been defined for the EL nodes, the network topology is switched from single hop to the multi-hop (cluster-tree) and then, the superframe must be adapted to the new situation. In the cluster-tree topology, we distinguish two types of coordinators, the PAN coordinator which acts as a sink, and the ordinary coordinator which routes the EL node data to the sink. To fit to the topology change, the MAC sub layer changes the format of the superframe to adjust with the new topology, which is actually the continuous overlap of superframes used in the original single-hop mode. The ordinary coordinator shall maintain the timing of both the superframe in which its coordinator transmits a beacon (the incoming superframe) and the superframe in which it transmits its own beacon (the outgoing superframe) [28].

The WBAN coordinator transmits its beacon at the appropriate time and then the WBAN superframe is started. All leaf nodes listen to the beacon and synchronize with the superframe. Each node wants to communicate with the WBAN coordinator must ensure that all transactions must finish before the end of the active part. While the node selected as convoyed node (EL) may enter a sleep mode during this period to save energy. In the inactive period and when the PAN coordinator enters in the sleep mode, each relay node acts as an ordinary coordinator to interact with the convoyed node, using the outgoing superframe as illustrated in the Figure 3. It is worth noting that, by choosing the appropriate values for the SO and BO parameters, it can be guaranteed that the active period of each outgoing superframe terminates before the end of the WBAN superframe. This superframe remains active until the coordinator node receives a new relay demand (LE). At this moment, the PAN coordinator must read just the superframe after the decision for the new relay (EE), while the relay nodes that have sufficient energy must maintain their superframe "outgoin" as before. Note that the duty cycle of the WBAN superframe should be low enough to receive the multiple outgoing superframes for different relaying nodes [32].

2. SIMULATION ENVIRONMENT

2.1 Network Simulator NS2

In order to validate the behavior of the proposed protocol, the NS2 network simulator was used. It is an open source simulator, developed at joint laboratories of Samsung and the University of New York [34] and conforms to the IEEE802.15.4/D18 Draft. It is one of the most popular simulators among networking researchers. NS2 consists of two key languages C++ and OTCL (Object-oriented Tool Command Language). While the C++ defines the internal mechanism of the simulation objects, the second sets up simulations by assembling and configuring objects as well as scheduling discrete events.

2.2 Evaluation Metrics :

The following metrics are used in order to evaluate the performances of the proposed protocol, taking into consideration all the nodes involved in the simulation.

- **Average End to End Delay :** This represents the transfer time of a data frame to one hop neighbor. For each data frame, it represents the interval between the data frame reception instant and the instant the corresponding data frame transmit request is issued.
- **Throughput :** It represents the amount of data transmitted from the source to the destination in a unit period of time (second). The throughput of a node is defined as the number of bits received successfully by the coordinator on a time period (simulation time). The throughput of the network is defined as the average of the throughput of all nodes involved in data transmission.
- **Packet delivery rate (PDR) :** It is an important metric which can be used as an indicator to a congested network. It represents the ratio between the number of packets successfully received and the number of packets sent in the MAC sub layer. This measure does not distinguish between the transmission and retransmission, and therefore does not reflect what percentage of packets delivered by the upper layers, even if they are related. The number of packets dropped does not take into account retransmissions. If the packet is successfully received by the destination after several retransmissions, the drops are not considered.
- **Packet dropped (falling) rate (PFR):** this metric can reflect the reliability of the network. It expresses the ratio between the number of dropped packets by the queue at source nodes and the number of packets delivered in the MAC sub layer.
- **Energy consumption :** it represents the amount of energy consumed by the nodes in joule. The energy consumption calculation is based on the difference in the initialization energy (taken from the energy model of sensor node) and the remaining energy at the end of the simulation.
- **Network lifetime :** is defined as the time duration from the simulation beginning to the moment when the first sensor node expired its energy.

2.3 Simulation setup

Initially, the star topology is used in this simulation. The network was simulated with seven heterogeneous nodes, where one of them represents the PAN coordinator. All nodes are in the range of radio transmission of the coordinator. These nodes represent, in fact, medical sensors worn by a monitored person at home, where they transmit the collected physiological data to the coordinator. The latter is connected to a computer located in the corner of the same room. To evaluate the network performance, the nodes with the high data rate transmit their data frames to the coordinator during the CFP period, whilst the nodes with low data rate use the CAP period for transmitting their data frames. All sensor nodes were coniňĄgured with constant bit rate (CBR) traffic, which means that data frames are transmitted at a constant rate between nodes and the coordinator. The parameters used in the simulation are summarized in Table 1. Since the GTS mechanism is not implemented in the IEEE 802.15.4 standard within NS2 (version 2.35), the CFP implementation code referenced in [35] and [36] has been used. For the adjusted beacon frame format in relay reply, we added some changes in the NS2 code for both additional field in the files 802.15.4 field.h and P802.15.4 MAC.h.c. The first field (relay

Table 1: *Simulation parameters*

Network dimension	10*10 m
Simulation time	1500s
Traffic type	CBR
Coordinator queue size	50
IFQ size (buffer node)	2
Packet size	70
Hop number	1, 2, ...
Node number	7(which 1 coordinator)
Traffic direction	Nodes to coordinator
Radio propagation model	Two ray ground
Network topology	Star& peer-to-peer
Routing	Dumb Agent
Data rate	0.05, 0.1, 0.5, 1
Phy layer & MAC	IEEE 802.15.4
Channel frequency & MAC	2.4 Ghz to 250 kbps
Beacon Order BO	0, 1, 2, ..., 15
Superframe order SO	0, 1, 2, ..., 15
Initial energy	1000j
Reception power	35.28e-3
Emission power	31.32e-3
Idle power	712e-6
Sleep mode power	144e-9

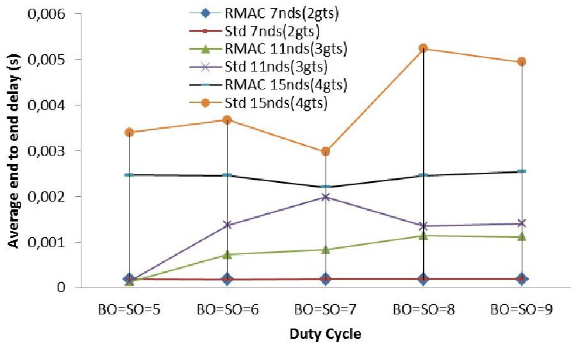

Fig.7: *End to end delay Vs. duty cycle.*

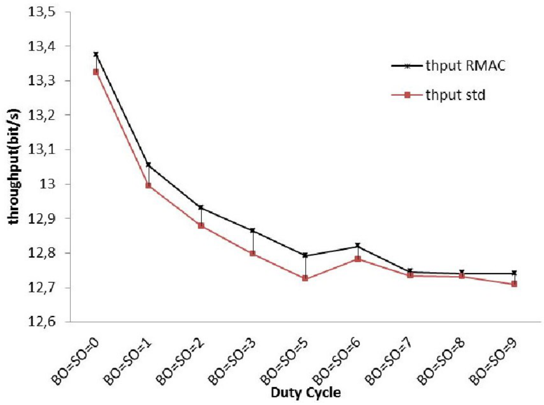

Fig.8: *Throughput Vs. duty cycle.*

pending address) will contain a list of nodes having successfully communicate their energy lack situations to coordinator. The second field (Distance) contains the distances between the various sensors worn by the patient.

3. RESULTS & ANALYSIS

In the precedent section, the simulation environment is described. This section will present a comparative study between the RMAC protocol proposed in this work and the standard IEEE 802.15.4 MAC protocol in both steps previously described in section 1.3.

3.1 Simulation results for step 1

In this section, we evaluate the performance of the metrics mentioned in previous section. Figure 7 shows the average end-to-end delay as function of duty cycle values, with the variation of nodes number. From the results, the average end-to-end delay rises significantly with the increasing of the nodes number in the both protocols. We can also observe that the RMAC protocol gives lower time transfer than the standard IEEE 802.15.4. This is because in the original standard, the sent packets have incurred severe contention which induces a pretty long delay, especially with high value of duty cycle. The number in parenthesis represents the number of nodes using GTS in the CFP period.

In Figure 8, the throughput depending to duty cycle is presented. The curve shows that the proposed protocol RMAC gives a slight improvement in term of throughput than the IEEE 802.15.4 MAC protocol, for the different duty cycle values. This is because RMAC presents less collision than the standard, by using GTS in CFP before the CAP period. And therefore, more packets successfully reach the destination node (coordinator).

Figure 9 exhibits the Packet Dropped (Falling) Rate (PFR) as function of duty cycle for various numbers of nodes. We set the total nodes to 7, 11 and 15 respectively with GTS node to 2, 3 and 4. We remark that the reliability increased with the decrease of nodes number, this is due in fact to the collision caused by the increasing number of the competitor's nodes. With low values of duty cycle, we show that the IEEE 802.15.4 MAC protocol (Std) gives better PFR than the RMAC protocol, this is due to the length of the CAP being reduced, because the CFP takes up a large portion of the interval, which, in turn, aggravates the contention on the sharing media among the nodes. Otherwise, RMAC protocol gives better performance in term of PFR than the original standard.

Regarding the Packet Delivery Rate (PDR), as il-

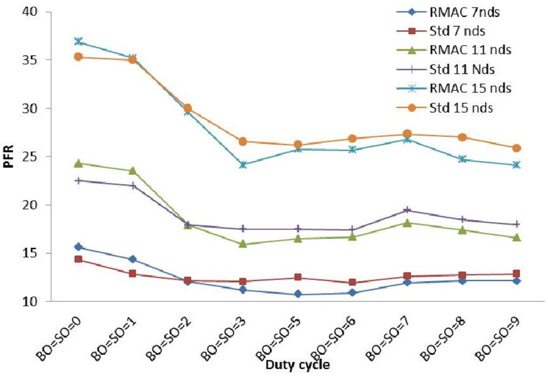

Fig.9: *Packet Dropped Rate (PFR) Vs. duty cycle for various nodes number.*

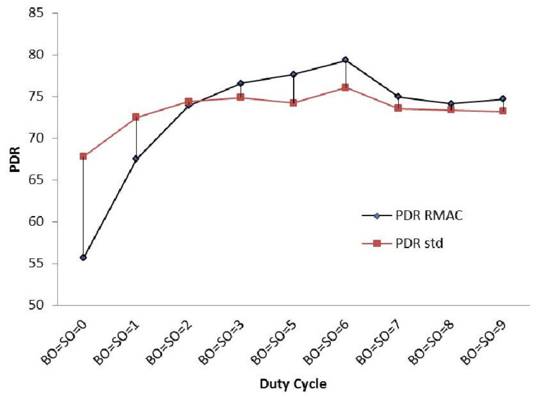

Fig.10: *Packet Delivery Rate (PDR) Vs. duty cycle.*

lustrated in Figure 10, the IEEE 802.15.4 MAC protocol (std.) gives better PDR values than RMAC protocol solely when BO is less than 2. This means that in short period, there is a lot of dropped packets when nodes try to access the channel using CSMA-CA mechanism and the GTS node take most of the superframe duration. When the superframe duration increases, the RMAC protocol gets a best PDR than the standard. This means that most of competing nodes can successfully access to the channel and therefore reach the destination.

Figure 11 depicts the total energy consumption depending on the duty-cycle values. The RMAC protocol consumes slightly less energy than the IEEE 802.15.4 MAC protocol, except for small duty cycle values, and this because of the collision generated by the attempt to access the channel, by nodes within a very short period by using CSMA-CA mechanism. From the results obtained in the first step, we can already conclude that the proposed protocol RMAC gives slightly better performance than IEEE 802.15.4 MAC protocol, in terms of throughput, PFR, PDR and consumed energy.

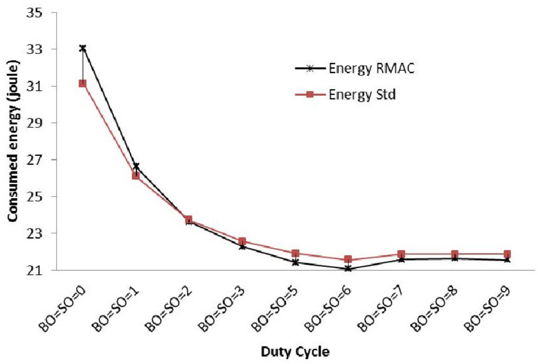

Fig.11: *Total energy consumed Vs. duty cycle.*

3.2 Simulation results for step 2

The second step is much more concerned by the extension of the lifetime of the network when the first node detects its energy lack. We recall that all sensors are of utmost importance especially it concerns the health of a person and they give vital parameters. The network lifetime is defined as the time duration from the simulation beginning to the moment when the first sensor node expired its energy. We used six heterogeneous medical sensors distributed on body. According to their functions, they transmit their data to the coordinator and we considered the proposed protocol RMAC without additional relay. The relay is chosen among the worn sensors to ensure a proper convenience for patient. We always keep the same configuration (step 1), nodes with the low data rate use the CAP period and those with high data rates use GTS in the CFP period.

To know more the importance of the energy enough (EE) nodes in favor of energy lack (EL) nodes, we set 10 nodes which 5 are EE nodes (here, we set 10 nodes instead of 6 only for more clear up the differences). Figure 12 describes the total energy consumption depending on EL nodes. From the curve, we find that RMAC protocol is more efficient in term of reducing energy consumption than the Standard 802.15.4 MAC Protocol, this is due in fact that EE node takes place when EL node detects its energy lack and reaches the defined threshold. We can see clearly that when the number of EL nodes increases, this leads to the reduction of energy consumption.

Figures 13 and 14 represent respectively the packet delivery ratio and the packet dropped rate depending on EL nodes number. It shown from the first one that the (PDR) is significantly better in the (RMAC) protocol than the standard. This is due, in fact that each (EL) node communicates only with its parent (EE node), which decreases the collision and therefore increase the (PDR).

We can also observe from the Figure 14, that the PFR is lower in RMAC protocol than the standard. This means that only a few packets are dropped be-

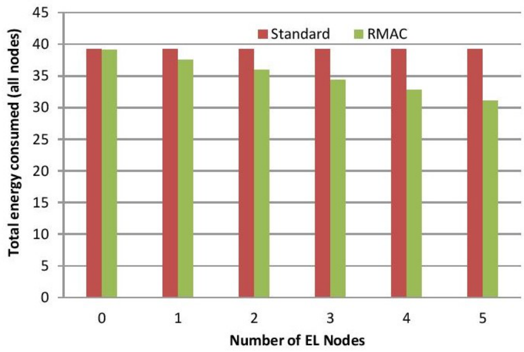

Fig.12: *Total energy consumed Vs. EL nodes.*

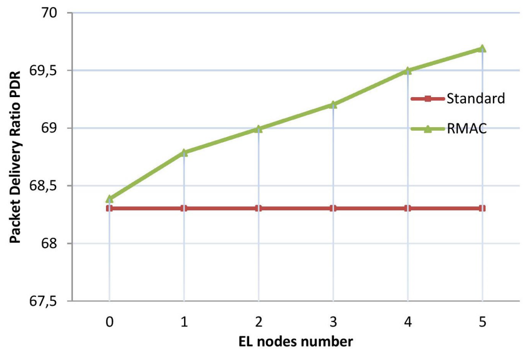

Fig.13: *Packet Delivery Ratio PDR Vs. EL nodes.*

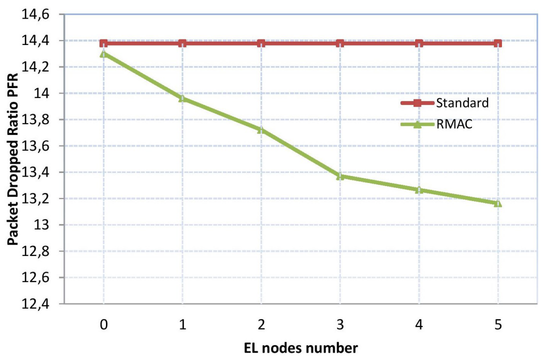

Fig.14: *Packet Dropped Ratio PDR Vs. EL nodes.*

fore being transmitted. This is due, in fact to the collision decrease and then more packets reach the destination. It is worth noting that if the EL node uses the GTS for transmit their data in the first step, then the EE node keeps the same manner of forwarding packets to destination.

The network lifetime depending on the defined energy threshold is shown in figure 15. From the curve, it is clear that the network lifetime of the RMAC protocol network is longer than the IEEE 802.15.4 MAC protocol. First, we see a slightly improvement of network lifetime for the RMAC protocol with zero energy threshold value, this is due to the fact of the betterment of the RMAC protocol in the previous (first) step. The figure shows that the peak performance is

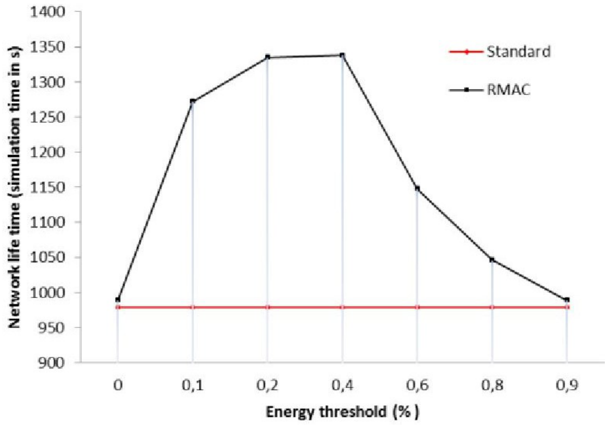

Fig.15: *Network lifetime(s) Vs. energy threshold(%).*

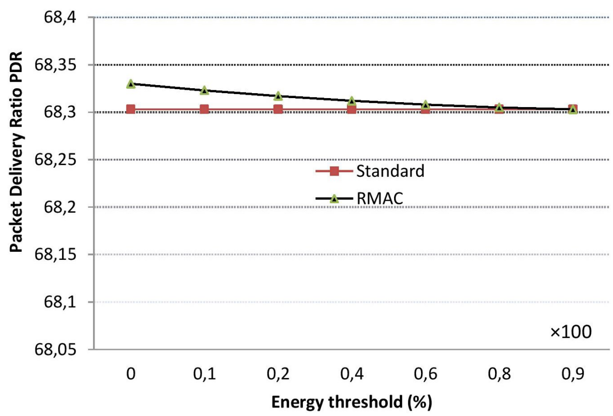

Fig.16: *Packet Delivery Ratio Vs. energy threshold(%).*

reached when the energy threshold is equal to 40% of the initial energy. The reason is that the EL node will begin to request the EE node very tardy, and this leads to reduce the services offered by the EE node, and therefore, the resources of relay node are not efficiently used. Contrariwise, if the energy threshold is set too high, the EL node will initiate relay demand from EE node very soon and this leads to benefit for the services offered by EE nodes. But from the perspective of EE node, when the energy threshold is set to high, this is leads to use relay function earlier and consequently, ends the relay service in short time.

Regarding the PDR according to the energy threshold which is presented in figure 16, it is clear that the different values of the energy threshold have only little effect on the PDR. This is due to the fact that the energy threshold only depends on the beginning and duration of the assistance operation (relay). In addition, in this step, it keeps the same coniňĄguration as that of the previous step. But, even so, we see a slight improvement with the RMAC protocol especially for small values of energy threshold, because the EL nodes have started too early using relay nodes (point to point communication), which increases the PDR (less collision).

4. CONCLUSION

In this paper, we proposed a reinforcement MAC protocol, dubbed RMAC, which can enhance the reliability and extend the lifetime of the network for medical applications. This kind of applications habitually contains sensors nodes with different data and sampling rates, such as electrocardiographs, glycemia, pulse, respiration, heart rate and body temperature sensors. In the RMAC protocol, GTS is allocated in CFP period before the CAP for communication with coordinator. For network lifetime extension, RMAC switches from one hop to multi-hop topology when EL node detects its energy threshold, keeping the previous step for communication. We compare via thorough simulations, the performance of the proposed RMAC protocol and the original IEEE 802.15.4 MAC protocol in various metrics. The results show that the proposed RMAC protocol significantly outperforms the standard, in terms of reliability and network lifetime.

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