



Multi operating mode for energy adaptability in WSN

Hayfa Ayadi, Ahmed Zouinkhi, Thierry Val, Boumedyen Boussaid, Naceur Abdelkrim

► To cite this version:

Hayfa Ayadi, Ahmed Zouinkhi, Thierry Val, Boumedyen Boussaid, Naceur Abdelkrim. Multi operating mode for energy adaptability in WSN. 25th Mediterranean Conference on Control and Automation (MED 2017), Jul 2017, Valletta, Malta. pp. 974-979. hal-01873737

HAL Id: hal-01873737

<https://hal.science/hal-01873737>

Submitted on 13 Sep 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Open Archive TOULOUSE Archive Ouverte (OATAO)

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible.

This is an author-deposited version published in : <http://oatao.univ-toulouse.fr/>
Eprints ID : 19034

The contribution was presented at MED 2017 :
<https://www.um.edu.mt/events/med2017/>

To link to this article URL : <http://dx.doi.org/10.1109/MED.2017.7984245>

To cite this version : Ayadi, Hayfa and Zouinkhi, Ahmed and Val, Thierry and Boussaid, Boumedyen and Abdelkrim, Naceur *Multi operating mode for energy adaptability in WSN*. (2017) In: 25th Mediterranean Conference on Control and Automation (MED 2017), 3 July 2017 - 6 July 2017 (Valletta, Malta).

Any correspondence concerning this service should be sent to the repository administrator: staff-oatao@listes-diff.inp-toulouse.fr

Multi operating mode for energy adaptability in Wireless Sensor Network

Hayfa AYADI ¹, Ahmed ZOUINKHI ², Thierry VAL ³
Boumedyen BOUSSAID and M. Naceur ABDELKRIM ⁴

Abstract—Wireless communication presents the most attractive sign of development in this decades. It contributes to the appearance of Wireless Sensor Network (WSN) which is invented in order to increase the supervision capacity for such phenomenon. It gets more regard from both the customers and the research society. (WSNs) is composed from numerous wireless sensor nodes which suffer from a very serious energy constraint. For this reason we are interested to the standard of IEEE 802.15.4 with beacon enabled mode. This work suggests a multi mode approach to the technology of IEEE 802.15.4 as a new technique to extend the lifetime of the network. The paper interests to network largely extended with cluster tree topology. In such a way that the network becomes divided to many subgroups. In each subgroup, a PAN coordinator is placed as a coordinator to its children. Besides, every subgroup has its specific parameters of Beacon Order (BO) and Superframe Order (SO) which depend only from the remaining energy in the battery of the nodes. When a node suffers from lack of energy, its PAN coordinator parent intervene by changing its main parameters (BO, SO) in order to postpone its death.

Index Terms—The IEEE 802.15.4 Standard, BO, SO, Energy, WSN.

I. INTRODUCTION

The Wireless Sensor Network was integrated in many domains blessing to its different advantages such as the environments supervision [1], military domain, health care [2] as well as civil engineering [3]. Although, WSN suffer from divers trouble such as the energy efficient and its sensibility to faults. That is why many approach was developed in order to solve that [4], [5] and [6]. The IEEE 802.15.4 is an Low Rate Wireless Personal Area Network (LR-WPAN) standard. It is destined for network with low cast energy consumption. In addition to that the LR-WPAN have so closed characteristics such as short-range operation, easy in installation and theirs simple and flexible protocol [7].

The IEEE 802.15.4 presents one of the standard developed in order to solve the problem of the energy. This technology is a member of the WPAN family. There are two kinds of devices in this technology. The node could be a Full Function Device (FFD) device or a Reduced Function Device (RFD). A network of a LR-WPAN must be composed by at least

one FFD and one RFD. The FFD node could play both roles of the PAN coordinator or a device. Although a device could be only an RFD. Many topologies could be formed by this network such as peer to peer, mesh and star topology. In star topology, the communication is established between a single PAN and a at least one node (device). Also, in peer-to-peer topology, a PAN coordinator (FFD) must be present. This topology contributes also in the mesh topology which is the most complex network. It is employed in many applications such as the ad hoc network. The architecture of the IEEE 802.15.4 is composed by four layers. Each one presents a part of the standard. The Physical layer is the responsible for the data service and the PHY management. The PHY data service enables the transmission and reception of PHY protocol data units (PPDUs) across the physical radio channel. The main role of this layer are the control of the activity of the radio transceiver, Clear Channel Assessment (CCA), Channel Selection, Link Quality Indication (LQI), Energy Detection (ED) [7].

Also the MAC sublayer has two services which are the MAC data service and the MAC management service. But the most important role are always the beacon control, GTS authority, channel access, frame validation. In addition to that the MAC block contributes in the application witch are suitable to the security mechanism. The upper layer is responsible for the configuration and the manipulation of the network as well as the message routing. It is connected to the MAC layer through the logical link control LLC and the Service-Specific Convergence Sublayer (SSCS). There are two modes allowed by this technology: beacon enabled mode and non beacon enabled mode. Each one has its advantages and main specific. For the first one, a beacon frame is send periodically to all members of network. it allows the start of the active period:Superframe Duration (SD). The Superframe Duration (SD) and the Beacon Interval (BI) are expressed with both relation (1) and relation (2), have a direct intervention in activity period of the node that is why the idea of increasing the lifetime get through both BI and SD [7].

$$BI = aBaseSuperframeDuration * 2^{BO}; \quad (1)$$

$$1 \leq BO \leq 14$$

$$SD = ABaseSuperframeDuration * 2^{SO}; \quad (2)$$

$$0 \leq SO \leq BO \leq 14$$

The superframe of this standard is defined by the PAN coordinator which sends periodically the beacons frames in

¹Hayfa AYADI, Ahmed ZOUINKHI, Boumedyen BOUSSAID and M. Naceur ABDELKRIM are with National Engineering School, Research Laboratory Modeling, Analysis and Control of Systems (MACS) LR16ES22, University of Gabes, Tunisia ayadihayfa.ing@gmail.com, ahmed.zouinkhi@enig.rnu.tn, boumedyen.boussaid@gmail.com

²Thierry VAL. Researcher is with Institut de Recherche en Informatique de Toulouse, Université de Toulouse, 1 pl. Georges Brassens BP60073 F-31703 Blagnac Cedex France thierry.val@irit.fr

order to synchronise the network node. The period of time separated two successive beacons frames is named Beacon Interval (BI). The (BI) is divided to 16 slots which are equally sized slots. The Superframe is divided also in active and inactive period. In the first part, the node tries to communicate to other members of network by sending or receiving data. Although in the second part, all activities of this node will be stopped [7]. In the active period the node has the choice between two protocols of communication which are the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) used in the Contention Access Period (CAP) and the Time Division Multiple Access TDMA employed in the Contention Free Period (CFP), showed in figure 1. In the CAP, the slotted version of the CSMA/CA in the technology of the IEEE 802.15.4, is employed with its both version slotted and unslotted form. The slotted version presented by figure 2 is manipulated in the beacon enabled mode although the unslotted one is used in the non beacon enabled mode.

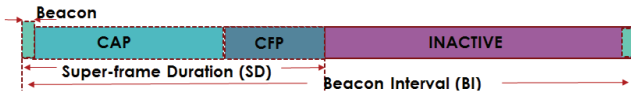


Fig. 1. Superframe composition

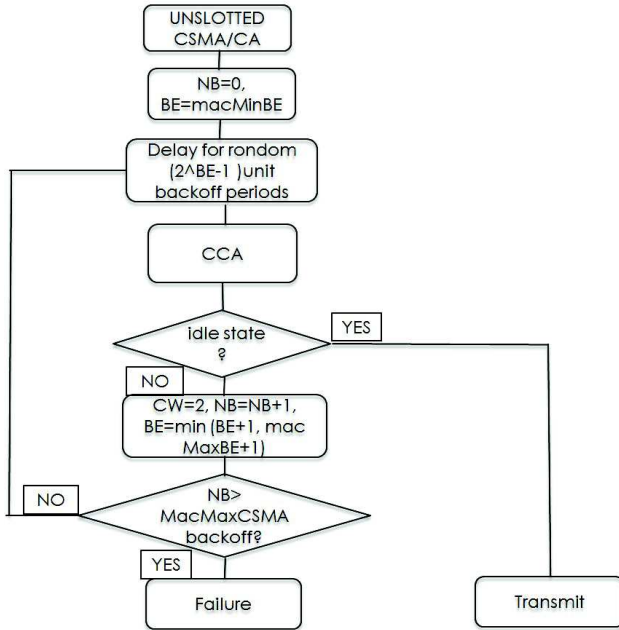


Fig. 2. CSMA/CA slotted algorithm

The first step is to initialize the different parameters of the protocol such as the Congestion Window (CW), the Backoff Exponent (BE) and NB which is the number of times that the algorithm required to backoff. Then the node waits two Clear Channel Assessment CCA to test the channel state. If the node is idle in the first CCA so CW will lost 1 (CW-1) and continue with the second CCA. In the case that the

channel is again idle so CW will be set to 0 and the data will be transmitted. In the case that the channel is busy the value of NB and BE will be decreased to 0 and CW set to 2. After that the different parameters will be updated and the node will try to access to the medium if it has another data for transmission.

II. RELATED WORK

As the Superframe Duration (SD) and the Beacon Interval (BI) are both the principal contributors in the activity duration of the node. There are considered the main manager of the energy consumption of the network across to the node. There are three possibilities to contribute in this technology via the Beacon Order (BO) and the Superframe Order (SO). The first choice is to modify just the BO and fixing the SO. The second one presents exactly the opposite by changing the SO and fixing the BO or simply to adjust both value (BO and SO). Many works were concentrated in the first approach so in [8], the authors try to improve the duty cycle of the node by just modifying the BO value with regard to the network traffic load. So in the case that the data traffic is developed then BO value decrease despite if sleeping period decrease BO will be increased. An other approach in [8] was proposed with the same standard named Beacon Order Adaptive Algorithm (BOAA). Despite it is not suitable for the large network. It is just employed in start topology of the network. Also in [9] the authors propose an other method named Duty Cycle Algorithm (DCA). This modification is based on the end-to-end delay and the transmit queue occupation. In order to get the value of the queue occupation they get the average of all the queue embedded. In [10], also, the writers choose a fixed value of SO and modify the value of BO without specifying the manner of this choice of the SO value against its importance on specifying the activity of the node. For the second choice, fixing the SO and modifying the BO, many other research groups were interested in this approach. In [11], the writers invent a new techniques called the Dynamic Super-frame Adjustment Algorithm (DSAA). So the PAN coordinator start by estimating the super-frame occupation and collision rate. The super-frame occupation define the delay of time in which the coordinator is busy in different communication phases. Although the collision rate is expressed with reference on the received data at the coordinator. Then the coordinator make a small comparison between theses values with other considered as a thresholds. After that, it selects the Super-frame Order.

The way to get the SO value depend from many others parameters such as the queue state of nodes, the throughput during CAP as well as the idle time in the technique of Adaptive Duty Cycle Algorithm (ADCA) [12]. The decision of the change is made by the coordinator with reference to the length of the idle time. In the case that its length is more then the half of the CAP, SO will be decreased. On the other hand, the coordinator continue to examine the number of received packets and the number of pending packets during the CAP. In the case that received packets are less then received packets then SO will be decreased.

The most difficult techniques interested in the technology IEEE 802.15.4 parameters is to make the adjustment of both Beacon Order and the Superframe Order. Divers methods are proposed to adapt the duty cycle to the network condition such as the approach of the Duty cycle Self-Adaptation Algorithm (DBSAA) in [13]. The DBSAA adjustment depend from four parameters which are super-frame occupation ratio (OR), the number of source nodes, the collision ratio (CR), as well as packets received by the coordinator.

III. ENERGY EFFICIENT

Energy stays again the main trouble in divers domains specially in wireless network. The solutions are in exploring new way to produce energy or to make very efficient solution to manage the last quantity of energy lasted in the node. This work is interested in the second solution. Its main hypothesis is that the network is really very extended network in which we propose cluster tree topology. The first step is calculating the energy consumed in different nodes of the network and in different states: emission, reception, idle, overhearing and overmitting, as mentioned in the figure 3. The approach is based on the beacon enabled mode of the

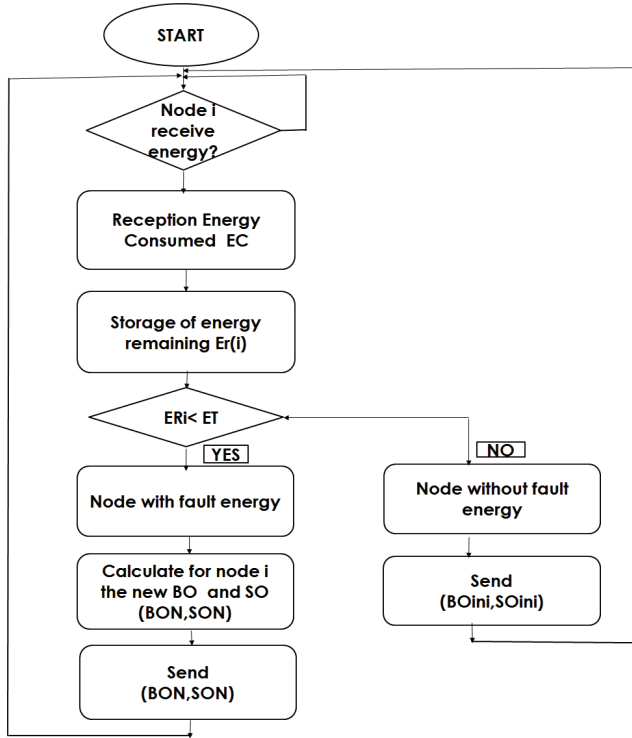


Fig. 3. Organigram of our approach

technology of the IEEE 802.15.4. This work proposes a new way to detect every kinds of possible energy consumed which depends from some parameters of the CSMA/CA protocol. The emission energy E_{em} is the energy consumed by node in order to send data to other nodes or to send it to the PAN coordinator. It is giving by equation (3).

$$E_{em} = (nbt_{sd} * Ttt * Eb) + 2 * U * I * CCA * Tp_{back} \quad (3)$$

(Ttt) is the size of frame. (Eb) presents the binary energy. Although (nbt_{sd}) express the number of data frame present in SD, U is the voltage value, CCA is the Clear Channel Assessment as well as I express current value. Where (Tp_{back}) is expressed by equation (4).

$$Tp_{back} = (2^{cst_{back}} - 1) * 20symbol \quad (4)$$

The (cst_{back}) presents the backoff period. Also in reception phase the node consumes some quantity of energy called (Erc) which is giving by formula (5).

$$Erc = nbr_{SD} * Eb \quad (5)$$

With (nbr_{SD}) is the number of bit received in SD period. The energy consumed in overhearing and overmitting phase, is mentioned by equation (6).

$$E_o = nbr_{tr} * dtra * Eb * PER \quad (6)$$

(Eb) is the binary energy. ($dtra$) shows the size of frame (bit). nbr_{tr} is the number of bits transmitted by node. Although PER presents the error rate which is obtained as the average of packet transmitted without being well received. Concerning energy of collision (E_{col}), it is get by expression(7).

$$E_{col} = Tatt * U * I * Nbpk \quad (7)$$

($Tatt$) is among of time to access to the transmission canal. ($Nbpk$) is the number of try to transmit information without receiving any acknowledge from destined node.

In order to conserve more quantity of energy, the technology of the IEEE 802.15.4 gives the chance to the node to enter in sleep duration in order to manage the little portion of its power. The next expression (8) presents the energy in sleep period (E_{SLP}).

$$E_{SLP} = Eb * (BI - SD) \quad (8)$$

The energy consumed in idle state is presented by equation (9).

$$E_{idle} = TsIFS * U * I \quad (9)$$

$TsIFS$ presents the duration of SIFS, U is the voltage value and I presents the current value. The objective of this work is to manage the power lasted in the battery in one side and to postpone the energy fault of a specific node of the network in which the quantity of power reaches very important threshold defined by user by a way to maximise the lifetime. In other side, all the other nodes of network must not be affected by this very specific faults. So the PAN coordinator tries to intervene to its children node without affecting the activity of other members. So this approach begins by estimating the energy remaining (E_R) in the battery of node. The next step is to send this value to its PAN parent. The energy remaining (E_R) is presented in the attached formula (10).

$$E_R = E_{ini} - E_c \quad (10)$$

E_c is the sum of all types of energy consumed. It is calculated by following equation (10).

$$E_c = E_{em} + E_{col} + E_o + E_{SLP} + E_{rc} + E_{idle} \quad (10)$$

IV. IEEE 802.15.4 PARAMETERS ADJUSTMENT

In the case of extended network every PAN collects the energy information (energy consumed E_c) from all the network nodes. When it detects serious state of one node of this network that is mean that the energy remaining in the battery of this node is less then very specific threshold E_T . In this case the PAN parent must intervene by changing its standard parametric (BO and SO) values which are expressed with reference to the energy values.

The energy consumed in the Superframe duration E_{BI} is showmen by the next expression (11).

$$E_{BI} = \frac{BI}{T_{tt}} * E_T \quad (11)$$

With (BI) presents the size of Beacon Interval period, (T_{tt}) defines the frame length, (E_T) introduces the Energy of frame. (E_R) is the Energy Remaining. The main hypothesis in this approach is that energy consumed is again less then the energy remaining in the battery giving by equation (12).

$$E_{BI} \leq E_R \quad (12)$$

The relation (13) is expressed used both relations (12) and (11).

$$\frac{BI}{T_{tt}} * E_T \leq E_R \quad (13)$$

As defined in the standard the Beacon Interval (BI) is calculated by relation (14).

$$BI = 15,36 * 10^{(-3)} * 2^{BO} \quad (14)$$

That is why equation (14) changes to this way (15).

$$(15,36 * 10^{(-3)}) * \frac{2^{BO}}{T_{tt}} * E_T \leq E_R \quad (15)$$

The 2^{BO} is extracted by relation (16).

$$2^{BO} \leq \frac{E_R * T_{tt}}{15,36 * 10^{(-3)} * E_T} \quad (16)$$

So BO value is expressed by equation (17).

$$2 * \log(2) \leq \frac{E_R * T_{tt}}{15,36 * 10^{(-3)} * E_T} \quad (17)$$

In the case of the majoration aspect, the BO becomes by the way mentioned in the formula (18).

$$BO = \frac{\log(\frac{E_R * T_{tt}}{15,36 * 10^{(-3)} * E_T})}{\log(2)} \quad (18)$$

For raison of management of the last quantity of energy, just 10% of the energy remaining in the node E_{R1} is manipulated in order to well exploit it. It is presented by relation (19).

$$E_{R1} = E_R * 0.1 \quad (19)$$

Consequently SO becomes as mentioned in equation (20):

$$BO = \frac{\log(\frac{0.1 * E_R * T_{tt}}{15,36 * 10^{(-3)} * E_T})}{\log(2)} \quad (20)$$

For the case of the Superframe Duration SD , just 70% from the BI period is exploited. So SO is expressed by relation (21).

$$SO = 0.7 * \frac{\log(\frac{0.1 * E_R * T_{tt}}{15,36 * 10^{(-3)} * E_T})}{\log(2)} \quad (21)$$

V. IMPLEMENTATION AND SIMULATION RESULTS

The implemented of this approach was through the OMNET++/INETMANET simulator for its large simulations functionalities. OMNET++/INETMANET is an open-source discrete event network simulator. So OMNET++ can be used for network simulations or just to model computer networks. OMNeT++ only arranges only the fundamental framework for developing a certain simulation module, but these models are developed separately of OMNeT++ [14]. It has many advantages such as it supports hierarchical models, graphical analysis tools as well as graphical editor [15]. It offers rich environment for simulation at different layers. INETMANET framework is an open-source model library. OMNet++ present an extensible and modular simulator. It is defined using C++ simulation library. It is an oriented object modular with discrete event network simulation. It is used for wired and wireless networks. Our simulation parameters are mentioned in table I.

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Simulation time (h)	192
Network size	(800,400)
E initial (J)	18720
Nodes number	20
PAN number	5
Channel frequency	2.4 GHz
Radio Type	IEEE 802.15.4 radio
dispersion	random

Five PAN coordinators was manipulated. Each one is the main responsible over its subgroup which is composed by some children as mentioned in figure 4. The PAN coordinator is an FFD node. So it has not an energetic problem as it is known in the technology of the IEEE 802.15.4 with cluster tree topology. So PAN 1 is the responsible of node (9, 10, 11, 27, 28) and formed together the subgroup 1. The PAN 2 is the main parent of the nodes (0, 1, 2, 21, 22) and compose the subgroup 2. While the subgroup 3 is designed by the PAN 3 with its three children (13, 14, 15). Although the subgroup 4 is modeled by PAN 4 with nodes (5, 6, 7, 23, 24). PAN 5 is the responsible of node (17, 18, 19, 25, 26) and formed together the subgroup 5. So the PAN sends beacons

frames periodically to its children in order to synchronise its activity. Each Subgroup has its specific parameters of the Beacon Interval and the Superframe Duration. By this way, five modes in the same network were presented. The advantage of this work is to give the chance to manage every subgroup with the real energy level of its node.

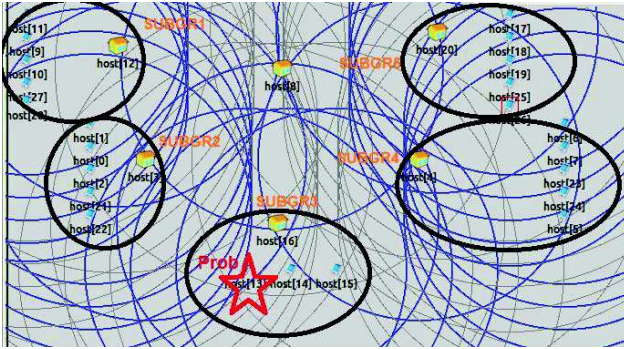


Fig. 4. multimode network

In this case the node number 13 in the subgroup 3 has a problem with energy. The energy consumed by this node exceeds the threshold energy which is 9360 J as mentioned in figure 5. The threshold energy presents 50% of the start value (18720J).

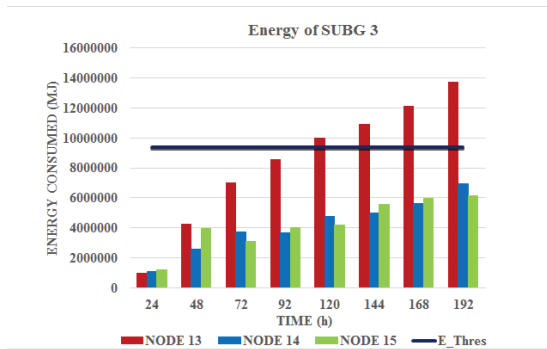


Fig. 5. CONSUMED ENERGY IN SUBGROUP3

Also this problem appears at the level of total energy consumed by this subgroup compared with other subgroups, showed by figure 6. After detecting the energy trouble the PAN coordinator intervenes in order to postpone the death of the node. Its main contribution is about changing the duty cycle of the node by modifying both the (BON) and the (SON) value based on the current level of energy which leads to decrease the duty cycle from 50 percent to 6,25 percent.

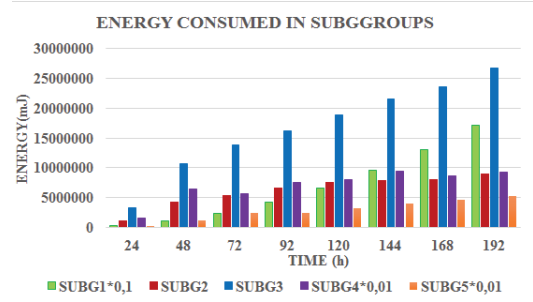


Fig. 6. CONSUMED ENERGY IN THE SUBGROUPS

The figures 7, 8, 9, 10 as well as 11 present the results of the PAN intervention in the duty cycle of the node number 13 which is detected as the node with the energy fault.

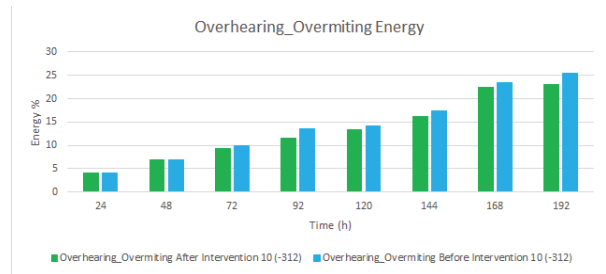


Fig. 7. Overhearing-Overmitting Energy

The energy of overhearing and overmitting, mentioned in figure 7, the IDLE energy, presented by figure 8 and the Reception energy, showed by figure 9 are all declining with very significant way. There are affected by the same manner as a results of the decrease of the duty cycle. Emission energy and sleep energy results are given by figures 10 and 11. It decreases with the increment of time for the same raison as the other kinds of energy.

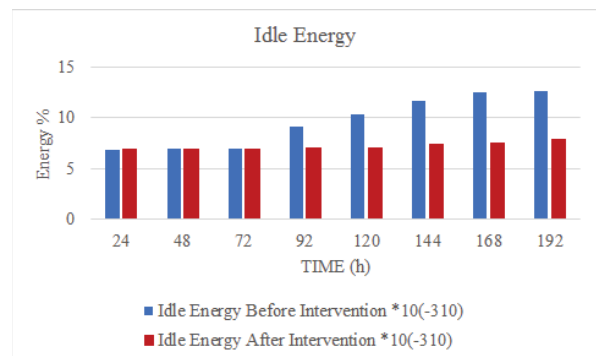


Fig. 8. IDLE Energy

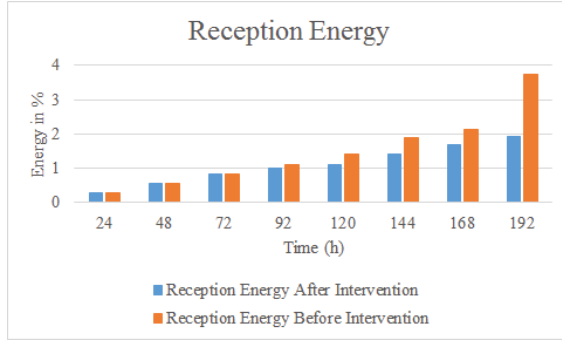


Fig. 9. Reception Energy

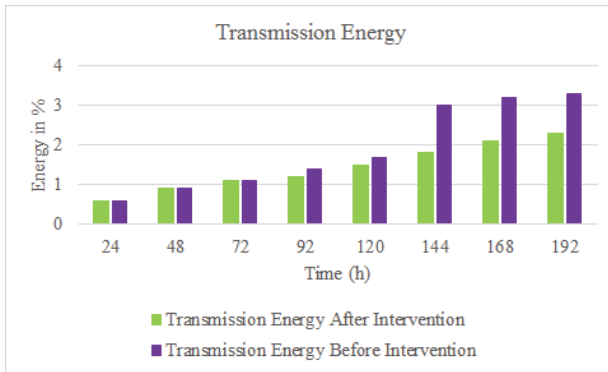


Fig. 10. Transmission Energy

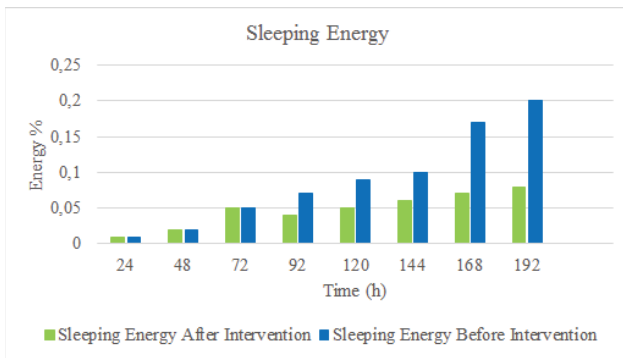


Fig. 11. SLEEP Energy

VI. CONCLUSION

This work was inspired by the need to enhance the existing approaches that deal with energy efficiency. A new technique is investigated for the technology of the IEEE 802.15.4 with beacon enabled mode. It is destined for extended network. The topology employed is cluster tree topology. This contribution focuses on the implementation of different mode of activity in the same network. So every PAN coordinator sends to its children very specific parameters of the technology of the IEEE 802.15.4 which are the Beacon Order (BO) and the Superframe Order (SO). When the PAN

detects the lack of power in one of its children, it tries to postpone the energy fault of this node by getting both values of BO and SO with referring to its quantity of energy lasted in the battery. This work gives the chance to proceed to the same network with different modes and consequently different Duty Cycle (DC) are employed in the same network just in different subgroups. As perspective, it will be very interesting to apply this methods in mesh topology and with divers thresholds.

ACKNOWLEDGMENT

This work was supported by the Ministry of the Higher Education and Scientific Research in Tunisia.

REFERENCES

- [1] M. F. Othman and K. Shazali, "Wireless sensor network applications: A study in environment monitoring system," *Procedia Engineering*, vol. 41, pp. 1204–1210, 2012.
- [2] A. Lambebo and S. Haghani, "A wireless sensor network for environmental monitoring of greenhouse gases," in *Proceedings of the ASEE 2014 Zone I Conference. University of Bridgeport, Bridgeport, CT*, 2014.
- [3] M. P. Ananya chatterjee, "Practical applications of wireless sensor network based on military, environmental, health and home applications: A survey," vol. 5, January-2014.
- [4] K. Mekki, A. Zouinkhi, W. Derigent, E. Rondeau, A. Thomas, and M. N. Abdelkrim, "Usee: A uniform data dissemination and energy efficient protocol for communicating materials," *Future Generation Computer Systems*, vol. 56, pp. 651–663, 2016.
- [5] N. Fourty, A. Van Den Bossche, and T. Val, "An advanced study of energy consumption in an ieee 802.15. 4 based network: Everything but the truth on 802.15. 4 node lifetime," *Computer Communications*, vol. 35, no. 14, pp. 1759–1767, 2012.
- [6] H. Ayadi, A. Zouinkhi, B. Boussaid, and M. N. Abdelkrim, "A machine learning methods: Outlier detection in wsn," in *IEEE 16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), Dec 21-23, Tunisia*, 2015, pp. 722–727.
- [7] I. C. Society, "Ieee 802.15.4 wireless lan medium access control (mac) and physical layer (phy) specifications for low-rate wireless personal area networks (lr-wpans)," 2006.
- [8] M. Neugebauer, J. Plonnigs, and K. Kabitzsch, "A new beacon order adaptation algorithm for ieee 802.15. 4 networks," in *Proceedings of the Second European Workshop on Wireless Sensor Networks*, 2005. IEEE, 2005, pp. 302–311.
- [9] J. M. L. Caldeira, J. J. P. Rodrigues, and P. Lorenz, "Intra-mobility support solutions for healthcare wireless sensor networks—handover issues," *IEEE Sensors Journal*, vol. 13, no. 11, pp. 4339–4348, 2013.
- [10] I. standard 802.15.4, "Wireless medium access control (mac) and physical layer (phy) specifications for low rate wireless personal area networks (wpans) (amendment of ieee std 802.15.4-2003)," in *Proceedings of the Second European Workshop on Wireless Sensor Networks*, 2005. IEEE, 2003.
- [11] B.-H. Lee and H.-K. Wu, "Study on a dynamic superframe adjustment algorithm for ieee 802.15. 4 lr-wpan," in *Vehicular Technology Conference (VTC 2010-Spring)*, 2010 IEEE 71st. IEEE, 2010, pp. 1–5.
- [12] H. Rasouli, Y. S. Kavian, and H. F. Rashvand, "Adca: adaptive duty cycle algorithm for energy efficient ieee 802.15. 4 beacon-enabled wireless sensor networks," *IEEE sensors journal*, vol. 14, no. 11, pp. 3893–3902, 2014.
- [13] C. H. Oliveira, Y. Ghamri-Doudane, and S. Lohier, "A duty cycle self-adaptation algorithm for the 802.15. 4 wireless sensor networks," in *Global Information Infrastructure Symposium-GIIS 2013*. IEEE, 2013, pp. 1–7.
- [14] R. Stanica, E. Chaput, and A.-L. Beylot, "Simulation of vehicular ad-hoc networks: Challenges, review of tools and recommendations," *Computer Networks*, vol. 55, no. 14, pp. 3179–3188, 2011.
- [15] A. Varga, "Omnet++," in *Modeling and Tools for Network Simulation*. Springer, 2010, pp. 35–59.